*African Development Perspectives*

*Yearbook 2018*

# SCIENCE, TECHNOLOGY AND INNOVATION POLICIES FOR INCLUSIVE GROWTH IN AFRICA – GENERAL ISSUES AND COUNTRY CASES

EDITED BY
REUBEN A. ALABI, ACHIM GUTOWSKI, NAZAR MOHAMED HASSAN, TOBIAS KNEDLIK, SAMIA SATTI OSMAN MOHAMED NOUR, KARL WOHLMUTH

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Reuben A. Alabi, Achim Gutowski, Nazar Mohamed Hassan,
Tobias Knedlik, Samia Satti Osman Mohamed Nour,
Karl Wohlmuth (Eds.)

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# African Development Perspectives Yearbook

Edited by the

Research Group on African Development Perspectives Bremen:
Reuben A. Alabi, Achim Gutowski, Nazar Mohamed Hassan,
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Reuben A. Alabi, Achim Gutowski,
Nazar Mohamed Hassan, Tobias Knedlik,
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# African Development Perspectives Yearbook, 2018
# SCIENCE, TECHNOLOGY AND INNOVATION POLICIES FOR INCLUSIVE GROWTH IN AFRICA - GENERAL ISSUES AND COUNTRY CASES

# The Research Group on African Development Perspectives Bremen

The uneven growth in Africa, the lack of inclusive development in most of Africa, and the aggravating social, political and economic crisis in some countries of the African continent require new policy initiatives. These developments force institutions, organisations, researchers, development practitioners, ad hoc working groups and networks being active on Africa, and all others involved in African development affairs to intensify the analytical and conceptional work on alternative development visions and designs for Africa. There exist a growing number of development plans and restructuring programmes, strategy conceptions, researches on specific issues, and ideas for policy action and projects which being published world-wide and which are focussing on the peculiarity of the African crisis factors, Africa's recent growth dynamics, the opportunities and chances for structural adjustment and transformation. Also, the issue of revitalizing development planning in Africa, the issue of structural change beyond caring merely for adjustment, and the issue of responding to the globalisation trend are intensively discussed. The discussion referring to Africa's development problems and perspectives is widening. However, it is difficult to get an overall view of the different approaches and proposals and, subsequently, to make the discussion useful for the programming and co-ordinating of development policies and for development co-operation. So, there is a need for a comprehensive publication that compiles, evaluates, and analyses the scattered material and the often not easily available sources. Most important, it is necessary to present a balanced view of the medium to long-term developments.

To fill this gap, the *Research Group on African Development Perspectives Bremen*, established at the University of Bremen, Faculty of Economics and Business Studies, is presenting the *African Development Perspectives Yearbook*, being published since Volume 1 on "Human Dimensions of Adjustment" in 1989. Research activities of the group members comprised over the years country case studies and comparative country analyses; studies on macroeconomic policies and strategies, aspects of labour market policies and informal sector activities, human development policies and strategies, agriculture and food security policies; studies on natural resources development and environmental policies, but also researches on the promotion of small-scale industries, private sector development policies, entrepreneurship development, and assessments of sector and structural adjustment policies, trade and regional integration policies, as well as reviews of economic diversification options. The issues of scientific and technology policies and of innovation experiences were also considered in some of the volumes, but the volumes 20 and 21 of the *African Development Perspectives Yearbook* present a comprehensive analysis of their importance for Africa.

The *African Development Perspectives Yearbook* is the leading English-language periodical which is published in Germany and which is relating to the key development problems and perspectives in Africa. African, European and North-American experts from universities, research institutes, international and regional organisations, and from non-governmental and donor organisations are reporting on problems and on possible solutions, on new political and economic approaches, on specific economic programmes, and on visions for alternative African development paths. Country cases and project cases highlight the issues of implementing sustainable policies and ventures.

Africa's future will depend on both, on its economic and political connections with the international community at the Pan-African, sub-regional, national, provincial and sectoral levels, and on local projects and development efforts at the micro and sector level. Most important are own African development visions, programmes, strategies and policies. The *African Development Perspectives Yearbook* contains information and analyses regarding these various dimensions. Global analyses, regional and country studies, sectoral studies and individual project evaluations are published in the *African Development Perspectives Yearbook*, as well as statements and declarations on Africa submitted as the result of international and regional African conferences; important documents of African regional organisations and of individual African states, and important programmes of African civil society organisations and African self-help groups are presented.

Beside the analytical, comparative and documentary character of the *African Development Perspectives Yearbook*, the editors successfully established an extensive network for the exchange of news and information; by this way the editors of the *African Development Perspectives Yearbook* are relating and connecting development organisations and research institutions that are working in and for Africa. The members of the *Research Group on African Development Perspectives* are interested to deepen the contacts with partners in and outside of Africa who are sharing similar objectives.

The *African Development Perspectives Yearbook* is targeted to political decision-makers, to project and research personnel in development policy institutions, and to experts and staff members in project development offices, consultancies, media, research and development agencies, donor and aid institutions, and to all others that are interested in Africa's development. It also offers comprehensive analyses and information about recent developments regarding the African continent, but the main focus is on Africa's development perspectives.

Thus, the *African Development Perspectives Yearbook* is reporting on

- visions and conceptions regarding the long-term development strategies for Africa;

- strategies that emphasize a longer-run planning process that goes beyond conventional structural adjustment policies;
- successful projects and programmes concerning countries, regions, institutions, or specific sectors of African economies, by analysing the conditions of their success;
- resourceful and creative activities of socio-economic interest groups, local development initiatives and NGOs, which could serve as models for other regions;
- innovative strategies for and prospects of regional integration in Africa; and on
- economic, social, and political trends in Africa's sub-regions, nation-states, provinces, towns and local communities.

The *African Development Perspectives Yearbook* uses sources and information from all relevant levels of action, policymaking, planning, discussion, and research, i.e. from international, regional, and national organisations and institutions, committees, working groups, and NGOs, but of particular relevance are those ideas and approaches which are originating from Africa.

**Research Group on African Development Perspectives Bremen**
**c/o**
**Professor Emeritus Dr. Karl Wohlmuth, Scientific Coordinator and Volume Editor, University of Bremen, Germany**
Address:
University of Bremen,
Faculty of Economics and Business Studies,
P.O. Box 330 440
28334 Bremen, Germany
Phone: +49 421 218-66517
Email-Address: wohlmuth@uni-bremen.de
and:
**Professor Dr. Tobias Knedlik, Managing Editor, Fulda University of Applied Sciences and Halle Institute for Economic Research (IWH)**
Address:
Fulda University of Applied Sciences
Department of Business
Leipziger Straße 123
36037 Fulda
Phone: +49-6619640-251
Email-Address: Tobias.Knedlik@w.hs-fulda.de

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# Foreword and Acknowledgements

This Volume 20 of the *African Development Perspectives Yearbook* with the title *"Science, Technology and Innovation Policies for Inclusive Growth in Africa. General Issues and Country Cases"* has again benefited from many contributions, from various inputs and from important institutional support. The great number of contributions to this volume (essays, review articles and book reviews) was made possible because of the continuing support from African and international organisations, from numerous research and development institutions, and from many individual experts cooperating continuously with us on Africa. A great number of international and regional organisations, universities and research institutes have supported this project, such as: UNESCO (United Nations Educational, Scientific and Cultural Organisation); the ACBF (African Capacity Building Foundation); UNECA (United Nations Economic Commission for Africa); the FAO (Food and Agriculture Organization) in Rome, Italy; UNCTAD (United Nations Conference on Trade and Development), Trade and Poverty Branch, Division for Africa, LDCs and Special Programmes in Geneva, Switzerland; the Department of Economics, University of Khartoum, Sudan; the Department of Agricultural Economics, Faculty of Agriculture, Usmanu Danfodiyo University, Sokoto, Nigeria; the Department of Agricultural Economics and Rural Sociology, Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria; the National Institute for Animal Production, Shika, Ahmadu Bello University, Zaria, Nigeria; the Research and Innovation Management Department at the Egyptian Academy of Scientific Research & Technology (ASRT); the Agricultural Extension and Management Department, Lagos State Polytechnic, Lagos, Nigeria; the Economics Department, University of Lagos, Akoka, Yaba, Lagos, Nigeria; the Centre for Business and Technology in Africa, Flensburg University of Applied Sciences (FUAS); the University Institute of Technology, at the Faculty of Sciences of the University of Douala in Cameroon; the Department of Economics, University of Kassala, Sudan; the Royal Docks School of Business and Law, University of East London, UK; the Higher Education Academy, York, UK; the African Technology Policy Studies Network Nairobi, Kenya; the National Research Center (NRC), Khartoum, Sudan; the Department of Agricultural Economics, Ambrose Alli University, Ekpoma, Nigerira; the Federal Ministry of Agriculture and Rural Development, Abuja, Nigeria; and many others.

All these partners have directly supported the Yearbook project, comprising this volume 20 and the forthcoming volume 21 on *"Science, Technology and Innovation Policies for Inclusive Growth in Africa. Human Skills Development and Country Cases"*, with contributions, expertise and suggestions. Special thanks go to Professor Dr. Samia Satti Mohamed Nour, Department of Economics, University of Khartoum, and to Dr. Nazar Mohamed Hassan, Regional Adviser, UNESCO Regional Office for Science and Technology for the Arab States, Cairo,

Egypt. Both have given advice from the first phase of planning this publication project. The volume editor, Professor Karl Wohlmuth (from IWIM/Institute for World Economics and International Management and the Research Group on African Development Perspectives Bremen), is indebted to these two experts for encouragement, ideas, concepts, and valuable contributions to this volume 20 of the African Development Perspectives Yearbook.

Institutional support is welcomed. Many organisations in Africa, like the African Development Bank (AfDB) Group, the United Nations Economic Commission for Africa (UNECA), the African Union (AU), and the NEPAD (New Partnership for Africa's Development) Secretariat have contributed with information and encouragement. Also, the OECD (Organization for Economic Cooperation and Development) and its Development Centre, the IMF (International Monetary Fund) and the World Bank (with various offices at headquarters and in Africa) have given advice and information. We, as the Editors of the Yearbook, are always interested in their advice and guidance to structure the future work on the *African Development Perspectives Yearbook*.

For Volume 20 of the *African Development Perspectives Yearbook* the Editors of the Yearbook took up the issues of Science, Technology and Innovation (STI) Policies for Inclusive Growth in Africa: These issues are so important for the much-needed redirection of economic policies in Africa. Volume 19 had the theme of New trade and Investment policies for Africa, as structural reforms and structural transformation in Africa request policies which directly support structural change. STI policies can support structural change in many ways, via acceleration of productivity growth, development of agriculture and agribusiness, diversification of industrial production and exports towards higher value-added products, via making the services sector more productive, building human capacities for growth, and implementing inclusive growth strategies. Unit 1 of this volume 20 focusses on “Science, Technology and Innovation (STI) Policies for Inclusive Growth in Africa – General Issues”. In various essays key issues are discussed, such as the role of innovations for diversification and inclusive growth, the development of STI policies in Africa and the support by UNESCO and building capacity for Africa's STI systems. Unit 2 of Volume 20 is presenting essays on “Science, Technology and Innovation (STI) Policies for Sudan's Economic Revitalization”. These essays cover important aspects of Sudan's STI system, such as: How to reform the national innovation system (NIS) and the subsystems (education, science & technology, ICT) in Sudan? How can innovative firms operate in Sudan, and how can these firms be supported by policies? How important are agricultural research systems for the field testing of research results and for yield increases in various agricultural subsectors and for various local crops? How important are foreign investors in generating knowledge spillovers to domestic firms? Unit 3 of Volume 20 is discussing the theme of “Science, Technology and Innovation (STI)

Polices for Agricultural Transformation in Nigeria". In various essays specific issues of Nigeria's overdue agricultural transformation are presented: the role of indigenous agricultural technologies and their development and production in local Nigerian research institutes; the role of GM (Genetically Modified) crops, such as cowpea as a local staple food crop, to increase pest-resistance and yields while preserving acceptability among farmers and consumers; and the importance of looking at developing the overall value chain of local crops, such as cassava, to increase production and yield and to fortify the crop by bio-technology and breeding so that consumers receive the important minerals they need.

While the volume 18 of the Yearbook focussed on "transformative regional integration in Africa", the volume 19 focussed on "new trade and investment policies for Africa", and volume 20 is presenting a strategy on "STI policies for inclusive growth in Africa"; Volume 21 will continue the debate from volume 20 by focussing on "human capacity building and STI policies in Africa". Also, volume 21 will focus on North African countries, like Egypt and Tunisia. The role of STI in private sectors in these countries, the role of technoparks, the behaviour of innovative firms, and the spread of innovations in health sectors will be discussed. Volume 21 has also a Book Reviews and Book Notes section; this section (Unit) is rich in presenting numerous review articles, book reviews and book notes on the core themes of volumes 20 and 21.

In Volumes 20 and 21 of the *African Development Perspectives Yearbook* with the common theme of STI policies for inclusive growth in Africa major strategic and policy issues are analysed. The guiding issue is how to make the STI policies becoming a part of the structural transformation process in Africa. So far, these policies are not applied in a comprehensive, integrative and coherent approach, and they lack a focus on structural transformation. The disappointing results in mobilizing resources for development, in promoting production and export diversification, in allowing for a participation of local firms in global and regional value chains, in establishing production, R&D, tertiary education and vocational training, and trade partnerships, in strengthening regional integration, and in attracting foreign direct investment for high-value added manufacturing and high-technology services sectors request a new approach towards STI systems development. Also, the limits in African intra-regional trade, investments, technology diffusion, skilled labour migration, enterprise-to-enterprise cooperation, etc., within and between the regional economic communities (RECs) in Africa, request a completely new approach towards STI development.

Many institutions have contributed to the various volumes of the *African Development Perspectives Yearbook*, with news and information about countries and regions, with information about new research projects, with publications about policies and strategies, with documents about declarations and agreements, and with research papers, also at their early stage. So, the editors of the Yearbook can grasp new development in Africa very early, what helps in inviting contributors

who are then key persons of specific units. Many regional and international organisations, like the African Development Bank (AfDB), the African Union (AU) and affiliated institutions, the UNECA (United Nations Economic Commission for Africa), the World Bank, UNCTAD (United Nations Conference on Trade and Development), UNDP (United Nations Development Programme), IMF (International Monetary Fund), UNIDO (United Nations Industrial Development Organization), and ILO (International Labour Organization), continue to support our scientific effort by sending us materials and making available - always timely - new strategy documents and drafts of their researches for our publication series, especially the *African Development Perspectives Yearbook*, but also for our Book Review and Book Notes Unit. For volumes 20 and 21, UNESCO (United Nations Educational, Scientific and Cultural Organisation) and ACBF (African Capacity Building Foundation) stepped in with huge support. But it is also true that persons in these important organizations matter; they open the doors and invite us to cooperate and to share our knowledge with them.

Also, UNU-WIDER (United Nations University - World Institute for Development Economics Research) as an institution of global importance for development research has continuously supported our work with most recent research papers, with access to their networks of researchers and affiliated institutes, and with publications and information about important scientific events in their domain of development studies. Furthermore, we would like to thank all those institutions to make us part of their global research networks, as they are informing so many others in the development field about our work for Africa, in our endeavour of continuously publishing the *African Development Perspectives Yearbook*. This is the case now since 1989 when the first volume appeared under the theme of “Human Dimensions of Adjustment”.

We would also like to express our gratitude to three researchers who accepted the position as members of the Editorial Committee for Volume 20, to act as Co-Editors of a Unit and as a Volume Editor. We are indebted to Dr. Nazar Mohamed Hassan, Regional Adviser, UNESCO Regional Office for Science and Technology for the Arab States, Cairo, Egypt, for his work, together with Karl Wohlmuth, towards the Unit 1 of Volume 20 on “STI - General Issues”, thereby introducing the theme to the readers. We are thankful to Professor Dr. Samia Satti Mohamed Nour, Department of Economics, University of Khartoum, for her work, in cooperation with Professor Karl Wohlmuth, on Unit 2 about “STI for Sudan’s Revitalization”, providing expertise on STI systems and on Sudan’s economic perspectives. Also, we are thankful to Professor Reuben A. Alabi, Professor of Agricultural Economics, Department of Agricultural Economics, Ambrose Alli University, Ekpoma, Nigeria, who is still guest professor and project director at the Institute for World Economics and International Management (IWIM), University of Bremen, at the invitation of the Dean of the Faculty of Economics and Business Studies. Professor Alabi has contributed, in cooperation with Professor Karl Wohlmuth, to Unit 3 of

Volume 20 with the theme "STI Policies for Agricultural Transformation in Nigeria". These three Co-editors of the three Units of Volume 20 have done an excellent job, and we hope to cooperate with all of them towards publishing future volumes of the Yearbook.

We are also indebted to Andrew Mold from UNECA for his continuous encouragement; beside of being an author in several of our volumes he always has pushed us to present the new Yearbook Volumes at the UNECA offices in Addis Ababa and Kigali, and/or elsewhere in Africa. In October 2016 this idea was realised. Andrew Mold, at that time Acting Director of the Kigali Office of UNECA, organized the launch event with a fine programme. A major launch event took place in Kigali, Rwanda. Our Managing Director, Professor Tobias Knedlik from the Fulda University of Applied Sciences, and our Project Adviser, Dr. Nazar Mohamed Hassan, Regional Adviser, UNESCO Regional Office, were present in Kigali. They informed the attending experts, policymakers, ambassadors, the UN staff, and the representatives of donor organizations and the media about the Yearbook Project. It was a great event, and African TV and Radio Stations reported in 48 African countries about the launch event for volumes 18 and 19 of the *African Development Perspectives Yearbook*. We are planning to hold such events in the future more regularly. Dr. Nazar Mohamed Hassan has already mentioned the idea to present the two volumes 20 and 21 of the Yearbook at UNESCO offices. This could give additional weight to the theme of "STI Policies for Inclusive Growth in Africa". We hope that we can realise this project with the publication of the new volumes of the *African Development Perspectives Yearbook*.

Professor Dr. Tobias Knedlik, the Managing Editor of the *African Development Perspectives Yearbook,* and Professor Karl Wohlmuth, the Director of the *Research Group on African Development Perspectives Bremen* and Volume Editor, are also thankful to Professor Dr. Achim Gutowski for his continuous work as the Book Review/Book Notes Editor of the *African Development Perspectives Yearbook*; he is already preparing the Unit 3 with Book Reviews and Book Notes for Volume 21, the forthcoming volume. This Unit will provide a great number of book reviews and book notes on books, research papers and documents being related to STI systems in Africa, but also general studies on Africa's development will be reviewed in Volume 21. The impressive list of subjects for the Book Review Unit 3 for Volume 21 is made available in the final part of this volume 20 (see the Contents of Volume 21 for the Yearbook Edition for 2019).

We are thankful to all the contributors and supporters of the *African Development Perspectives Yearbook* for their hard work, their steady encouragement and their continuous assistance. The valuable inputs from leading African research institutions and their experts have contributed over the years to the success of the *African Development Perspectives Yearbook* as an outstanding publication on and for Africa. In 2019 the project will celebrate its 30th birthday, as the first volume has appeared in 1989. The readers of the various Yearbook volumes have continuously contributed with their critical comments and with supportive encouragement, so that over time a valuable partnership has emerged between readers, contributors and editors.

Various institutions have made over the years donations and have funded specific allocations to the *African Development Perspectives Yearbook* project, but the support of the University of Bremen, Bremen, Germany is of invaluable importance. The University of Bremen was awarded by the German scientific research community in June 2012 the title "Excellence University", and the *Research Group on African Development Perspectives Bremen* is very proud about this distinction. The great honour for the University of Bremen is helping in the further work of the Research Group on African Development Perspectives Bremen. These donations, supports and research grants to the Yearbook Project have helped us to intensify researches on African development issues, to distribute the various volumes of the Yearbook to African partner universities and to major African research institutions, and to invite research scholars from leading African research institutions to work with us in Bremen. Institutions like the Volkswagen Foundation and the Alexander von Humboldt Foundation have generously financed the stay of senior researchers at IWIM (Institute for World Economics and International Management) in Bremen. Currently, the African Economic Research Consortium (AERC) and the International Monetary Fund (IMF), African Department, are financing research of our staff/guest researchers. We are thankful for all these contributions to the researches on African development issues in Bremen and to the work on the Yearbook volumes.

Africa Research Workshops were regularly held in Bremen at the University to discuss the draft papers which were intended for publication in the Yearbook. These Africa Research Workshops served as forums for the intensive discussion of the draft papers and of related research topics. Still there is contact to many of these visitors. The Editors also want to express the thanks to the many reviewers of the draft contributions for the Yearbook volumes for their committed work. By this input the *African Development Perspectives Yearbook* has become over the years a fully refereed publication. Also, the reviewers of the many books and documents for the Book Review Unit are doing an excellent job. Past volumes, volume 19 and forthcoming volume 21 give evidence of this important part of the work of the *Research Group on African Development Perspectives Bremen*.

Many persons have given support, advice, and encouragement; others have helped with frank and critical assessments. However, the responsibility for the final product remains with the editorial team of the *Research Group on African Development Perspectives Bremen*. Both volumes, the Volume 20 for the year 2018 and Volume 21 for the year 2019 are released during the year 2018. The *Research Group on African Development Perspectives* has already started its work on Volume 22 for the year 2020 with the title *"The Sustainable Development Goals and*

*African Development – New Ways Forward"*. The theme is related to important research and cooperation programmes of the *Research Group on African Development Perspectives Bremen* at IWIM (Institute for World Economics and International Management), University of Bremen.

In the name of the Editorial Team:

Professor Dr. Tobias Knedlik, Fulda University of Applied Sciences and IWH Halle, Managing Editor, and

Professor Emeritus Dr. Karl Wohlmuth, University of Bremen, Director of the Research Group on African Development Perspectives Bremen at IWIM, and Volume Editor.

# List of Abbreviations and Acronyms

| | |
|---|---|
| 2iE | International Institute of Water and Environmental Engineering |
| 3D | 3 Dimensions |
| AAA | Addis Ababa Action (Agenda) |
| AAA | Addis Ababa Accord |
| AAEA | Agricultural & Applied Economics Association |
| AATF | African Agricultural Technology Foundation |
| ABIs | Agro-Based Industries |
| ABU | Ahmadu Bello University |
| ACBC | Agro-politan Cooperative Business Cluster |
| ACBF | African Capacity Building Foundation |
| ACC | Agro-politan Cooperative Community |
| ACCI | Arab Composite Competitiveness Index |
| ACI | Africa Capacity Index |
| ACMD | African Cassava Mosaic Disease |
| ACR | Africa Capacity Report |
| ACR | Arab Competitiveness Report |
| ADAs | Agricultural Development Agencies |
| ADDA | Agriculture and Dietary Diversity in Africa |
| ADEA | Association for the Development of Education in Africa |
| ADF | Augmented Dickey-Fuller test |
| ADPs | Agricultural Development Programmes |
| AEHE | Agricultural Equipment Hiring Enterprise |
| AERC | African Economic Research Consortium |
| AES | Agricultural Equipment Sector |
| AfDB | African Development Bank |
| AIC | Akaike information criterion |
| AIDS | Acquired Immuno-Deficiency Syndrome |
| AIF | African Innovation Framework |
| AIO | African Innovation Outlook |
| AIS | agricultural innovation system |

| | |
|---|---|
| AISI | African Information Society Initiative |
| AISs | Agricultural Innovation Systems |
| ALECSO | Arab League Educational, Cultural and Scientific Organization |
| AMCOST | African Conference of Ministers responsible for Science and Technology |
| AMFS | African Maize Fortification Strategy |
| ANPR | Tunisian National Agency for Scientific Research Promotion |
| ANSTI | African Network of Scientific and Technological Institutions |
| AOSTI | African Observatory for Science, Technology and Innovation |
| API | Arab Planning Institute |
| APP | Agricultural Promotion Policy |
| APRC | Animal Production Research Centre |
| ARC | Agricultural Research Corporation |
| ARCH | Autoregressive conditional heteroskedasticity |
| ARCN | Agricultural Research Council of Nigeria |
| ARDL | Autoregressive Distributed Lag |
| ARDS | Agriculture R&D System |
| ARII | Africa Regional Integration Index |
| AROC | Agricultural Research Outreach Centre |
| ARRC | Animal Resources Research Corporation |
| ARTTCs | Agricultural Research Technology Transfer Centres |
| ASARECA | Association for Strengthening Agricultural Research in Eastern and Central Africa |
| ASEC | Arab Swiss Engineering Company |
| ASRT | Academy of Scientific Research and Technology |
| ASSTI | Arab Strategy for Science, Technology and Innovation |
| ASTIF | African Science, Technology and Innovation Fund |
| ASTII | African Science Technology and Innovation Indicators Initiative. |
| ATA | Agricultural Transformation Agenda |
| AU | African Union |
| AUC | African Union Commission |

| | |
|---|---|
| AUST | African University of Science and Technology |
| AVs | Adopted Villages |
| BC+ | Bio-Cassava Plus |
| BDS | business development services |
| BHEL | Bharat Heavy Electricals |
| BRICS | Brazil, Russia, India, China, South Africa (group of countries) |
| Bt | Bacillus thuringiensis (biological pesticide) |
| CAES | Canadian Agricultural Economics Society |
| CAP | Capacity Building Programme of ACBF |
| CAPRI | Collective Action and Property Rights |
| CAR | Conventional Agricultural Research |
| CARD | Coalition for African Rice Development |
| CASTAFRICA | Conference of Ministers Responsible for the Application of Science and Technology in Africa |
| CASTARAB | Conference of Ministers Responsible for the Application of Science and Technology for the Arab States |
| CATISA | Cassava Transformation In Southern Africa |
| CBB | Cassava Bacterial Blight |
| CBN | Central Bank of Nigeria |
| CBoS | Central Bank of Sudan |
| CBRST | Benin Centre for Scientific and Technical Research |
| CBS | Central Bureau of Statistics |
| CCC | CAST-Arab Continuing Community |
| CD | Capacity Development |
| CEOs | Chief Executive Officers |
| CEs | Choice experiments |
| CFT | confined field testing |
| CGAP | Consultative Group to Assist the Poor |
| CGIAR | Consultative Group for International Agricultural Research |
| CGM | Cassava Green Mite |
| CIAT | Centro Internacional de Agricultura Tropical |
| CIBS | China, India, Brazil and South Africa |

| | |
|---|---|
| CIMMYT | International Maize and Wheat Improvement Center/Centro Internacional de Mejoramiento de Maíz y Trigo |
| CIP | Comparative Industrial Performance (Index) |
| CIRCLE | Centre for Innovation, Research and Competence in the Learning Economy, Lund University |
| CL | Central Laboratory |
| CLM | conditional logit model |
| CMD | Cassava Mosaic Disease |
| CNHDE | Centre for National Health Development in Ethiopia |
| CNPC | China National Petroleum |
| CNRST | National Centre for Scientific and Technical Research |
| COAG | Committee on Agriculture |
| CODIST | Committee on Development Information Science and Technology |
| COLCIENCIAS | Administrative Department of Science, Technology and Innovation (in Columbia) |
| COM | Combinatorial Optimization Method |
| COP 21 | 21st Conference of the Parties |
| COSCA | Collaborative Study of Cassava in Africa |
| CPA | Consolidated Plan of Action |
| CPA | Comprehensive Peace Agreement |
| CPF | Country Programming Framework |
| CPI | Corruption Perceptions Index |
| CRIG | Cocoa Research Institute of Ghana |
| CRSP | Bean/Cowpea Collaborative Research Support Program |
| CSA | Climate-Smart Agriculture |
| CSD | Committee on Sustainable Development |
| CSIR | Council for Scientific and Industrial Research |
| CSIRO | Commonwealth Scientific and Industrial Research Organization, in Australia |
| CTA | Cassava Transformation Agenda |
| CV | compensating variation |
| CVRL | Central Veterinary Research Laboratory |
| DAAD | Deutscher Akademischer Austauschdienst/ German Academic Exchange Service |

| | |
|---|---|
| DAL | Daoud Abdel Latif (Group of Industries) |
| DALY | Disability-Adjusted Life Year |
| DDPSC | Donald Danforth Plant Science Center |
| DFID | Department of International Development |
| DFID | Department For International Development (of UK) |
| DFRC | DAL Food Research Centre |
| DGRST | Délégation Générale pour la Recherche Scientifique et Technologique/ General Directorate for Scientific Research and Technology |
| DOI | Digital Object Identifier |
| DRC | Democratic Republic of Congo |
| DSF | Dynamic Strategic Fit |
| DST | Department of Science and Technology |
| DTIS | Diagnostic Trade Integration Study |
| DW | Durbin-Watson |
| E-Agric | Electronic Agriculture |
| EAP | economic adjustment programme |
| EARC | Egyptian Agriculture Research Centre |
| EASSy | Eastern Africa Submarine Cable System |
| EBA | Everything But Arms |
| EC | ECronicon (journal publisher) |
| ECA | Economic Commission for Africa |
| ECOSOC | Economic and Social Council of the United Nations |
| ECOWAS | Economic Community of West African States |
| ECT | Error Correction Term |
| ECX | Ethiopian Commodity Exchange |
| EDAP | experimental development accelerator programme |
| EEs | Emerging Economies |
| EIF | Enhanced Integrated Framework |
| E-Innovation | Electronic Innovation |
| EMBRAPA | Brazilian Agricultural Research Corporation |
| EOLSS | Encyclopaedia of Life Support Systems |
| ESCWA | Economic and Social Commission for Western Asia, |
| ESRB | Economic and Social Research Bureau |

| | |
|---|---|
| ESTC | Ethiopia's Science and Technology Commission |
| ESTIO | Egyptian Science, Technology and Innovation Observatory |
| EU | European Union |
| FAO | Food and Agriculture Organization (of the United Nations) |
| FAO/GIEWS | FAO/Global Information and Early Warning System |
| FAOSTAT | FAO Statistics |
| FCT | Federal Capital Territory |
| FDI | Foreign Direct Investment |
| FDIS | FDI stock |
| FEC | Federal Executive Council |
| FED | Feddan (1 feddan = 24 kirat = 60 metres × 70 metres = 4200 square metres (m2) = 0.42 hectares = 1.038 acres) |
| FFI | Food Fortification Initiative |
| FGN | Federal Government of Nigeria |
| FIIRO | Federal Institute of Industrial Research |
| FMARD | Federal Ministry of Agriculture and Rural Development |
| FMST | Federal Ministry of Science and Technology |
| FoEN | Friends of the Earth Nigeria |
| FPE | Final Prediction Error criteria |
| FRC | Fisheries Research Centre |
| FRCN | Federal Radio Corporation of Nigeria |
| FRN | Federal Republic of Nigeria |
| FTE | Full Time Equivalent |
| FTER | Full Time Equivalent Researchers |
| GAIN | Global Alliance for Improved Nutrition |
| GCI | Global Competitiveness Index |
| GCP | Generation Challenge Programme |
| GDP | Gross Domestic Product |
| GEMS | Growth and Employment in States |
| GERD | Gross Expenditure on Research and Development |
| GET | Global Employment Trends |
| GFKF | gross fixed capital formation |

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| GGDC | Groningen Growth and Development Center |
| GICO | Government Implementation Coordinating Office |
| GII | Global Innovation Index |
| GIN | Global Innovation Network |
| GITR | Global Information Technology Report |
| GIZ | Deutsche Gesellschaft für Internationale Zusammenarbeit |
| GKF | gross capital formation |
| GM | Genetically Modified |
| GMAR | GM Agricultural Research |
| GMO | Genetically Modified Organism |
| GNI | Gross National Income |
| GoN | Government of Nigeria |
| GSC | Guneid Sugar Company |
| GTZ | Gesellschaft Fuer Technische Zusammenarbeit |
| HCI | Human Capital Index |
| HCI | High Council for Investment |
| HDI | Human Development Index |
| HDR | Human Development Report |
| HEP | Health Extension Programme |
| HESPI | The Horn Economic and Social Policy Institute |
| HEST | Higher Education, Science and Technology |
| HEW | Health Extension Worker |
| HHD | High Human Development |
| HIV | Human Immunodeficiency Virus |
| HNLSS | Harmonized Nigeria Living Standard Survey |
| HQ | Hannan-Quinn information criterion |
| HQCF | High Quality Cassava Flour |
| HRS | Hydrology Research Station |
| IAR | Indigenous Agricultural Research |
| IAR | Institute for Agricultural Research |
| IARC | International Agricultural Research Centre |
| IBRD | International Bank for Reconstruction and Development |

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| ICA | Investment Climate Assessment |
| ICRISAT | International Crops Research Institute for the Semi-Arid Tropics |
| ICT | Information and Communication Technology |
| ICTP | International Centre for Theoretical Physics |
| ICTs | information communication technologies |
| IDB | Islamic Development Bank |
| IDI | Inclusive Development Index |
| IDRC | International Development Research Centre |
| IER | innovation efficiency ratio |
| IF | Innovation Fund |
| IFAD | International Fund for Agricultural Development |
| IFP | Integrated Framework Programme |
| IFPRI | International Food Policy Research Institute |
| IIAG | Ibrahim Index of African Governance |
| IIMs | Indian Institutes of Management |
| IITA | International Institute of Tropical Agriculture |
| IITs | Indian Institutes of Technology |
| IK | Indigenous knowledge |
| ILO | International Labour Organisation |
| IMF | International Monetary Fund |
| INRAB | National Institute of Agricultural Research of Benin |
| INSEAD | Institut Européen d'Administration des Affaires |
| IP | Industrial Policy |
| IPA | investment promotion agency |
| IPAR | Institute of Policy Analysis and Research (in Kigali, Rwanda) |
| IPM | Integrated Pest Management |
| IPRs | Intellectual Property Rights |
| IRCC | Industrial Research and Consultancy Centre |
| IRCN | Industrial Research Council of Nigeria |
| IRESEN | Institute for Research in Solar and New Energy |
| ISAS | International Society of African Scientists |
| ISO | International Sugar Organisation |

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| IT | Information Technology |
| ITA | Institut de Technologie Alimentaire (in Dakar, Senegal) |
| ITU | International Telecommunication Union |
| IWIM | Institute for World Economics and International Management |
| IWSD | Integrated Whole System Design (approach) |
| IWVWW e. V. | Internationale Wissenschaftliche Vereinigung für Weltwirtschaft und Weltpolitik e. V. |
| JICA | Japan International Cooperation Agency |
| JKUAT | Jomo Kenyatta University Of Agriculture And Technology (in Nairobi) |
| JRF | Joint Research Fund |
| KEI | Knowledge Economy Index |
| KEM | Kenana Engineering and Manufacturing |
| KII | Key Informant Interview |
| KIST | Kigali Institute of Science and Technology |
| KM | knowledge management |
| KMN | Kigali Metropolitan Network |
| KNUST | Kwame Nkrumah University of Science and Technology |
| KSC | Kenana Sugarcane Company |
| KTI | Knowledge-Technology-Innovation |
| KTP | Knowledge Transfer Partnership (programme) |
| L | Litres |
| LDCs | Least Developed Countries |
| LGA | Local Government Area |
| LHD | Low Human Development |
| LISs | Local Innovation Systems |
| LM | Langrage-Multiplier |
| LMOs | Living Modified Organisms |
| LP | Livestock production |
| LPPDI | Large-scale Pilot Projects Direct Implementation |
| LR | Likelihood-ratio test |
| LSI | Large-scale irrigation |

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| LUANAR | Lilongwe University of Agriculture and Natural Resources |
| M&A | Mergers and Acquisition |
| M&E | Monitoring and Evaluation |
| MAD | Moroccan Dirham |
| MAF | Ministry of Agriculture and Forestry |
| MAFAP | Monitoring African Food and Agricultural Policies (project) |
| M-Agric | Mobile Agriculture |
| MAS | Marker Assisted Selection |
| MDA | Minimum Daily Allowance |
| MDGs | Millennium Development Goals |
| MENA | Middle East and North Africa (region) |
| MESRS | Ministry of Higher Education and Scientific Research |
| MGDS | Malawi Growth and Development Strategy |
| MHD | Medium Human Development |
| M-Innovation | Mobile Innovation |
| MIP | Mechanisation Intervention Programme |
| MIS | Moroccan Innovation Strategy |
| MIT | Massachusetts Institute of Technology |
| MNC | multinational corporation |
| MNDC | Micronutrient Deficiency Control |
| MoA | Minister of Agriculture |
| MoHE | Ministry of Higher Education |
| MoHESR | Ministry of Higher Education and Scientific Research |
| MOPs | Multi-Objectives Programmes |
| MoSaC | Ministry of Science and Communication |
| MoSR | Ministry of Scientific Research |
| MOST | Ministry of Science and Technology |
| MPDI | Mega Projects Direct Implementation |
| MRCN | Medical Research Council of Nigeria |
| MRSI | Ministry of Scientific Research and Innovation |
| MSK | Modern Scientific Knowledge |
| MSMEs | Micro, Small and Medium Enterprises |

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| MSNDAP | Multi-Sectoral National Developmental Action Plan |
| MSR | Ministry of Higher Education, Universities, Regional University Centres and Scientific Research |
| MST | Ministry of Science and Technology |
| MT | Metric Tons |
| MTRM | Monthly Technical Review Meetings |
| MTRP | Medium Term Research Plan |
| MUST | Malawi University of Science and Technology |
| MW | Megawatt |
| MWRI | Ministry of Water Resources and Irrigation (of Egypt) |
| MZUNI | Mzuzu University |
| N | nitrogen fertilizer |
| N | Naira (Nigerian currency) |
| N.A. | Not Available (data) |
| n.e.s. | not elsewhere specified |
| NABC | National Agricultural Biotechnology Council |
| NABDA | National Biotechnology Development Agency |
| NACOSTI | National Commission for Science, Technology and Innovation |
| NAFDAC | National Agency for Food and Drug Administration and Control |
| NARP | National Agricultural Research Project |
| NARS | National Agricultural Research System |
| NARSP | National Agricultural Research Strategy Plan |
| NAS | National Academy of Sciences |
| NASEI | National Agency for Science and Engineering Infrastructure |
| NASS | National Assembly |
| NBER | National Bureau of Economic Research |
| NBMA | National Biosafety Management Agency |
| NBS | National Bureau of Statistics |
| NBTI | National Board for Technology Incubation |
| NCAM | National Centre for Agricultural Mechanisation |
| NCCs | National Crop Campaigns |
| NCR | National Centre for Research |

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| NCRP | Nationally Co-ordinated Research Programme |
| NCSIR | National Council on Scientific and Industrial Research |
| NCSR | National Council for Scientific Research |
| NCST | National Commission for Science and Technology |
| NDA | National Development Agenda |
| NDS | national development strategy |
| NECTAR | Network for the Expansion of Converging Technologies in the Arab Region |
| NEPAD | New Partnership for Africa's Development |
| NEPC | Nigerian Export Promotion Council |
| NGICA | Network for Genetic Improvement of Cowpea in Africa |
| NGO | Non-Governmental Organizations |
| NIA | National Investment Authority |
| NIMR | Nigerian Institute of Medical Research |
| NIRDA | National Industrial Research and Development Agency |
| NIS | National Innovation System |
| NISER | Nigeria Institute for Social and Economic Research |
| NISIR | National Institute for Scientific and Industrial Research |
| NISs | National Innovation Systems |
| NMAIST | Nelson Mandela Africa Institute for Science and Technology |
| NMPs | National Mega Projects |
| NOTAP | National Office for Technology Acquisition and Promotion |
| NPCA | NEPAD Planning and Coordinating Agency |
| NRC | National Research Centre |
| NRCRI | National Root Crops Research Institute |
| NRF | National Research Fund |
| NRI | Natural Resources Institute |
| NRI | Networked Readiness Index |
| NRIC | National Research and Innovation Council |
| NRIF | National Research and Innovation Fund |
| NSPRI | National Stored Products Research Institute |
| NSTC | National Science and Technology Council |

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| NSTDA | National Science and Technology Development Agency |
| NSTF | National Science and Technology Fund |
| NSTI | National Science, Technology and Innovation (Policy) |
| NSTP | National Science and Technology Policy |
| NTBC | National Technology Business Centre |
| NT-EP-EE | Novel Technologies – Equal Partnership – Ensured Equity (Nexus) |
| OCP | Office Chérifien des Phosphates |
| OECD | Organization for Economic Co-operation and Development |
| OFAB | Open Forum on Agricultural Biotechnology |
| ONGC | Oil and Natural Gas Corporation |
| P | phosphorus fertilizer |
| PC | Personal Computer |
| PCT | Patent Cooperation Treaty |
| PDESR | Priority Programme Reform and the Development Plan for Higher Education and Research |
| PES | Plan for an Emerging Senegal |
| PfE | Payment for Equipment and Other Services |
| PGFKF | private gross fixed capital formation |
| PI | Presidential Initiative |
| PP | Phillips-Perron test |
| PPD | Post-harvest Physiological Deterioration |
| PPP | Purchasing Power Parity |
| PPPP | Public Private Partnership Policy |
| PPPs | public private partnerships |
| PRPs | Priority Research Projects |
| R&D | Research and Development |
| REC | Regional Economic Community |
| REFILS | Research Extension Farmers Input Linkage System |
| RIEF | Rwanda Innovation Endowment Fund |
| RISP | Reconstruction and Innovation Support Programme |
| RORS | Risks, Opportunities, Resources and Skills |
| RRTC | Rice Research and Training Centre |

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| RSA | Refined Sugar Association |
| RSES | Rent Seeking Economic Structure |
| RTEP | Roots and Tubers Expansion Programme |
| RTT | Research and Technology Transfer |
| S&T | Science and Technology |
| SADC | Southern Africa Development Community |
| SAEC | Sudan Atomic Energy Commission |
| SAPFF | Strengthening African Processors of Fortified Foods |
| SC | stated choice |
| SCRC | Sugar Cane Research Centre |
| SDA | Sustainable Development Agenda |
| SDG | Sustainable Development Goals |
| SED | Senior Experts Dialogue |
| SERB | Social and Economic Research Bureau |
| SERG | Sudan Economy Research Group |
| SETI | Science, Engineering, Technology, and Innovation |
| SIC | Schwarz Information Criterion |
| SIDA | Swedish International Development Cooperation Agency |
| SIRDC | Scientific Industrial Research and Development Corporation of Zimbabwe |
| SISs | Sectoral Innovation Systems |
| SITC | Standard International Trade Classification |
| SMA | Sudan Meteorological Authority |
| SMART | Specific, Measurable, Attainable, Replicable and Time Bound |
| SMEDAN | Small and Medium Enterprises Development Agency of Nigeria |
| SMEs | Small and Medium Enterprises |
| SMR | Semi-Mechanised Rainfed |
| SMS | Short Message Service |
| SoE | Supply of Equipment, Information and Training |
| SON | Standards Organisation of Nigeria |
| SPI | Social Progress Index |
| SPLM | Sudan People’s Liberation Movement |

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| SPV | Special Purpose Vehicle |
| SRF | Strategic Research Fund |
| SSA | Sub Saharan Africa |
| SSARTO | Southern Sudan Agricultural Research and Technology Organization |
| SSMO | Sudanese Standards and Metrology Organization |
| STAG | Science and Technology Advisory Group |
| STDF | Science and Technology Development Fund |
| STEM | Science, Technology, Engineering and Mathematics |
| STI | Science, Technology and Innovation |
| STISA | Science, Technology and Innovation Strategy for Africa |
| STO | Science and Technology Observatory |
| STP | Science and Technology Policy |
| STS | Science, Technology and Society |
| SWOT | Strengths/Weaknesses/Opportunities/ Threats |
| t | Tons |
| TAI | technology achievement index |
| TIKE | Technology, Innovation and Knowledge - based Economy |
| TIP | Transformative Industrial Policy |
| TMS | Tapioca Mosaic Selection |
| TMS | transcranial magnetic stimulation (seed varieties) |
| TNC | Total National Capacity |
| TNDP | Tenth National Development Plan |
| TR | Traditional rain-fed |
| TSD | Training and Skills Development |
| TVET | Technical and Vocational Education and Training |
| U.A.E | United Arab Emirates |
| U.S.A | United States of America |
| UAVs | Unmanned Aerial Vehicles |
| UECM | Unrestricted Error Correction Model |
| UI | University of Ibadan |
| UIS | UNESCO Institute of Statistics |
| UN | United Nations |

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| UN DESA | United Nations Department of Economic and Social Affairs |
| UNAAB | University of Agriculture Abeokuta |
| UN-CSTD | UN Commission on Science and Technology for Development |
| UNCTAD | United Nations Conference on Trade and Development |
| UNDP | United Nations Development Programme |
| UNECA | United Nations Economic Commission for Africa |
| UNEP | United Nations Environment Programme |
| UNESCO | United Nations Educational, Scientific and Cultural Organisation |
| UNIDO | United Nations Industrial Development Organization |
| UNIMA | University of Malawi |
| UNISPAR | University-Industry-Science Partnership |
| UNRISD | United Nations Research Institute for Social Development |
| UNU | United Nations University |
| UNU-INTECH | United Nations University-Institute for New Technologies |
| UNU-MERIT | United Nations University-Maastricht Economic and Social Research Institute on Innovation and Technology |
| US | United States |
| US$ | United States Dollar |
| USA | United States of America |
| USAID | United States Agency for International Development |
| USD | United States Dollar |
| USDA | United States Department of Agriculture |
| VAD | Vitamin A-Deficient/Vitamin A-Deficiency |
| VAR | Vector Autoregression Analysis |
| VECM | Vector Error Correction Model |
| VHHD | Very high human development |
| WAAPP | West Africa Agricultural Productivity Programme |
| WABCG | World Association of Beet and Cane Growers |
| WACCBIP | West Africa Centre on the Cell Biology of Infectious Pathogens |

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| WACCI | West Africa Centre for Crop Improvement |
| WAEA | Western Agricultural Economics Association |
| WB | World Bank |
| WDI | World Development Indicators |
| WEF | Water-Energy-Food (Security Nexus) |
| WEF | World Economic Forum |
| W-E-FS | Water-Energy-Food Security (Nexus) |
| WEMA | Water Efficient Maize for Africa |
| WFP | World Food Programme |
| WHO | World Health Organisation |
| WiBro | Kigali Wireless Broadband (WiBro) Network |
| WIPO | World Intellectual Property Organization |
| WP | Working Paper |
| WRC | Wildlife Research Centre |
| WSRO | World Sugar Research Organisation |
| WTO | World Trade Organization |
| WTP | Willingness to Pay |
| WTRL | Wellcome Tropical Research Laboratories |
| YIF | Youth Innovation Fund |
| You Win | Youth Enterprise with Innovation in Nigeria |
| ZEPARU | Zimbabwe Economic and Policy Analysis Research Unit |
| ZERA | Zimbabwe Energy Regulatory Authority |

# Unit 1: Science, Technology and Innovation (STI) Policies for Inclusive Growth in Africa – General Issues

# Science, Technology and Innovation (STI) Policies for Inclusive Growth in Africa – An Introduction

**Nazar Hassan**[1] **and Karl Wohlmuth**[2]

## 1 The Issues

### 1.1 STI policies are important for inclusive and sustainable growth in Africa

Science, technology and innovation (STI) is of critical significance for sustainable development in all its dimensions – economic, social and environmental, as it is through basic and experimental research that sciences buttress all technological innovation and engineering solutions needed to address contemporary challenges, such as environmental degradation and restoration, water scarcity, and energy needs, but also widespread poverty, unplanned urban growth and rural underdevelopment, and hence lead any nation towards attaining sustainable development. Evidence-based research indicates that the backbone of developed knowledge-based economies is the existence of diversified manufacturing capabilities, and such capabilities are continuously extended by STI in society and economy. As the production of modern manufactured goods and related services is the essence of the Knowledge-driven Economy or the Innovation-led Economy, STI policies matter in Africa as a tool to promote economic diversification and manufacturing development, as well as solving the other development problems mentioned above. Manufacturing development, which is based on STI, will induce inclusive and sustainable growth in Africa. This position was expressed by the African Union (AU) in its Science, Technology and Innovation Strategy for Africa 2024 (STISA-2024) which was adopted in June 2014 as a 10-year programme.[3] The strategy is part of the long-term AU Agenda 2063 and has six distinct priority areas related to the AU Vision.[4] The six priority areas are: Eradication of Hunger and

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[1] Nazar Hassan is Senior Regional Adviser on Science and Technology at UNESCO Cairo Office in Cairo, Egypt. Statement by the Co-Author: The ideas and opinions expressed in this article are those of the author and do not necessarily represent the views of UNESCO.
[2] Karl Wohlmuth is Professor Emeritus at the University of Bremen in Bremen, Germany.
[3] See on STISA 2024: https://au.int/en/documents/29957/science-technology-and-innovation-strategy-africa-2024
[4] African institutions have done a lot to develop an STI policy for Africa, for the African Continent, for its regional economic communities (RECs), and for the African nation states (see the following major reports and projects): ACBF 2015; ACBF 2016; ACBF

Achieving Food Security; Prevention and Control of Diseases; Communication (Physical and Intellectual Mobility); Protection of our Space; Live Together - Build the Society; and Wealth Creation. The strategy also defines four mutually reinforcing pillars as prerequisite conditions for its success. The pillars of STISA-2024 are: building and/or upgrading research infrastructures; enhancing professional and technical competencies; promoting entrepreneurship and innovation; and providing an enabling environment for STI development in the African continent. At the regional and national levels, the strategy is followed up by policymakers in Africa. It is a main purpose of the strategy to lay the foundations for economic diversification and manufacturing development in Africa, beside of responding to the contemporary challenges (environment, security, poverty reduction, management of urban and rural development).

Any Science, Technology and Innovation (STI) policy is aimed at rigorously promoting strong national institutional capabilities that will permit to absorb, adapt, develop, and utilize knowledge and technology for developing the knowledge-based economy in any given State, with a focus on a pre-defined set of national priorities. Such a policy shall also ensure a high level of diversification in the knowledge production and technology utilization processes. Science, Technology and Innovation (STI) policies are most effective when they are closely linked to the political and socio-economic evolution of any State. Such policies enable the State to forge a set of institutions and processes to cultivate scientific and technological endeavour that is needed to contribute to its national development. Any STI policy should hence comprise all the necessary measures for creating, funding and mobilizing private and public scientific and technological resources, aiming at fostering and orienting knowledge-producing activities towards strengthening technological innovation through the build-up of robust National Innovation Systems (NIS).

The example of Malaysia, from beyond Africa, is often cited by decision-makers as a developing country that has achieved the desired economic success, thanks in part to the contribution of S&T (before the 1990s STI was only referred to as S&T). In 1992, the former prime minister of Malaysia, Dr. Mahathir Muhammad, announced that the sole objective of the Malaysian S&T policy was to help Malaysia to become a fully developed country by the year 2020.[5] By 2015, this objective had already been achieved to a reasonable extent. Following suit, the scientific and technological communities in the developing countries strongly recommend a paradigm shift to enhance the STI role concerning a practical

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2017; ACBF/IPAR 2016; AfDB 2015; AOSTI 2013 a, b; NEPAD; NPCA/NEPAD 2010, 2014; UNECA 2003; UNECA/AU (African Union) 2014; UNECA/AU/AfDB Group 2016; WEF/AfDB/WB 2017, 2015, 2013.

[5] See on the development of STI in Malaysia: *mastic.mosti.gov.my/.../NPSTI+2013-2020+ENGLISH+final.pdf*

roadmap that will achieve sustainable development. Today, STI policies and initiatives are even integrated in the activities framework of international economic organizations, as knowledge and research are becoming more pivotal to developing successfully diversified economic activities. But STI policies are becoming also more important as cornerstones of national development planning and policy frameworks.

STI policies are basically enablers for the implementation of a well-designed STI agenda for development, and they are meant to remove all anticipated institutional, regulatory, technical and financial impediments, to identify and to close all related implementation gaps, and to create the necessary synergy by utilizing an integrated approach in achieving the multi-objectives developmental action plan which any government is trying to implement. The STI policies will only be as good as the developmental action plan if such policies are supporting its implementation, and should be as concise and practical as possible to guide the implementation process with a set of clear strategies. A major task of the STI policies is the strengthening of the national innovation systems (NISs). In most of the African countries these systems are in a rudimentary state, because the key five pillars of a NIS (R&D institutions, capacity and strategy of the country; funding mechanisms for R&D and for innovations; innovative activity and R&D staff/expenditures in the enterprises; public regulation/facilitation of R&D capacity and institutions, research inputs and outputs, and innovation inputs and outputs; and the higher education and vocational training systems, public and private) are not adequately linked. Although some of these elements are there, especially in countries like South Africa, Tunisia, Egypt, Morocco, and Mauritius, the linkages among the five pillars are deficient or non-existent.[6]

The 17 Sustainable Development Goals (SDGs) of the UN Agenda 2030 give a frame for a policy-oriented discussion about comprehensive STI policies (see UNDP/UNRISD 2017, especially chapter 6). The national reporting requested from all the governments who have agreed to the Agenda 2030 allows international comparisons of the SDG Index (see the full coverage in: Sachs, J. et al., 2017) ranks and values and may help to redesign national policies to forward the sustainable development agenda. Reporting on the state of the 17 SDGs of a specific country gives also a frame for building comprehensive STI policies. STI policies relate to all the 17 SDGs being an important input to ultimately realize the SDGs according to goals and targets. This is also part of the messages of ECOSOC (Economic and Social Council of the United Nations) when they work on the realization of the SDGs at the global level. Huge technological opportunities are to be seen when looking at the individual SDG and as well at the collective of SDGs.

[6] See on these policy issues of inappropriate NISs: Mugabe 2009; Naude/Szirmai 2013; UNCTAD 2007; UNIDO 2015a; WEF et al. 2017; WEF et al. 2015; WEF et al. 2013; Wohlmuth 2017a; Wohlmuth 2011; World Bank 2010.

Also, huge business and employment opportunities are associated with the use of new technologies for realizing the SDGs.

The newly designed Inclusive Development Index (IDI), to be found in the Inclusive Growth and Development Report 2017 (see WEF/World Economic Forum 2017), can also be helpful to redesign growth and development policies towards more inclusion. In this report we find core elements for an inclusive economic and development policy, covering data for 109 countries. There are first, 7 pillars and 15 basic elements of an Inclusive Growth and Development Framework, and second, 3 groups (growth and development, inclusion, and intergenerational equity and sustainability) with 12 measurable performance criteria, labelled as National Key Performance Indicators. The Inclusive Growth and Development Framework and the National Key Performance Indicators build the basis for an Inclusive Development Index (IDI). The ID Index can supplement the SDG Index as it is the advantage of the IDI to be built on a synthesis of the major structural policy approaches which have to do with promoting inclusive growth and development. The theme of the SDGs is largely incorporated into the basic elements of the growth and development framework and the key performance criteria. The IDI also gives hints for technological opportunities related to the 7 pillars and the 3 groups of performance indicators. The ID Index and the SDG Index are important for peer reviewing, peer learning and peer pressuring for change at the national level. A new focus on STI policies emerges, related to inclusiveness of development and growth.

## 1.2 The outcome of the national STI policies in Africa after decades of regional and international support

Between the 1940s and the 1970s, the development of scientific knowledge and its utilization to spur economic transformation became a core developmental objective in many developing countries. This was mainly done through UNESCO regional ministerial conferences.[7] These conferences were regarded as important fora for information exchange between the countries of one region and as vehicles for general political recognition of the importance of science and technology to national development. Through the application of scientific knowledge and technology transfer from the developed to the developing countries, Member States began with the development of their science and technology potential and were working on a S&T policy framework as an important priority task for building their basis for development and welfare. By 1987, 18 African nations had already

[7] See on the role of UNESCO: http://www.unesco.org/new/en/natural-sciences/science-technology/sti-policy/africa/launch-of-the-african-science-technology-and-innovation-policy-initiative/

established national science and technology policy bodies at the ministerial level. However, such an increase in numbers does not necessarily imply adequate efficiency levels. Some countries established science policy bodies without any scientific tradition or even infrastructure; for these countries, the support of UNESCO was helpful in the starting period, and later too.[8]

During the period 1988-1993, many of the established programmes, such as the UNESCO's Science & Technology Policy Programme (STP) that evolved into a Programme on Science, Technology and Society (STS)[9], were determined to support the African Countries in the promotion of scientific and technological cultures in society, and to give assistance in the management of science and technology policies and in the training of personnel, with emphasis on the provision of policy advice and the establishment of regional networks for training and research in this field.[10] UNESCO and other international and regional organizations did contribute to networking in science and technology fields among African countries and between African countries and other world regions.

The establishment of networks, such as the African Network of Scientific and Technological Institutions (ANSTI)[11], were conceived to facilitate the cooperation among African institutions for national capacity building in science and technology. The purpose was to help African universities and research organizations engaged in training and research to establish such linkages among themselves to enable them to pool together their human and material resources and thereby to contribute more effectively to the application of science and technology to the development in Africa. In addition, such networks were utilized to disseminate information on S&T activities to faculties of science and engineering in more than thirty-three African countries, while identifying the strategic issues of scientific and technological education in Africa.

The outcome of STI policies can be measured by appropriate indexes, such as the Global Innovation Index/GII (to measure the innovation inputs, outputs and

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**8** See on the history of developing science and research policies in Africa the report by UNECA on Assessing Regional Integration in Africa VII, Innovation, Competitiveness and Regional Integration, especially chapter 5: https://www.uneca.org/publications/assessing-regional-integration-africa-vii, and the UNESCO website entries on Science, Technology and Innovation Policy: http://www.unesco.org/new/en/natural-sciences/science-technology/science-policy/

9 See on the programme: http://www.unesco.org/new/en/natural-sciences/science-technology/sti-policy/a-brief-history-of-unescos-science-policy-programme/

10 See on the history of UNESCO's science policy programme: http://www.unesco.org/new/en/natural-sciences/science-technology/sti-policy/a-brief-history-of-unescos-science-policy-programme/

11 See on ANSTI: http://www.ansti.org/

the efficiency of using inputs for outputs)[12], the Networked Readiness Index/NRI (to measure the IT capabilities in a society at various levels)[13], the Comparative Industrial Performance/CIP Index (to measure the technological capabilities of a country)[14], the Human Capital Index/HCI (to measure the components of human capital of a country),[15] and the Africa Capacity Index/ACI (to measure the capacity of a society to provide for adequate policy environments and processes of implementation)[16]. Most of the African countries provide now such data, so that the measurement of innovation capabilities, IT capabilities, technological capabilities, human development capabilities, and capacity development capabilities are measured. A quite diverse picture emerges when looking at the African countries. These indexes provide for a good picture of the capabilities existing in African countries, although the methodological divergencies between the indexes are great.

For Africa, also the informal sector needs to be considered as a source of capabilities. In this sector technological capabilities are developed, but also innovation capabilities, IT capabilities, and human capabilities. Studies for the informal sector show that such capabilities emerge in industrial clusters, but also outside the clusters. Especially important are informal sector activities in transport equipment, car repairs, PC repairs, uses of waste for recycling, local manufacturing of agricultural equipment. However, neither in terms of vocational training nor in terms of STI policies the informal sector is really part of the official government policies.[17] Also, African producers in formal and informal sectors are only loosely integrated into global and regional value chains. Some successes are recorded, but the overall picture is not promising. Studies show that key drivers of a deeper integration of local producers into global and regional vale chains are not developed enough. However, some African countries and some sectors show successful developments, but even in these cases they are not export drivers.[18]

[12] See: Johnson Cornell et al. 2017, 2016, 2015, 2014, 2013, emphasizing specific aspects of innovation.
[13] See: INSEAD et al. 2016, 2015, 2014, 2013, emphasizing different aspects of IT technology development; and see also McKinsey 2013 specifically for African countries
[14] See: UNIDO 2015b, 2013
[15] See WEF 2013
[16] See: ACBF, 2017
[17] See: Oluwale et al. 2013; Oyelaran-Oyeyinka/Mc Cormick, Eds., 2007; Sobanke 2012; UNCTAD 2007; World Bank 2013; World Bank 2010; Wohlmuth 2017a.
[18] See: AfDB et al., 2014; Wohlmuth 2016

## 1.3 Regional and international organisations and donor agencies have a key advisory and coordination role in regard of STI-related policies and actions in Africa

There are many lessons learned from the long term engagement between the international organizations and the targeted countries in Africa, but it should be considered that the following two principal sources have guided the support to these States: a) the general recognition that most of Africa's development challenges are amenable to resolution through the careful and purposeful application of STI; and b) the recognition by the international community that STI is an important means of implementation of the outcomes of recent UN summits (including the Addis Ababa Action Agenda of the Third International Conference on Financing for Development[19]; the Rio+20 Conference[20]; the United Nations 2030 Agenda for Sustainable Development (SDGs)[21]; the Istanbul Programme of Action for Least Developed Countries[22]; and the African Union's long-term plan for the structural transformation of the continent – the Agenda 2063 (AU 2014)[23], along with the continental Science, Technology and Innovation Strategy for Africa 2024 (STISA 2024), just to mention the most important events).[24] STI is becoming a strong force of African progress, and there are so many areas where its inputs are needed to come to solutions. Regional and international organizations, but also donor agencies and NGOs, do help African countries to identify the main opportunities and challenges at different policy and organizational levels and to drive innovation and invention in key fields, such as the growth of cities, the rapid growth of the working age population, the increasing inequalities, and the trend of premature deindustrialization.

Three main recommendations follow from an analysis of the lessons of the work of regional and international organisations in the field of STI in Africa. Following these recommendations, this will ensure that STI policies create such frameworks that STI contributes full scale to development and becomes truly transformational in Africa:

a. STI activities need to be connected to overall society, and need to translate innovative and creative problem-solving approaches from global to national and then to local levels. To successfully achieve the above, these

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[19] See: http://www.un.org/esa/ffd/ffd3/press-release/countries-reach-historic-agreement.html

[20] See: https://sustainabledevelopment.un.org/rio20

[21] See: https://sustainabledevelopment.un.org/post2015/transformingourworld

[22] See: http://unohrlls.org/about-ldcs/istanbul-programme-of-action/

[23] See: https://au.int/en/agenda2063

[24] See also on STISA 2024: UNU-MERIT 2014

countries need to embrace best proven practices, associated with establishing networks of national and regional champions of STI, of regional champions from business and from academia, and of champions from government and the political arena and from the society at large. This is necessary to bring about the aspired positive change towards achieving sustainable development;[25]

b. The people's knowledge, talents and skills need to be developed and strengthened with a specific focus on their mastering of science, technology, engineering and mathematics (STEM). It is hence critical to ensure adequate investments in STEM education at all levels;[26]

c. The development gap within Africa and between Africa and more advanced regions will need to be closed by working especially on the existing STI investment gap. Ambitious national minimum target investments for STI will have to be set up using innovative out-of-the-box financial models being mostly dependent on national resources.[27]

International Organizations should also assist African countries to identify the main opportunities and challenges at different policy and organizational levels for leveraging and maximizing the rapid rise of cities, including the rise of mega-cities on the continent to drive innovation and invention. Assistance should also be sought in in the formulation, adoption and implementation of new science, technology and innovation policies that will help African countries to accelerate the transformation process to improve the competitiveness of their firms, the welfare of their citizens, and the collective and individual security in these locations. Various UN organizations work on such issues, but their cooperation in Africa could lead to synergy effects. An organization such as the FAO is currently supporting many new programmes that research the best modalities for how science, technology and innovation could support sustainable development in agriculture and through better natural resources management systems. Effective systems need to

[25] A new role of science granting councils (SGCs) is envisaged to change public policy towards coherent STI policies in African countries; see: https://www.idrc.ca/en/project/strengthening-africas-science-granting-councils-champions-indicators-public-policy-making

[26] This is widely accepted in discussions on African development perspectives; see: https://www.huffingtonpost.com/mariame-jamme/africas-workforces-need-r_b_6340556.html

[27] This is discussed in STISA-24 in Chapter 5, highlighting the National and Regional Funding Mechanisms and the role of an African Science, Technology and Innovation Fund (ASTIF).

be built from local systems and from the knowledge that exists in local communities.[28] It is also essential to build partnerships with communities, civil society, private sector, governments and other actors.

In a globalized knowledge-based economy, innovation is among the most critical drivers of advancement in all spheres, including social, economic, and environmental issues. Harnessing adequate technologies to produce modern quality goods and services of higher added value is the essence of an "innovation- and knowledge-based economy". Developing countries should hence be supported to create and to develop the required critical mass of experts and knowledge workers who can develop and implement nation-wide new and innovative technological programmes that are aligned with each State's national developmental priorities. With the education system in all its forms being central in forming the required "critical mass", galvanizing all these different education sectors, namely education, higher education, vocational training and education, technology development, science and innovation, for fostering an innovation and techno-preneurship culture in these countries, becomes a must and the highest developmental priority.[29] An integrated approach clustering all the different education sectors into what could be called as the "Knowledge-Technology-Innovation" Nexus would clearly articulate the practical benefits that an interdependent approach to these different education sectors can offer, such as facilitating integrated planning and decision-making, informing the efficient allocation of resources between competing needs, and highlighting cross-sectional interactions that produce more synergy levels between these different actors.

In the context of the above, and among the many objectives which the international organizations and the donors could focus on, the following are the main and the core objectives to be aimed at:

• Support African countries by providing a forum for the exchange of knowledge and ideas on STI, bringing together key stakeholders and experts in each strategic economic field to present latest research and programmes;

• Create an Africa-focused global network of development innovators and problem solvers;

• Reinforce North-South and South-South collaborations in STI;

• Strengthen public-private partnerships between governments, industry and technology companies;

• Foster regional cooperation on STI among higher education institutions to cater to an increasingly demand-driven education system.

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[28] STISA-24 is promoting such a view from the local knowledge base up to the national STI policies and then down.

[29] See on the most important concept of "critical mass" in innovation and what it implies: http://igniteducation.com/2015/04/23/creating-a-critical-mass-of-innovators/

These five objectives, put together in a concerted strategy approach, will support Africa in its current drive for benefitting from progressive STI policies.

## 1.4 The role of national policies in the development of STI and the impact of a deeper regional integration in Africa

Africa is perhaps the continent that most needs science and technology to meet its education, energy, food, health, social and employment challenges, among others, within its limited resources. In East and Central Africa, half the region is 'fragile and conflict-affected', whereas other development challenges for the region include civil strife, religious militancy, and the persistence of killer diseases such as malaria and HIV, which sorely tax national health systems and economic productivity. Poor governance and corruption undermine economic activity and foreign investment in several countries. Interestingly, both the Transparency International's Corruption Perceptions Index (CPI) and the Ibrahim Index of African Governance (IIAG) consider Rwanda as having the best governance record in East and Central Africa, although African countries in the South, the West, the North and in Island States do better than Rwanda.[30] Especially rule of law is holding back progress in governance, and rule of law is a key factor in all dimensions of STI development. The case of Rwanda is interesting, as sources of improvements and drawbacks are deeply analysed; this allows it also to draw conclusions on the progress of STI development.[31]

The situation of STI by African regions is different. The Southern Africa region enjoys relative political stability and democratic political processes, although internal fragmentation continues to characterize the ruling political parties in most countries. The population is growing fast, at 2.5% per year on average between 2009 and 2013. By 2013, the region counted a combined population of over 294 million. Human development varies widely, from a high of 0.771 on the UNDP's Human Development Index (HDI) in Mauritius to a low of 0.337 in the Democratic Republic of Congo (DRC). A promising trend is that ten countries advanced in the overall world ranking from 2008 to 2013. Madagascar, Seychelles, and Swaziland, on the other hand, have slipped a few places. Most West African countries are striving to achieve lower or upper middle-income status within the next 15

[30] See on Rwanda with the rank 50 out of 176 countries and a Score of 50/by 100 in the Corruption Perceptions Index 2016: https://www.transparency.org/country/RWA; and see on the position of Rwanda in the Ibrahim Index of African Governance: http://mo.ibrahim.foundation/news/2016/progress-african-governance-last-decade-held-back-deterioration-safety-rule-law/

[31] See on Rwanda's rank and score in the Ibrahim Index of African Governance (IIAG) over the years 2006-2015: *s.mo.ibrahim.foundation/.../2017/.../Rwanda-Insights-2016-IIAG...*

years. This goal is enshrined in the current development plans and economic policies of Côte d'Ivoire, Gambia, Ghana, Liberia, Mali, Senegal and Togo, for instance. Nigeria even plans to join the world's top 20 economies by 2020. Yet, for two-thirds of West African countries, middle-income status remains an elusive goal: annual GDP per capita remains below US $ 1,045 in all of Benin, Burkina Faso, Gambia, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Sierra Leone, and Togo. The Economic Community of West African States (ECOWAS) has experienced strong economic growth in recent years, despite a series of crises, with projected sub-region's prospects of growth of 7.1% in 2014 compared to 6.3% in 2013.

Many of the African countries face common problems and constraints when it comes to the STI platform. Much STI development investment in many of these countries has been made during the last three decades for building the national infrastructure to produce goods and services, and visible progress has been made in the various infrastructure subsectors. However, the rate of progress on STI remains small due to various built-in inefficiencies of the development process which are mainly due to the weakness of the indigenous capacity in science and technology and the lack of linkages to the production and service sectors, which resulted in the technological dependence of these countries on external sources. As a result, the levels of technical know-how applied in production remain low, leading to small rates of technological progress and economic growth.[32]

Many recent reports have indicated that some countries are losing their winning ticket to development and progress; the motives may be economic or political, but the result is the same: an exodus of experts and researchers from countries which have spent millions of dollars educating them. The biggest migratory flows from Africa to the United States are from Egypt, Ghana, and South Africa, with more than 60 percent of immigrants from those three countries having a tertiary education, while migration of Africans with only a primary education is almost nil.[33] Researchers are not the only ones fleeing these countries, and there is no reason for them to remain hostages of governments that do not care or do not know how to use their talents. And if scientists will seek greener pastures to exercise their talents, it is the governments' task to offer the best conditions to retain their technical workforce and their researchers. In many of these countries, there is a

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[32] An overview on STI development in Africa region by region can be found in the recent Global UNESCO Science Report, Towards 2030: https://en.unesco.org/unesco_science_report

[33] See on more recent migration trends from Africa to the USA: *https://www.migrationpolicy.org/sites/.../AfricanMigrationUS.pdf* -

lack of a well-functioning national innovation system (NIS) with a clear governance and policy framework, compounded by a poor ICT infrastructure that hampers access to information and opportunities to create knowledge and wealth.[34]

It should be also noted that there is more to developing a national innovation system (NIS) than putting in place material institutions. Intangible considerations and values are vital, too. These include transparency, rule of law, intolerance of corruption, reward for initiative and drive, a healthy climate for business, respect for the environment, and the dissemination of the benefits of modern science and technology to the general population, including the under-privileged. Employability and placement in public institutions should depend solely on the expertise and seniority of the individual, rather than on political considerations.

Regional Integration should lead to collaboration and not to competition between the different African States. This would translate into successfully putting STI at the centre of policy dialogue in Africa, to achieve the following main objectives:

1. Showcasing global/regional best practices and innovations in Water, Energy, Natural Resources, Education, Health, Agriculture, Industry, Infrastructure, and Climate Change;
2. Making informed choices about applications of ICT to improve development effectiveness;
3. Developing skills (especially in STEM, teaching/reading, and mathematics), and promote job creation for the skilled at remunerative wages;
4. Support entrepreneurship development and start-ups, to build cross-border partnerships of innovative firms;
5. Building strategic partnerships to move the STI agenda forward.

Regional Integration in Africa, within and between Regional Economic Communities (RECs), delivers multiple options and chances to advance STI infrastructure and STI policies.[35] A new Regional Integration Index, developed by UNECA[36], measures the changes which take place in regard of regional integration of African countries; it is of interest how the respective membership to Regional Economic Communities influences the national economy. Measured are the

[34] The Networked Readiness Index (NRI) reveals the gaps in ICT infrastructure country by country; see the website: http://reports.weforum.org/global-information-technology-report-2016/

[35] See the most recent UNECA report on assessing regional integration in Africa with examples of such advantages- Assessing Regional Integration in Africa VII, Innovation, Competitiveness and Regional Integration; see the website: https://www.uneca.org/publications/assessing-regional-integration-africa-vii

[36] UNECA has developed an Africa Regional Integration Index (ARII) to assess the process of a deepening regional integration; see the website: https://www.uneca.org/publications/africa-regional-integration-index-report-2016

cross-border trade, finance and skilled labour flows, but also the cross-border co-operation of firms and the extent of policy coordination which is practised between member countries. All this shows trends of deepening regional integration in Africa. Although there are divergent trends of deepening in regional integration, the overall trend is positive. African countries deepen their regional integration step by step (mainly through transformative regional integration; see Osakwe/Wohlmuth, 2016; Wohlmuth 2017b; Wohlmuth et al. 2016). This process has implications for the STI infrastructure and the STI policies of members and RECs, as a more intensive cross-border cooperation of banks, enterprises and governments will also lead to more innovative activity.

Regional Integration in Africa has changed its outlook, moving from a linear integration view to a transformative integration view. While the linear integration view is the traditional line of thinking, starting with preferential trade arrangements and then moving up to free trade areas, customs unions, monetary and economic policy arrangements, and then ultimately leading to a political union, the transformative integration view is more specific, starting with bottlenecks and structural impediments in the process of integration, such as infrastructure gaps, border issues and barriers, hindrances for cross-border private sector activity, mobility of labour barriers, administrative obstacles, lack of coordination and cooperation, etc. STI policies and policies to strengthen national innovation systems (NISs) are the areas where early cooperation steps are helpful to promote regional integration. The newly designed Africa Regional Integration Index (ARII) highlights also the new thinking in contrast to the linear integration view.[37]

Parallel to the transformative regional integration approach a more transformative industrial policy is requested for African countries to develop competitive industrial sectors. Part of such a move towards a more transformative industrial policy is a pro-active STI policy which strengthens the national innovation system (NIS) in all its pillars and in all the required linkages between the pillars. A Transformative Industrial Policy (TIP) is needed because of the need to develop productive capabilities, as the capabilities argument resting, on regulation of direct technology imports and supports for small and medium enterprises, is a most convincing one for industrial policy (beside of benefitting from demand complementarities, externalities and the coordination of competing investments and the argument of risks and uncertainties affecting the finance side of investments and the private actors, such as entrepreneurs and workers). The argument of developing through concerted action (by public and private actors and sectors) productive capabilities is a convincing argument and leads to a guiding role for the state as a

[37] See on the transformative regional integration concept: AU/AfDB Group/UNECA 2016; Lopes 2016; Osakwe/Wohlmuth 2016; UNECA Observatory 2016; Wohlmuth 2017b, Wohlmuth et al., eds., 2016.

promotor of knowledge accumulation in the economy. As infant industry protection is an issue for most African countries, based on using the available policy space for industrialization, STI policies are relevant in the early phases of developing a competitive manufacturing sector, but also in the early phases of transformative regional integration.[38]

## 1.5 The identification of successful cases of STI development in Africa, and the lessons to be learned from these cases for national STI policies?

African regions show quite different conditions with regard of STI development, as the economic potential, the economic structure and the economic growth of the regions impact on the readiness of countries to absorb and apply knowledge and to generate and devote resources for STI development. The Southern Africa Development Community (SADC) is home to 33% of sub-Saharan Africa's population and contributes about 43% of its GDP (US $ 684 billion in 2013). The region combines middle-income countries with some of the fastest growing economies in Africa and some of the poorest countries of the continent. Nothing underscores the region's diversity more than the fact that one country alone generates about 60% of the GDP produced within the SADC and one-quarter of the continent's GDP: South Africa. Most West African countries are striving to achieve lower or upper middle-income status within the next 15 years. This goal is enshrined in the current development plans and economic policies of Côte d'Ivoire, Gambia, Ghana, Liberia, Mali, Senegal and Togo, for instance. Nigeria even plans to join the world's top 20 economies by 2020. Yet, for two-thirds of the West African countries, middle-income status remains an elusive goal: annual GDP per capita remains below US$ 1,045 in all of Benin, Burkina Faso, Gambia, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Sierra Leone, and Togo. The Economic Community of West African States (ECOWAS) has experienced strong economic growth in recent years, despite a series of crises, with projected sub-region's prospects of growth of 7.1% in 2014 compared to 6.3% in 2013. Also in other African regions (North Africa, Central Africa, East Africa) there is economic potential and some countries show remarkable growth. Southern Africa, West Africa, and North Africa have - as regions - a strong potential to develop STI, but the Central Africa region has still a rather limited potential (with some few exceptions), and the potential of East Africa is very much country-specific. However, despite of the economic potential in the regions and the economic growth in some of the countries the poor impact of STI on economic diversification is still creating massive problems as growth is not sustainable in many African countries. Episodes of growth and high volatility of

[38] See on such a view of transformative industrial policy as being linked with STI policies: Rodrik 2004; UNECA/African Union 2014; UNIDO 2015a; UNEP 2013; Wohlmuth 2017a.

growth impact on resources mobilization and on long-term budgeting for STI development. The impact of STI on agriculture, on manufacturing, on mining, and on services subsectors (public and private) is limited, although Africa has created centres of excellence and follows a tradition of specialized research institutes.

The lack of effective STI policies is a major reason for this poor impact of STI on development; this situation can be attributed to a set of problems associated with the R&D systems which are currently existing in many African countries. The following are general examples of what R&D systems face in many of the African countries:

a) Limited experience in R&D priority determination, programming and management, and a limited association of R&D as an integral part of the national development strategy/national development agenda (NDS/NDA);
b) Absence of national R&D programmes dealing with the main economic priorities such as water, energy, and agriculture; absence of programmes to manage deindustrialization and to reindustrialize the economies;
c) Dispersion of the limited R&D capacity within the country among numerous scientific fields, disciplines and institutions, resulting in small units of limited capacity, being then unable to deal effectively with real problems on a multi-disciplinary basis;
d) Weakness of the linkages between the R&D system and the production sector, together with the lack and/or smallness of R&D units in the firms of the production sector itself;
e) Scarcity of experimental development activity (the D component of R&D is underdeveloped) oriented to the transformation of results of applied research to processes, goods, and services; in other words, there is more scientific research than technological development; and
f) No motivation to resolve issues around limited financial resources with "out-of-the-box" innovative solutions; gaps exist along the whole "research to production" value chain.

The management of any well-designed R&D system requires a multi-disciplinary approach, utilizing management sciences, economics, systems theory, sociology, legislation, scientific disciplines, banking, marketing, etc. This also means that different groups involved in government, the private sector, and the scientific community should become well versed in the issues on a collective basis so that each group can play its proper role in enhancing and utilizing the indigenous STI capacity. Currently little is done in this respect and what is done is usually done in separate silos. Bringing together the many disciplines and the many stakeholders is an urgent task when building/rebuilding the national innovation system (NIS).

To address the issue of the limited experience/ability in R&D priority determination, programming and management, and to associate the R&D system as an integral part of the national development strategy or national development agenda (NDS/NDA), decision makers need to realize that there exists a scientific approach to the design and development of STI agendas and/or strategies, and that there are a number of techniques to successfully carry out the required analysis to identify both the needs as well as the feasible solutions within the finite resources being available. An example of one of the most effective strategic management techniques that are simple to use is known as the Dynamic Strategic Fit (DSF) concept that is defined as the match over time between external factors to a system (risks and opportunities) and its internal factors (resources and skills). This technique is best utilized in the environment of finite or limited resources such as with the cases in most African countries.

To succeed in their endeavour, the African countries need a level of commitment and resource mobilization which is as strong as it was demonstrated during the American "Sending a Man to the Moon" project, which is also an excellent example that illustrates how technical knowledge itself comes through R&D, specialized education and training, and learning-by-doing. Learning-by-doing can be achieved by developing new skills acquired from involvement in the production activities. Such acquired skills open the way for adopting newer and more efficient technologies for production. On the other hand, R&D is ultimately responsible for introducing these new technologies. Therefore, investment in R&D is not only viable for increasing the degree of self-reliance, but it is the main instrument being available for charting the road for technical progress and hence sustained economic growth in developing countries. The "Sending a Man to the Moon" project is an example which also highlights the importance of the experimental development type of research that is essential for creating the required level of innovation. However, in the case of African countries the "Sending a Man to the Moon" project would have a different outlook: useful large-scale projects would be how to arrange nation-wide basic social support, how to strengthen nation-wide the education and training system, and how to provide nation-wide for food security.

Following the model of the "Man to the Moon" project and observing the benefits of implementing experimental development research projects, it is strongly proposed to design and to implement Multi-Objectives Programmes (MOPs) that translate the Large-scale Pilot Projects Direct Implementation (LPPDI) approach for setting-up the STI agenda in African countries. Through hands-on training and learning by doing, countries will build up the STI national capacities in a modular form through the implementation of a limited number of specific national project(s) in few selected economic priority sectors, what is a good match for economies with limited resources. Examples of these "large-scale national programmes" might be found in the manufacturing sector (food industry, building materials, metal fabrication, agricultural equipment industry, automobile parts, transport vehicles production, basic pharmaceutical products, etc.); large-scale national programmes are aimed at and will create huge spillover effects. In such large-scale programmes the functions, the skills, the resources, the risks, and the competencies can be well defined. Such programmes will also facilitate the development of

SMEs; they could also be a nucleus for developing mass production facilities developed specifically for the manufacturing system; this is a drive to produce products and parts that will be required in big quantities to meet either national demand or demand for exportation. National Mega Projects (NMPs) will also attract experts from the Diaspora, and so turning brain drain into brain gain (also being an effective way of building proud among the fellow nationals); such projects could be implemented to promote sub-regional integration, to foster resources pooling, and to lead to collaboration instead of competition.

Most important is it to develop systematically capabilities in three forms (IT capabilities, innovation capabilities, and technological capabilities). While the Networked Readiness Index (NRI) measures country by country – based on various sub-indexes - the level and the development of IT capacities of a country, the Global Innovation Index (GII) measures country by country – based on input and output sub-indexes - the overall capacity to innovate of a country. The technological capabilities can be measured by the Competitive Industrial Performance Index (CIPI) – based on various sub-indexes related to manufacturing production/value added, level of technology, and export structure and destination. As all the three types of capabilities are deeply interrelated and mutually reinforcing, it is important to study country by country the respective results. More and more African countries are involved in data generation as a base for these indexes. Based on these measurements for the three types of capabilities it is possible to draw policy conclusions and to design reform agendas which are specific for the three categories. The data being available for the African countries show that very specific national agendas need to be developed, as sub-indexes of all the three categories of indexes show quite different gaps when looked at a specific country. Gaps in IT capabilities can impact on technological capabilities and on innovation capabilities, while gaps in innovation capabilities can impede progress in IT capabilities and in technological capabilities. Again, technological capabilities can impact on IT capabilities and on innovation capabilities.

## 2 The Contributions

In this Unit 1 of the volume 20 of the African Development Perspectives Yearbook three contributions consider the role of coherent STI policies for realising inclusive growth and structural transformation in Africa. This is done by presenting an analytical survey on the interrelations between innovation, structural transformation and inclusive growth, by analysing the overall policy cycle of effective STI policies, and by discussing the capacity development gaps and requirements for functioning STI systems.

In the first contribution to this Unit 1 of volume 20 of the African Development Perspectives Yearbook by **Patrick N. Osakwe and Nicole Moussa** with the title **Innovation, Diversification and Inclusive Development in Africa** the authors give a conceptual review of key concepts like innovation, diversification, inclusive growth and sustainable development. These important categories are interrelated. *Innovation* is a key instrument to generate successes in diversification of production and exports; innovation is important as a source of productivity increases and gives firms a competitive advantage over competitors; innovation is an instrument to gain advantages through product, process, organizational/logistical as well as marketing innovations. It is therefore important to measure the innovative activity in Africa carefully. *Diversification* is an urgent priority for many African countries as these countries still over-depend on the export of one or few commodities being exported in raw form; such a limited production and processing process leads to a high volatility of public revenues and to a lack of employment growth as non-commodity sectors are discouraged. The measurement of progress with regard of diversification is important so that policymakers get aware of opportunities and gaps. Inclusive growth and sustainable development depend on progress with regard of innovative activity and on successes in terms of diversification. *Inclusive growth* relates to quality of growth, and quality of growth implies economic, social, spatial and environmental characteristics of the growth process. Inclusive growth is not possible without a steady stream of innovations and successes in terms of diversification. It is possible to measure the inclusiveness of growth as well. The authors of this essay put a lot of emphasis on the interrelations of these three categories. These interrelations are not only of interest as analytical categories, but also because of their policy relevance. An inclusive growth policy requires

A key guiding principle of the newly adopted Sustainable Development Goals (SDGs) is to "leave no one behind." This is enshrined in the 17 SDGs and the many targets put forward in the process and measured along important policy dimensions. It is an intention to bring the vision of the Agenda 2030 to fruition, but this will require the eradication of poverty, a fairer income distribution, and sustained social progress over the next fifteen years. It is obvious that all the 17 SDGs have part in the process of generating inclusive growth and sustainable development. “Zero poverty” (goal 1) and “zero hunger” (goal 2) are goals which require action on sustainable innovation, industrialization and infrastructure (goal 9). But as well the other goals are relevant for the main task to realize the goals 1 and 2. Furthermore, realising the principle to “leave no one behind” will inevitably require creating decent employment through transformation of the production and export structures of African economies. Employment growth is brought about by a diversification of the economy, and innovations contribute to this process. The greater the successes in terms of inclusive growth, the more quality jobs will be created. This essay argues that technological innovations are vital to addressing both challenges for Africa, the low speed of structural transformation and the lack of inclusive development. Against this backdrop, the linkages between innovation (technical and non-technical ones), structural transformation (diversification) and inclusion (of the growth and development process) are analysed and related to policy reforms. The essay also presents stylized facts on structural transformation, the state of innovation and of inclusion in Africa and, more importantly, offers policy recommendations on how to promote technological and non-technological innovation to trigger structural transformation and to build inclusive societies in Africa.

The authors go a long way in their analysis and policy-related work. After an Introduction they analyse the Interactions of Innovation (technical and non-technical), Structural Transformation (diversification in production and trade) and Inclusion (of growth and development). The analytical and policy Linkages of these concepts with regard of African development are presented in a review of arguments. Then, the authors analyse in detail the scope and the nature of the structural transformation process in Africa to identify the observable gaps in the process and the opportunities which are open to go ahead with this process. This part of the essay is followed by analyses of the concept of inclusive growth and development and by analyses of the state of technology and innovation in Africa. Finally, the authors go a long way to outline policies to foster technological and other innovation for structural transformation and inclusive development in Africa. The idea is to present an agenda for action; this is a much-needed task because of the gaps in policy-making to be seen in most of Africa in the fields of innovation, diversification and inclusion.

The second contribution to this Unit 1 is the study by **Nazar M. Hassan** with the title **Science, Technology and Innovation (STI) Development in Selected African Countries - A UNESCO Experience Perspective**. This is an overview of STI developments in various African countries, covering the major African regions. The overview has a historical dimension as it is asked how STI developments came about in African countries and at regional economic communities in Africa. The historical context is important as the author shows what the source of the policy debates about STI was. Although UNESCO has played a significant role, local factors also played a great role. Some countries were pro-active, while others reacted to ongoing processes in other African countries. The purpose of the essay is also to identify country cases where progress was reached through interventions form UNESCO and other international and regional organisations and donor agencies. Interestingly, early in development history many international and regional organisations but also donor agencies have supported the idea that Africa needs STI to develop. Although often only single dimensions were promoted by external agents of change, such as education, higher education, vocational training, R&D at universities, the policy interventions broadened and deepened over time. It is also asked in the essay to what extent the African countries can learn from each other, and what the role of peer reviewing, of peer learning and of peer pressuring for STI development could be, such as for individual countries and for regional economic communities.

The essay concludes that much more could be learned from neighbours if their performance is properly assessed. Looking mainly at UNESCO strategies and policies in Africa, the author concludes that it is also possible to identify the effects of the long-term engagement towards science and technology in Africa. The evidence on such long-term effects is important knowledge as too often there are sceptical views prevalent on the performance of international organisations in the development process. The mutual learning process itself is demonstrated by looking at examples, cases, interventions, recommendations, showing how UNESCO and other agencies develop their work agenda for Africa through a dialogue with national governments and regional organisations and economic communities, but also with the science & research community, the universities and other higher education institutions, and the civil society organisations.

This essay provides also a synthesis of the key characteristics of the national science, technology and innovation (STI) platforms in selected countries in Africa. Countries were selected because of their key role in African STI development, because of the early involvement of UNESCO in the process, and because of the intention to have a balance between African sub-regions. The cases of the different countries and of the sub-regions in Africa which were reviewed reveal that the governments have often failed to catalyse the knowledge production effectively to add value to products and services. The contribution of STI to structural change, to value addition and to competitiveness of firms remained largely insignificant. The reasons as identified in the country cases were, just to mention some of them: insufficient government commitments for STI and research & development; inadequate financing of new technologies and STI capacity development; a serious disconnect between policy-makers, scientists and society in generating, sharing and utilizing scientific knowledge; poorly designed national STI policies and/or lack of adequate organizational capacities to implement STI policies; and ineffective government action to ease the “doing business” conditions in the country as a precondition for the start-up of innovative firms and foreign investment. These are some of the factors that have exacerbated the “cycle of marginalization” of the science, research and technology communities in these countries. This essay tries to give answers to the questions why it is that in most cases developing countries in Africa are still falling behind in efficiently utilizing the STI platform, and how the STI agenda and related policies could become robustly effective to reap the socio-economic development objectives which are desired in these countries? The essay concludes with a set of “must-have” national mechanisms to patch these deficiencies towards knowledge-based economies. This is then an agenda for action to be followed by domestic authorities and firms in Africa and by external actors working for the African STI systems.

After an Introduction the author outlines the path of development of STI policies in Africa over the decades of independence, by focussing on the historical background of the STI policies, on the opportunities and challenges in the process of developing STI systems, and on the frame of STI policies and the shortcomings in design and implementation. Also, the author looks at the potential of the STI policies to generate and to sustain conditions of inclusive growth in Africa, through a complete policy-making cycle, through novel approaches for developing a future-oriented STI Agenda, through a deliberate process of deriving the goals of STI development from the sustainable development goals (SDGs), and through adequate measures to identify the "critical mass" of investment funds for R&D and of numbers of full time equivalent researchers. An agenda for action is also presented in the form of policy recommendations.

A group of authors**, Emmanuel Nnadozie, Thomas Munthali, Robert Nantchouang, Samia Mohamed Nour, and Nicholas Ozor,** contribute a third study to Unit 1 of volume 20 of the African Development Perspectives Yearbook with the title **Successful Cases of Building Capacity in Africa's Science, Technology and Innovation Systems**. It is most important to identify successful cases of capacity development in Africa's STI systems. While the identification of successful cases of capacity development in Africa is important for all spheres of development activity, the specific issue in this essay is how to identify such cases in regard of STI systems. The results may be a help for designing better STI policies which are then also implementable. Some questions are important: Which are the experiences of African countries in learning from other African countries - in terms of developing STI systems, financing STI activities, strengthening in-door R&D in domestic firms, mobilizing foreign investment of innovative firms, transferring specialized knowledge and appropriate technologies from other African countries, but also from Third Countries? What can be done to optimize the STI policy development process along the whole policy development cycle? Which countries are leading in the respective capacity building processes, and how are their STI institutions and systems organized? All these issues and questions matter in this essay, as it is based on the most recent Africa Capacity Report 2017. The Report is dealing with capacity building of STI systems with the view on Africa's structural transformation process. The basic question is to what extent STI system-related capacity building is strengthening structural transformation in Africa.

Most African countries have underdeveloped science, technology and innovation (STI) institutions/systems and largely fail to effectively generate and deploy knowledge and technological innovations for socioeconomic growth. The gap between the needs and the actual state of STI systems is even greater when the concept of inclusive growth is brought in. Inclusive growth requires that STI systems respond to economic, social, environmental and spatial characteristics. New initiatives for capacity building of STI systems are then requested. This challenge largely reflects how STI institutions are staffed with skills, expertise, financial resources, infrastructural capabilities, and equipment. Encouragingly, the 2017 Africa Capacity Report (ACR 2017), which is focussing on 'Building Capacity for Science, Technology and Innovation for Africa's Transformation', shows that it is possible to build STI institutions and to use them for socioeconomic transformation, with a good number of African countries providing practical success stories based on strategies and initiatives that can easily be adapted to other countries.

There are encouraging trends in R&D spending and in building human resources for STI, in financing R&D and innovations in public and private institutions, in building technical and vocational education and training as complementary human resources for STI system workers. There are successful programmes on health as an important subsector of STI, but also on extension services, etc., but also successful programmes to develop the next generation of African scientists and engineers, as well as new programmes to support innovative partnerships between firms and research institutions, to build centres of excellence to train high level researchers and to spread high quality researches, and to use more fully agricultural research as there are so many new approaches to develop new seed varieties and to make them relevant for agricultural production increases via national crops campaigns, Applying all these success stories more broadly will lead to more effective national innovation systems (NISs) in Africa.

Despite the growing emphasis on the importance of STI for Africa's development, significant capacity bottlenecks still hinder many African countries from using STI in national development. Evidence suggests that African countries lack specific human resources and institutional capacities, critical technical skills, and resources to promote STI. All these gaps are known for a long time, but not much action was put on STI development in recent years. To some extent, the capacity lag in STI infrastructure is linked to the investment priorities of African countries, which have yet to convert their political commitments into practical programmes for STI-based development. Specifically, the African countries have to identify the "critical mass" of researchers and engineers and of R&D spending volumes to move ahead. The current average of African spending on research and development (R&D) stands at about 0.5 percent—below the one percent of GDP pledged in 1980 and emphasized again in 2005. Unless countries build STI capacities to innovate and to promote STI for development, Africa risks being left behind in the race toward inclusive globalization. However, capacity development is since years an issue and the messages of the Africa Capacity Reports are made public widely in Africa.

The African Capacity Building Foundation (ACBF) has done in recent years a tremendous work to publish the Africa Capacity Report while emphasizing different fields of capacity gaps. The purpose of the publication is it also to measure the progress of capacity development and to examine ways of how to develop such capacities. Emphasis is on pursuing the development agenda by analysing the key determinants and the key components of the capacity for development. Changes in this regard are analysed and measured. The meaning of the term “capacity” is a complex one, referring to the ability of people, organizations and the society to manage its affairs successfully, while “capacity development” is understood as a process to unleash, to strengthen, to create, to adapt and to maintain capacity over time.

All the three contributions take a view on the STI development steps and problems in an Africa-wide perspective, although country cases and regional integration cases are considered. The contributions have a general focus on the key issues of how to close the STI capacity gaps.

## 3 The Strategy

Three strategy recommendations follow from the analyses presented in this Unit 1. First, technical and non-technical innovations are of key importance for realising inclusive growth and structural transformation in Africa, and so they need to be strengthened in the context of STI policies. Second, to design and to implement effective STI policies in Africa it is necessary to look at the whole policy cycle of STI policies, and therefore all the steps from design to implementation need to be planned carefully. Third, capacity development is a must not only for the implementation of effective STI policies but also for generating a broad impact on the economy in terms of innovative activity, and therefore capacity development needs to be based on “critical mass” assessments,

### 3.1 Developing Comprehensive STI Policies for Inclusive Growth in Africa

Comprehensive STI policies need to cover all economic sectors of the economy (Agriculture, Manufacturing, Other Industry, Government Services, Private Services) and all institutions of economic, political, social and corporate governance. To make such STI policies inclusive requires that not only economic, but also social, spatial and political criteria of inclusiveness are aimed at. Using the national reports on the SDGs performance, released by African governments as part of their commitment towards the international community, is obviously a valuable instrument for development policymakers to reflect on the progress towards the realization of the SDGs and on the opportunities given by comprehensive STI policies at the country level. The international rankings on SDG performance country by country can help to improve policies in certain areas, and the international analyses of the interdependence of realizing SDG goals and targets, via building clusters or groups of goals for deeper investigation, will help national policymakers to improve on their inclusive development programmes.

The SDGs approach is moving the policymakers beyond the classical type of Innovation policies by pursuing sound macroeconomic stability policies plus coherent structural change policies. The policy environment is important, as measures towards ease of doing business can support the innovative activity of the enterprises (of private and public ones). But the SDGs approach gives a broader frame for Innovation. The SDGs approach is also associated with a new role for Science, as Science is becoming relevant for all the 17 SDGs. Science in the SDGs approach is contributing to the major human development fields, to industrialization and infrastructure, but also to improving the conditions of decent work, employment generation, peace, strengthening of institutions, and governance as well as forming new global partnerships. Science in the SDGs is well important for reforming education and health systems at all levels and institutions, as new research results are applied on a broader scale and more quickly. New education and health systems will raise the productivity of workers, firms and institutions. The SDGs approach allows for a new wave of technology development and diffusion. New technologies suitable for realizing the SDGs, new sector-related specific technologies, and new digitalization technologies can support the implementation of comprehensive STI policies and of inclusive growth and development policies in different ways.

The Sustainable Development Goals (SDGs) give a framework for STI policies related to inclusive growth and development. All the 17 SDGs have an agenda which could be enriched by focussing on STI policies. The Agenda 2030 gives a frame for the use of technological innovations to realize the 17 SDGs in a way that leads to localized, inclusive and sustainable effects. New technological opportunities exist in central areas of inclusive growth and development concerns (see chapter 6 in: UNDP/UNRISD, 2017). First, new technologies can be used for food security and water security. There are many examples for such technologies - nanotechnology applications, improved seeds and new agricultural practices, resources-saving and resources-conserving modes of production, possibilities to use renewable energies in traditional and new fields of economic and social activity, especially for the mobile communication of small farmers, for the water treatment in households, for remote area information about weather conditions, labour market chances and insurance options, etc. Major SDGs are covered with this area of applying new technologies (SDG 1: no poverty; SDG 2: zero hunger; SDG 6: clean water and sanitation; SDG 7: affordable clean energy; SDG 8: decent work and economic growth; and SDG 9: industry, innovation, infrastructure; but also, various other SDGs are affected by such new technologies to secure food and water).

Second, new technologies are important for the health systems, and many of these technologies are in the reach of also of low income African countries. New technologies matter in such fields as telemedicine for patients in remote areas, to get health advice by using mobile phones and apps; also the wider use of Nano sensors, the development and use of new vaccines, new forms of audio-visual communication systems will help to relate more effectively between doctors and patients; but also using new payment systems are of relevance to get health support and medicine in time; new technologies also will support initiatives of health services development at local and communal levels. Although these new technologies relate mainly to SDG 3: good health & well-being, many other SDGs are affected, as improving health conditions affect positively the realization of other SDGs. These new technologies have an impact on labour productivity, education and training, access to services, and so they are supporting various other SDGs (SDG 10: Reducing Inequalities, SDG 12: Responsible Consumption and Production, SDG 16: Peace, Justice and Strong Institutions).

Third, new technologies for education and training are extremely important for African countries. Such technologies relate to the following areas: Internet platforms for education at various levels of education; mobile educational programmes; online courses, especially at the level of tertiary education and for further education; computer-assisted Augmented Reality applications; new forms of using Radio and TV, especially for developing education and training in rural and peripheral urban areas; new technologies and new forms of regulating connectivity and access via mobile phones towards broadening access to educational programmes; adaptation of technologies for educational purposes to different linguistic and ethnic contexts; technologies for the educational support in post-conflict societies and fragile states. Although these technologies relate mainly to SDG 4: Quality Education, also other SDGs are affected positively, such as SDG 3: Good Health & Well-Being, SDG 5: Gender Equality, SDG 8: Decent work & Economic Growth, SDG 9: Industry, Innovation, Infrastructure, SDG 10: Reduced Inequalities, SDG 11: Sustainable Cities & Communities, SDG 13: Climate Action, and SDG 16: Peace, Justice & Strong Institutions.

Fourth, new technologies matter in the context of climate change and environment. Such technologies are related to areas such as renewable energy technologies, especially in the field of photovoltaics; controlling of air pollution; spread of such technologies via liberalisation of regional and international trade of renewable energy technologies and of energy-saving technologies; and technologies of relevance for Climate-Smart Agriculture (CSA), especially in the context of water-saving, production of new and improved seeds, and technologies for integrated agricultural/farm management. As African countries are more and more affected by climate change, adaptation and mitigation technologies play a huge and still increasing role. Although these technologies relate mainly to SDG 13: Climate Action, many other SDGs are affected also, such as: SDG 2: Zero Hunger, SDG 3: Good Health & Well Being, SDG 6: Clean Water & Sanitation, SDG 7: Affordable & Clean Energy, SDG 9: Industry, Innovation, Infrastructure, SDG 11: Sustainable Cities & Communities, SDG 12: Responsible Consumption & Production, SDG 14: Life Below Water, SDG 15: Life on Land, and SDG 16: Peace, Justice and Strong Institutions. Again, one can see how crucial these key technologies are in the various clusters which are bundled together, such as here the climate change and environment cluster.

Bundling together these new technologies under the four headings of “food security and water security”, “health”, “education”, and “climate change and environment” (see UNDP/UNRISD, 2017) opens the door for building clusters, identifying interactions, and benefitting from spillovers. New technologies of all these types contribute to the intensification of interactions and spillovers among/from SDGs. New technologies in all these areas allow also for a clustering of action programmes to reach the most relevant SDGs in a cost-effective manner. Also, other new technologies matter for development, for humanitarian action, and for peace-related efforts. Unmanned Aerial Vehicles (UAVs) have a role to play in cases of disasters and for humanitarian responses to crises. 3D printing can play a great role for more decentralized production patterns and for employment creation in small units; 3D printing is changing work patterns and is opening production in smaller (formal and informal) production units at decentralised levels. Platforms for initiatives of the sharing economy can also be mentioned under the heading of new technologies, especially when these platforms are used for identifying and securing low-cost ways to access services and goods, such as the Ugandan example of Yoza[39] is showing (by connecting people with local laundry washers). All such technologies have an impact on development but are also affected by commercialization trends with the ultimate use of the platform for gaining monopoly profit (if competition does not remain strong enough).

The Agenda 2030 also proposes a Technology Facilitation Mechanism to support the realization of the 17 SDGs through annual STI (Science, Technology and Innovation)-Forums and through continually enlarged online platforms to facilitate the global transfer of knowledge. It is expected that the private sector will take a lead role in the introduction of new technologies into the markets of the countries with differing levels of development. But, the public authorities will determine in the frame of their regulation competencies the direction and the speed of the changes with regard of technology development. A new equilibrium will emerge between private and public actors in regard of supporting technological transfer and change at the global level. This refers to all the 17 SDGs. This new role of technology for realizing the 17 SDGs can be supported by an inclusive economic and development policy along the methodology of the Inclusive Development Index (IDI), if such policies are introduced at national, regional and global levels (see WEF 2017).

[39] See: http://edition.cnn.com/2016/01/20/africa/uganda-yoza-uber-laundry-app/index.html

## 3.2 Using a Project Cycle Approach for Implementing Inclusive STI Policies in Africa

Most important for a strategy to strengthen STI policies in African countries is the use of more sophisticated methods to close the project and programme cycle to avoid gaps and disproportions in the cycle. Also, important in this context is it to work out threshold levels for the "critical mass" in the sense of minimum levels of R&D staff and R&D funding. Such minimum levels need to be approached during the project and programme cycle. The reviews of STI development policies in Sub Saharan African and North African countries show that there is a serious deficiency in applying these sophisticated methods for planning the project cycle and for identifying the critical mass of staff and funding levels. These deficiencies are responsible for the misconduct of planning processes and for the failure of policies. Although some African countries are more advanced in following the project cycle approach than others, the state of action in this regard is not satisfactory. Even South Africa can improve in this regard its planning process. Also, it is obvious that the African countries have levels of R&D staff and levels of R&D funding which are far below the critical mass; this refers to absolute levels and the path of expansion. This hinders the development of STI-based policies which are effective enough to allow the African countries to catch up with the emerging and the advanced countries in Africa. Some countries have strong ambitions to move in this direction, such as Rwanda and Mauritius, but also in these cases much more can be done to catch up with STI policies and outcomes of STI policies.

It is not realized by so many decision makers in Africa that there exists a scientific approach to the design and development of STI agendas and/or strategies, and that there are various planning techniques available to successfully carry out the required analyses to identify both the needs as well as the feasible solutions within the finite resources available. An example of one of the most effective strategic management techniques that are simple to use is known as the Dynamic Strategic Fit (DSF) concept that is defined as the match over time between external factors to a system (risks and opportunities) and its internal factors (resources and skills). This RORs-technique (Results Oriented Responses) is best utilized in the environment of finite or limited resources such as the cases in most African countries.

Also, decisionmakers need to realize that the policy-making cycle is a dynamic process and usually involves five main stages:

First, the Developmental Agenda-Setting Stage: This stage refers to the process by which STI-related problems and the linkages between STI and both the society and the economy come to the government's attention. This is the first phase of the STI engagement process and it is usually optimally done through: sensitization, and a preliminary assessment and commitment with a strong science community engagement to properly allow for needs assessment and the selection and mapping of the appropriate national priorities in government and industry, to be reached with the optimal resources management and utilization. In African countries, as part of the developmental agenda-setting stage, the National Developmental Strategy (NDS) should indicate a modular approach to attend to the list of national priorities selected. Such a modular approach allows it to incorporate specific STI targets for sectors, regions, and groups of enterprises and workers. Development planning can be revitalized in Africa by using fully the project cycle approach towards STI development. So far, the neglect of synchronizing the agenda-setting activities for national development and STI development is hindering progress on both sides.

Second, the Policy Formulation Stage: It refers to the process by which STI policy options are formulated by the government to support the implementation of the Multi-Sectoral National Developmental Action Plan (MSNDAP). STI policies are basically enablers for the implementation of a well-designed STI agenda for development, and they are meant to remove all anticipated institutional, regulatory, technical, and financial impediments, to identify and to close all related implementation gaps, and to create the necessary synergy by utilizing an integrated approach in achieving the multi-objectives developmental action plan which any government is trying to implement. The STI policy will only be as good as the developmental action plan that the policy is supporting in its implementation, and should be as concise and practical as possible to guide the implementation process with a set of clear strategies. Therefore, an STI policy should be an integral part of a national socio-economic transformation programme and should comprise at least the following five basic components: STI for Development Policy, Policy Focus on STI Development; Relating Development Policies for STI and the Private Sector; International/Regional Collaboration and STI Development; and STI and Governance Reforms. Also, at this stage of STI development, many African countries do not synchronize the steps towards national development and STI development. This has to do with different actors on the government side being involved: Planning Agencies and Sector Ministries are working on national development policies, and Ministries of Higher Education and Research are active in the field of STI development.

Third, the Decision-Making Process Stage: It refers to the process by which governments adopt a specific course of action (or non-action). In African countries, this stage is usually done through the process of Expert Group Decision-Making, which is as good as the competence of the members of the expert group and the practiced teamwork and reporting of the Expert Group. The science community could play a substantive role in guiding this process by utilizing many of the existing scientific approaches and techniques, such as the Strengths/Weaknesses/Opportunities/Threats (SWOT) analysis and the Combinatorial Optimization Method (COM) to mention a few. The advantage of such decision-making tools is that the optimal path can be found more easily and in a shorter time than examining in detail all theoretically possible options. When dealing with sustainable development, the formulated multi-objectives problem is usually complex, and the number of feasible solutions are many, and without the use of such techniques, a great deal of error becomes possible. Science, Technology and Innovation (STI) contributes to the realization of many of the SDGs (Sustainable Development Goals) and therefore quick and cost-effective assessments of the impact of STI policies on the SDGs matter. For this purpose, it is necessary to lay the foundations of national development through incorporating the 17 SDGs and through impact analyses of STI policies.

Fourth, the Policy Implementation Stage: It refers to the process by which governments and other stakeholders put STI policies into effect. This implies that all the required policy instruments for implementation should be ready and able, including the qualified human resources as well as the financial resources. A high level of commitment for all stakeholders is needed to reap the fruits of such programmes, which should be large-scale in nature and which are multi-objectives and multi-sectoral to maximize the synergies produced between collaborating economic sectors. The "Sending a Man to the Moon" project of the United States of America in 1961 is the best example to understand what type of commitment and collaboration is needed to implement a huge project at the national level. Although such a giant project as in the USA is out of the reach of African countries, the implementation of STI policies in Africa, through concerted action and in parallel with the implementation of national development programmes, is a comparable effort requesting a new type of commitment, resource mobilization and collaboration. Therefore, such an approach needs to be followed in African countries that want to successfully cross the development bridge.

Such a project as the implementation of STI polices is also leading to progress on many fronts, such as R&D, specialized education and training, and learning-by-doing in production. Learning-by-doing is generated in terms of developing new skills acquired from involvement in the production activities. Such acquired skills open the way for adopting newer and more efficient technologies for production. On the other hand, R&D is ultimately responsible for introducing these new technologies. Therefore, investment in R&D is not only viable for increasing the degree of self-reliance, but it is the main instrument available for charting the road for technical progress and hence sustained economic growth in developing countries. The project "Implementing STI Policies" also highlights the importance of the experimental development type of research that is essential for creating the required level of innovation. Therefore, implementing STI policies goes far towards important outcomes, like learning by doing in production, acquiring skills which can be used in production, and adapting the R&D system so that major economic and social sectors can benefit. Such a vision of STI implementation will also contribute to managing de-industrialization and to re-industrialize African countries.

Fifth, the Policy Evaluation Stage: It refers to the process by which the results of the STI policies are monitored by both the State and the societal actors. The evaluation may lead to a re-conceptualization of policy problems and solutions, in which the effectiveness, the efficiency, and the continuing appropriateness of policies and policy instruments are assessed, and so the evaluation may fed-back into another round of agenda-setting and/or reforming the development action plan. Again, the Policy Evaluation Stage is highly important, but is neglected in most of the African countries as it is assumed that the practised STI policies can be continued for long without changes in agenda-setting, formulation of objectives, decision-making processes, and modes of implementation, Therefore, the Evaluation Stage is highly important, but this stage needs critical expertise and strong political will to start another round of the project cycle.

## 3.3 Learning from Successful African Cases of STI Policies for Inclusive Growth and Development

Evidence shows that there are successes in developing STI policies in Africa, at the continental, the regional, and the national levels. Despite of the fact that most of the African countries have so far only rudimentary developed national innovation systems (NISs), and these countries are not really working towards strengthening the role of the STI policies as based on the project cycle approach, some positive changes can be recorded. Recent reports, such as the ACR 2017 (see ACBF 2017), give examples of some improvements, some successes, some positive changes. But most of the positive changes are found in the spheres of creating awareness, successfully introducing single projects, and spreading positive images about the role of STI policies.

First, successes are observable in Africa at the level of creating awareness about the role of STI policies. Indeed, awareness increases, but the increasing awareness is not too often translated into actions. African countries have discovered in recent years the importance of building capacities for STI development, and have more often acknowledged the need to invest more in the sector. Some indicators of capacity development give evidence that the measured scores on capacity development have improved since 2015. Africa has also agreed on an AU Agenda 2063 with a strong emphasis on STI policies, and the AU as the representation of the continent has agreed to invest more in this sector. Also in terms of initiatives to generate new data and indicators for sound STI policies some progress was recorded; a better data and indicator base is in the making although much more needs to be done. In Africa it is now recognized that the quality of key research institutions needs to be maintained and further improved. It is also acknowledged that a critical mass of R&D staff and a critical mass of R&D funding are needed but planed in a long-term context. Increasing women's participation in the STI system is another important goal to make the system roe resilient, although the reality in this regard is highly unsatisfactory. It is also considered as necessary to invest strategically in the areas education, capacity development in STI and engineering, and innovation systems (at the national, the sector, and the local levels). STISA-2024 and the SDGs are considered as a useful basis for national strategies to STI development, but the problem is to build action programmes on this basis. Donor-financed programmes are considered as helpful only when they are Africa-led and when they concentrate on building institutional STI capacity. So, there is increasing awareness that contributions to STI from outside should be transformed towards institutional capacity-building for STI development. It is also recognized that STI policies should be linked to national development goals and should be integrated more directly into development plans. It is also mentioned often that the innovation activity at enterprise level needs more support in terms of creating a conducive environment and providing for ease of doing business conditions. It is also stated that international R&D partnerships are key for STI development, this in all forms and with all relevant partners. So, the level of awareness is increasing, but action plans do not always follow.

Second, important STI initiatives are increasingly getting momentum. That such initiatives are becoming more important in Africa, can also be considered as a successful process towards STI development. Initiatives are highlighting the need for new forms of collaboration, involving more and new stakeholders to the process of STI development. Various African Union (AU) decision-making levels contribute with proposals for new STI-related initiatives, and initiatives for reforming R&D and higher education systems. Such initiatives are brought forward at the level of the AU Commission (AUC), at the level of regional economic communities (RECs), at the level of NEPAD, AOSTI, ASTII, African Universities, African Research and Technology Networks, at the level of the African Development Bank Group and UNECA but are also coming from various African nation states as they try to reform the STI policy framework Africa- wide. Regional collaboration on STI is supported especially by initiatives from the sides of the AU, NEPAD and the RECs (regional economic communities). In this context important are initiatives to create specialized S&T universities, and important as well are initiatives to improve (public and private) higher education systems. But, also important at the regional African level are exchanges of skilled personnel and forms of enterprise-to-enterprise R&D cooperation. Initiatives for new bilateral and multilateral partnership projects aim to contribute to STI capacity building and to relate national African STI institutions to global STI networks. Initiatives to enhance regional cooperation in STI policies (referring to major cross-border technology and skills transfers) and initiatives for a deeper cooperation of stakeholders (between governments, scientists, universities, policymakers, and the civil society) are considered as mutually reinforcing approaches.

Third, the identification of critical gaps in STI development is coming forth Africa-wide. This is also an area of successful advances. Many of such gaps are identified. Such gaps are observed in the field of investment in the STI capacity, in the field of creating an STI capacity which is related to socioeconomic development, and in the field of critical technical skills (such as STEM: Science, Technology, Engineering, Mathematics). If these gaps are narrowed down, this will trickle down to the research and higher education systems, to the enterprises and governance institutions, and to the primary and secondary education levels, but up to now these trickle-down effects are rather weak. Critical gaps exist in terms of the R&D capacity at the level of enterprises, even the large ones in Africa, and so these enterprises have difficulties to take up new external knowledge via the internal R&D capacity. Critical gaps exist in modern teaching and in curricula development, as there is a gap in innovation-oriented and problem-solving capabilities. Based on new teaching and curricula modalities it will become possible to transfer more easily global knowledge to local institutions.

Critical gaps are observed in developing the national innovation systems (NISs), especially because of the widespread failure of linking the key pillars of the innovation systems. Enterprises, R&D institutions, public regulatory agencies, education and training institutions, and innovation finance institutions are not really linking up through institutionalized forms of collaboration. Incentives are not strong enough to link up. There is a gap in the matching of STI demand and supply sides, as STI inputs and STI outputs are not properly matched by functioning markets and by coherent state interventions. Highly skilled personnel is not absorbed at the labour market, and core qualifications are in scarce supply, as incentive system lead to imbalances. In some cases, it is even cheaper to hire unqualified labour to make profits, with the result that value addition is not taking place in the economy. There is also a gap in using indigenous skills, although absorption of traditional and indigenous skills in production can lead to production and export diversification. There are sector-specific gaps, such as in agriculture and agribusiness, in public management and in entrepreneurship development. Sector-specific gaps exist despite of the fact that key economic sectors are affected, such as agriculture. There is a huge gap in financing STI, by public and private finance institutions, and there is also a gap in competitive funding as core funding mechanisms prevail which guarantee the funding to established STI institutions irrespective of the output. There is also a gap in introducing additional financing mechanisms for STI development, such as tax incentives, industry innovation funds, matching funds, etc. A most serious gap is the extremely low private sector funding of R&D programmes – of in-house programmes and of programmes in collaboration with external institutions. There is as well a gap in terms of future-oriented strategic STI capacity-building partnerships; many of the established partnerships between African research and higher education institutions have no long-term perspective, as collaborative STI programmes in Africa are underfinanced and badly managed, and as political commitment is limited. But, the fact that critical gaps in STI are identified and communicated, is a success, as this adds to the new awareness and the move to specific initiatives.

Fourth, successes at the country level can be noticed, in regard of resource mobilization, organization, and planning for STI development. Some African countries have shown a rapid increase of public R&D expenditures in GDP, while the share of the private sector remains small, and is not moving in an upward direction. In some countries there is now more emphasis on STEM (Science, Technology, Engineering, Mathematics) rather than on social sciences and humanities in tertiary education. In some countries the reform of tertiary education systems is coordinated with new development policies and plans. Some countries in Africa have moved towards technological catching-up strategies by leapfrogging and by developing indigenous knowledge. Other countries have moved towards a more pro-active role of government in STI policies and have intensified collaboration with the private sector and with development partners. Some countries have successfully built new STI institutions, such as ministries for STI and Higher Education, STI councils, and specialized higher education and R&D institutions. Governments in some countries have used incentives to correct the distribution of students and graduates by academic subjects in the tertiary education systems, and have used award systems and matching grants to induce R&D in enterprises and collaboration with external R&D actors. Some countries have increased industrial innovation and research funds, and this also in times of scarce public funds. Some few countries have moved in the direction of integrating indigenous knowledge and technologies into the national innovation systems. Some countries have moved in the direction of new public-private partnerships in higher education and in sector-related joint research projects between enterprises and public research institutions. Member countries in some regional economic communities (RECs) have started to give incentives for regional cooperation in STI development. All this shows that there are good examples of useful interventions, but it is necessary to broaden the impact by peer reviewing, peer learning, and peer pressuring.

Fifth, successes can also be found at the sector, project and programme level. Such examples are of interest as it is possible to transfer the experiences to other projects and other countries. A report by UNESCO (UNESCO 2014) reveals that at the sector and project levels success stories become visible. On Agriculture, the case of oil production from the kernels of the Argan tree through women in Morocco emphasizes the employment creation aspect and the generation of new revenues for women as this oil can be used for various industries (food and cosmetics industries). The case of organic agriculture in Egypt is interesting as research, extension and local development are brought together. In Mozambique, efforts are under way to improve on the production of sweet potatoes by changing the flavour towards orange. In the field of Capacity Development and Innovation, Nigeria is working on fair technology transfer mechanisms, while Kenya is successful with its iHub initiative of software development. In Senegal, the activities of the Food

Technology Institute (Institut de Technologie Alimentaire/ITA) are improved for supporting a more stable agriculture. On Education, Cameroon is equipping girls in science education to drive for change. Africa-wide initiatives are under way to improve the network of African researchers by strengthening the African Network of Scientific and Technological Institutions (ANSTI) with the effect of further education of and deeper scientific exchanges for African researchers.

On Energy, the working on the West African “solar revolution” through solar villages in Benin, Burkina Faso, and Mali is of interest also for other countries in Africa. On Health, the telemedicine system is improved via mobile phone supports to front line health workers in South Africa, an effort that is relevant across Africa. Malaria Risk Mapping Systems help to identify malaria hotspots across Africa through maps that can be used to save lives by concentrating prevention measures to the hotspots. Although these are single projects in specific sectors and countries or Africa-wide specific initiatives, the successes of such projects and initiatives need to be made known more widely as they show what can be achieved through concerted effort.

Also, in the Africa Capacity Report 2017 (ACBF 2017, chapter 5) encouraging success stories are reported. Ethiopia shows encouraging trends on R&D spending, builds up a stronger technical and vocational education and training base, is active with its national health extension programme, and has improved on its Commodity Exchange system with advantages for marketing its raw materials. However, Ethiopia had also disappointments, such as on rainwater harvesting (to prepare for drought periods towards food security). Rwanda showed an interesting new role for STI in its Vision 2020, making STI to become a core pillar for state reconstruction, social cohesion, economic revitalization and inclusive development. The Rwanda Innovation Endowment Fund (RIEF) intends to stimulate economic transformation through STI projects in priority areas; although yet at small scale, the extension of the model through upgrading is possible. Zimbabwe is an interesting case, as the country is, despite of its economic crisis and bad governance, developing a new and integrated science, engineering, technology and innovation system, is successfully implementing an ethanol project, and was releasing a new maize seed variety with economic potential. The messages contained in these case studies reveal that, even in low income countries which are affected by austerity and crises, STI projects can be successfully implemented. However, the overall effect may be limited as STI and national development policies need some synchronization to be effective. This makes the difference between the case of Rwanda and the cases of Ethiopia and Zimbabwe.

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# Innovation, Diversification and Inclusive Development in Africa

**Patrick N. Osakwe and Nicole Moussa***

## 1 Introduction

An overarching principle of the Sustainable Development Goals (SDGs) adopted by global leaders in 2015 is to "leave no one behind." Realizing this vision will require poverty eradication, better income distribution and sustained social progress over the next 15 years. The assessment of performance in implementation of the Millennium Development Goals (MDGs) indicated that Sub-Saharan Africa (SSA) is the only region that did not meet the MDG of halving poverty by 2015. In addition, a recent study found that Africa will increasingly be home to a large part of the world's extreme poor (World Bank 2016). These facts suggest that if the international community wants to enhance prospects for achieving the SDGs, there should be a special focus and attention on SSA, particularly the least developed countries in the region. But there also should be a concerted effort by the international community to engender structural transformation and foster inclusive growth, thereby laying a solid foundation for sustained development and ensuring that no one is indeed left behind in the development process.

Technology and innovation are crucial for addressing the challenges of slow structural transformation and lack of inclusive development in Africa. For example, technological innovation can enhance competitiveness and trigger a shift of resources from low to high productivity activities, thereby inducing transformation of the structure of an economy. It can also foster inclusion through enabling the

* Trade and Poverty Branch, Division for Africa, LDCs and Special Programmes, United Nations Conference on Trade and Development (UNCTAD), Geneva 1211, Switzerland.
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acquisition of knowledge and skills which permit economic agents to fully participate in, and benefit from, the development process.[1] Against this backdrop, this paper presents stylized facts on structural transformation, the state of innovation and inclusion in Africa and, more importantly, offers policy recommendations. These policy recommendations will show how to promote technological innovation to trigger structural transformation, build inclusive societies, and enhance prospects for achieving the SDGs in Africa. The paper is organised as follows: Section 2 discusses channels through which technological innovation could affect structural transformation and inclusion. Section 3 presents some stylized facts on structural transformation in Africa, while Section 4 assesses Africa's performance in achieving the goal of building inclusive societies as reflected in the SDGs. Section 5 examines the state of technology and innovation in Africa, and Section 6 discusses policies that could be adopted to foster technology and innovation with a view to promoting transformation and inclusive development in Africa. Section 7 contains concluding remarks.

## 2 Innovation, Transformation and Inclusion: The Linkages

The economic literature suggests that development occurs through structural changes involving movements of labour and other resources from low to high productivity activities both within and across sectors (Page 2012). Osakwe (2016) shows that African countries have not been able to successfully transform their economies and foster inclusive development despite the rapid growth experienced by the continent over the past decade. This paper argues that technological innovation will play a vital role in addressing both the challenges of structural transformation and inclusive development, and African governments should, therefore, strengthen efforts to foster technological innovation. In this section, we draw on insights from the economic literature to delineate mechanisms through which technological innovation can be linked to transformation and inclusion. Economic theory suggests that technological innovation is the main driver of sustained long run growth, and the diffusion of such innovation permits lagging countries to shift production towards sectors with increasing returns thereby promoting growth convergence (Verspagen 2004; Aghion and Howitt 1998). Technological innovations are associated with new products and processes and also create new patterns of

[1] Note that technological progress can foster inclusion only if people can access and use new technology and innovation. If some segments of society (for example, unskilled workers) do not have good and affordable access to new technology and innovation, then technological progress can indeed become a source of social exclusion.

demand resulting in a change in the sectoral composition of an economy. In addition, they trigger investment, enhance productivity growth and facilitate changes in the organisation of firms (Sandven, Smith and Kaloudis 2005).

In the Schumpeterian literature on economic growth, the interaction of demand growth and technological learning induces structural change in an economy towards technology-intensive sectors then resulting in higher growth rates (Cimoli et. al. 2011; Schumpeter 1934). When a new technology is introduced and diffused, it tends to have a structural impact because it leads to an increase in activities that rely on the new technology and to a decrease in those activities associated with older technologies. Furthermore, new technologies are generally associated with an increase in productivity and so countries that are at the technological frontier are able to compete in new sectors and to shift their economic structure towards more technology-intensive sectors. The focus of the discussion so far has been on how technological innovation affects structural change. But the literature also recognises the fact that innovations tend to evolve much faster in some activities (such as manufacturing) than in others (such as agriculture), and so the structure of an economy can also have an impact on the pace of technological innovation. For example, countries that have an industrial structure tilted towards high-technology sectors experience faster technological progress than those relying on low-technology sectors. In this context, the structure of an economy can affect the rate at which it approaches the technological frontier and so can affect the technology gap between countries (Cimoli et. al. 2011).

With regards to inclusive development, the literature suggests that technological innovation plays a crucial role in determining whether the growth and development process in a society is inclusive or not. To the extent that new technologies result in better quality jobs (particularly for the poor), reduce environmental pollution, increase efficiency of resource use, and improve health, they can have a positive impact on living standards and make the growth process more inclusive (Naude and Nagler 2015). Innovation can also have a positive impact on income distribution if it gives vulnerable groups better access to markets and permits them to take advantage of opportunities created in the development process. For example, the rapid spread of mobile telephones in Africa has been credited with giving poor farmers better access to finance. It has also been used by some governments to provide input subsidies directly to farmers, thereby eliminating middle-men and reducing leakages in the delivery system (Osakwe and Poretti 2015). While technological innovation could have a positive impact on growth and inclusion, there is also recognition that it can be a source of social exclusion. One channel through which innovations could contribute to social exclusion in an economy is through the nature of technological change, as reflected in new technologies being capital-intensive rather than labour-intensive. Since labour is the only asset owned by most poor people, innovations that are associated with capital-intensive techniques (which use more of skilled rather than unskilled labour) make it a challenge for vulnerable groups to participate in the growth process, and so these innovations may increase inequality. But technological innovation can also foster social exclusion through having adverse effects on the environment or environmental services which tend to have a disproportionately negative impact on the poor (UNCTAD 2017). In sum, the literature suggests that technological innovation can have a structural impact on an economy and that its effect on the distribution of income will depend in part on the nature of new innovations and on whether vulnerable groups can access and use such innovations.

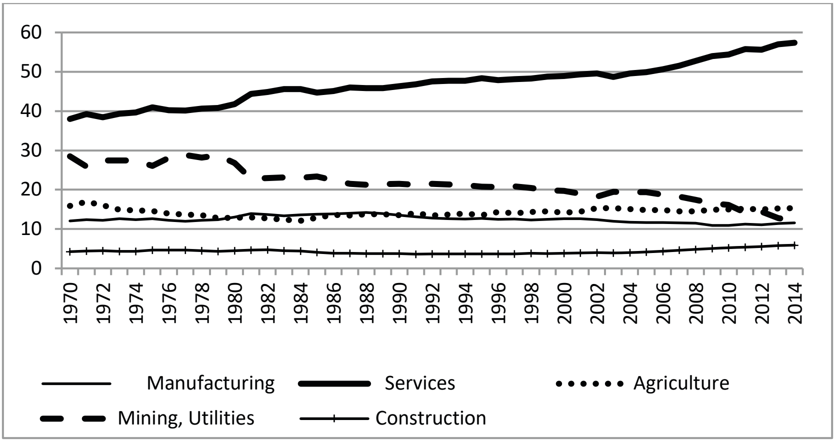
## 3 Scope and Nature of Structural Transformation in Africa

To understand the scope and nature of structural changes that have taken place in Africa over the past few decades, this section examines structural transformation from both a domestic and an international perspective. At the domestic level, the focus is on the contributions of key economic activities or sectors (agriculture, manufacturing, services, etc.) to output and employment. And at the international level, the focus is on the contribution of manufacturing to total exports and the contribution of technology-intensive exports to total manufacturing exports.

### 3.1 Output and employment

There has been a significant change in the structure of African economies over the past few decades, with services playing a dominant and increasing role both in output and employment. Figure 1 shows that the share of services in value-added increased from 38 percent in 1970 to 57 percent in 2014. This increase in the share of services went hand in hand with a decrease in the share of mining and utilities in total value added. Regarding agriculture, its share has been relatively low and flat over the period, and in 2014 it accounted for just 15 percent of total value added in Africa. As with the agriculture sector, the share of manufacturing in value added remains very low relative to the share of the services sector. In fact, in 2014 manufacturing accounted for only 12 percent of total value added, which is lower than its peak value of 14 percent in the 1980s.

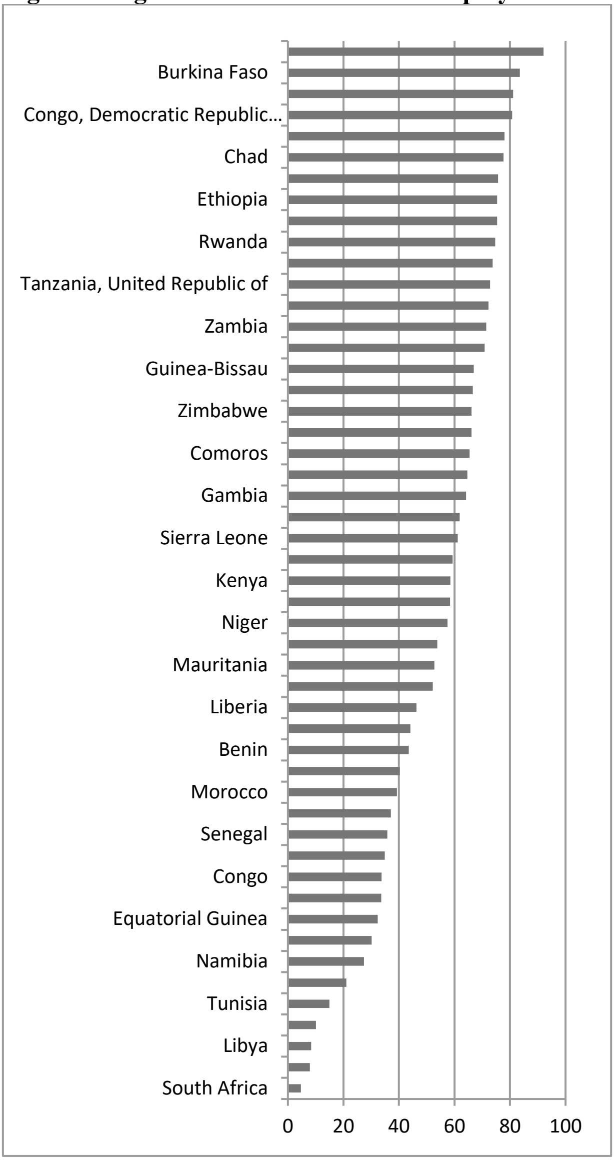
**Figure 1: Share of economic activities in real value added in Africa (%), 1970-2014**




**Note**: Value-added measured at 2005 constant prices.
**Source**: UNCTADStat database (http://unctad.org/en/Pages/statistics.aspx).

Another approach to examining the nature of structural change that has occurred in Africa at the domestic level is to look at the share of various activities in total employment. It is well-known that most of the continent's labour force is in the agriculture sector. In most countries, two-thirds of the labour force work in the agriculture sector (figure 2), which accounts for a low share of value added, indicating that average labour productivity is much lower in agriculture than in other key sectors. The finding that labour productivity in agriculture is very low suggests that there is a need to reallocate some labour to productive activities in industry and services. While some of this reallocation is already taking place, labour seems to be going mostly to the services sector and, more importantly, to low rather than high productivity activities in the services sector.

**Figure 2: Agriculture's share of total employment in 2012 (%)**




**Source**: GET (Global Employment Trends) database, ILO (http://ilo.org/global/research/global-reports/global-employment-trends/2014/WCMS_234879/lang--en/index.htm).

To further explore the productivity issue, we computed relative productivity levels across sectors, using an extended version of the Groningen Growth and Development Center (GGDC) database, which provides disaggregated data on employment and value-added for 13 African countries, beginning in 1960.[2] The results suggest that in 2010 (relative to the situation in 1960): (1) labour productivity in manufacturing either declined or remained largely unchanged in most of the countries in the sample, Botswana being an exception; (2) in most countries labour productivity levels were relatively high in the mining sector; and (3) a lot of the labour that moved from agriculture and industry into the services sector ended up in the category "other services", a group which consists of: community, social and personal services; government services; and trade, restaurants and hotels. These activities classified under "other services" have very low productivity compared to the other components of services, such as "finance, insurance, real estate and business services" and "transport, storage and communications." The category "other services" also has the second lowest productivity level after agriculture. Historically, at the initial stage of development labour tends to move from agriculture to manufacturing and then, as incomes rise, to services. However, African countries seem to be by-passing this normal process of structural change, with labour moving from agriculture and industry to low-productivity services. This development is of concern to African countries because it has negative consequences for their ability to exploit the potential of industrialisation for employment generation.

An interesting question to pose at this stage is what factors drive productivity changes in Africa? Following McMillan and Rodrik (2011) and de Vries et. al. (2015), we decompose labour productivity growth into three components: the within-effect (which captures productivity growth within sectors); the between-static effect (which reflects differences in productivity levels across sectors); and the between-dynamic effect (which reflects differences in productivity growth across sectors). The within-effect will be positive when labour productivity growth in the sectors is positive, and the between-effects are positive when labour moves from a less productive to a more productive sector. Figure 3 shows that a lot of the productivity growth that occurred in the African countries in the sample in the period 2000-2010 was driven by positive productivity growth within sectors (the within-effect) and a reallocation of labour from sectors with low productivity levels to those with higher productivity levels (the between-static effect). The results also show that the reallocation of labour across sectors has also created dynamic losses in the sense that the marginal productivity of additional workers in the expanding sectors has been below those of existing activities in those sectors, and this is reflected in the fact that the between-dynamic effects are negative.

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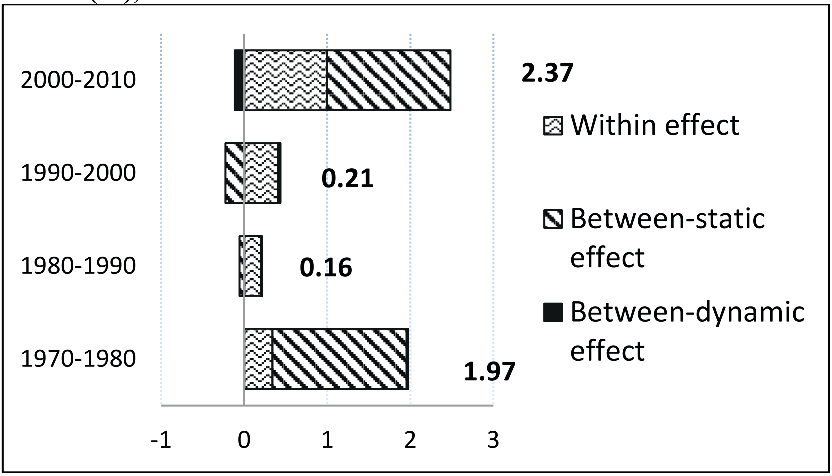
[2] The countries are: Botswana, Egypt, Ethiopia, Ghana, Kenya, Malawi, Mauritius, Morocco, Nigeria, Senegal, South Africa, United Republic of Tanzania, and Zambia.

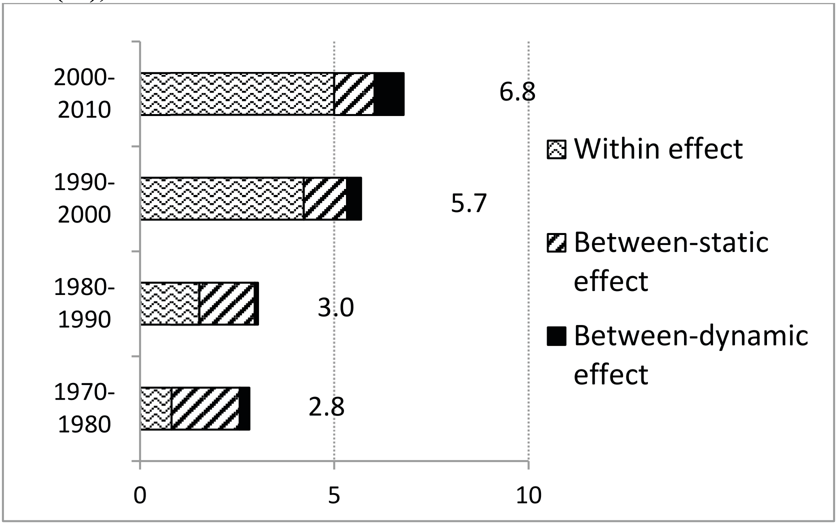
**Figure 3: Average annual labour productivity growth in Africa by driving factors (%), 1970-2010**




**Source**: Based on data from the GGDC database (http://www.rug.nl/ggdc/productivity/10-sector/).

Africa's patterns of structural change and productivity growth are quite different from those of developing Asia, where all three components of productivity growth made positive contributions over the past four decades (see figure 4). In the 1990s and 2000s, within-sector productivity grew in all sectors, but mostly in manufacturing, boosted by high investment levels, which in turn generated various linkages and positive effects of economies of scale, technological advance, and knowledge and skills acquisition (UNCTAD 2016). This process generated a positive dynamic reallocation effect that has been growing over the decades, indicating that the movement of workers affected positively the growth of productivity in the expanding sectors, which was mainly manufacturing.

**Figure 4: Average annual labour productivity growth in Asia by driving factors (%), 1970-2010.**

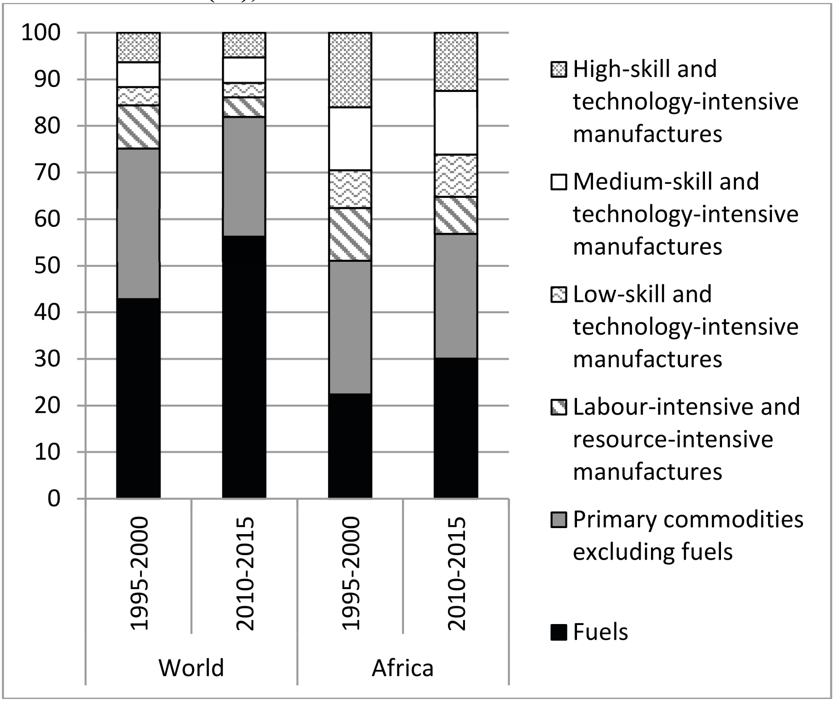



**Notes**: 1) Labour productivity is expressed in constant 2005 PPP dollars per employee, 2) Calculations are based on a weighted average for the following countries: China, Hong Kong (China), India, Indonesia, Republic of Korea, Malaysia, Philippines, Singapore, Taiwan, and Thailand.
**Source**: Based on data from the GGDC database (http://www.rug.nl/ggdc/productivity/10-sector/).

### 3.2 Structure of Africa's exports

The structural changes that are taking place in Africa can also be examined from an international perspective. A key feature of Africa’s participation in international trade is that the continent is an exporter of primary products and an importer of manufactured goods and services (Wohlmuth et. al. 2007). Furthermore, this dependence on primary commodity exports has increased over the past few decades (see figure 5). Being a result of the increase in commodity prices in the early 2000s, there was an increase in the share of primary goods in the value of SSA's total merchandise exports (from 75 percent in 1995-2000 to 82 percent in 2010-2015) and, consequently, a decline in the share of manufactured goods (from 25 to 18 percent).

**Figure 5: Technology composition of Africa's merchandise exports to the world and Africa (%), 1995-2015**




**Note**: Data used for computation of shares of each category are in current prices.
**Source**: UNCTADStat database (http://unctad.org/en/Pages/statistics.aspx).

Not only do African countries export mostly commodities, their exports are also highly concentrated in a few commodity products, and this pattern has accentuated in recent years (see table 1). While in 1995-2000 Africa's top 10 export products accounted for 54 percent of the value of total merchandise exports and included two manufacturing products (men's clothing and articles of apparel), in 2010-2015 they represented 65 percent and were exclusively composed of commodities.

**Table 1: Africa's top 10 merchandise exports, 1995-2000 and 2010-2016**

| **1995-2000** | Share in total (%) | **2010-2016** | Share in total (%) |
|---|---|---|---|
| Petroleum oils, oils from bituminous materials, crude (SITC code 333) | 30 | Petroleum oils, oils from bituminous materials, crude (SITC code 333) | 41 |
| Petroleum oils or bituminous minerals > 70 % oil (SITC code 334) | 6 | Natural gas, in liquefied form or not (SITC code 343) | 6 |
| Pearls, precious & semi-precious stones (SITC code 667) | 5 | Petroleum oils or bituminous minerals > 70 % oil (SITC code 334) | 5 |
| Natural gas, in liquefied form or not (SITC code 343) | 3 | Gold, non-monetary (excluding gold ores and concentrates) (SITC code 971) | 3 |
| Cocoa (SITC code 072) | 2 | Pearls, precious & semi-precious stones (SITC code 667) | 2 |
| Men's clothing of textile fabrics, not knitted (SITC code 841) | 2 | Copper (SITC code 682) | 2 |
| Articles of apparel, of textile fabrics, n.e.s. (SITC code 845) | 2 | Cocoa (SITC code 072) | 2 |
| Silver, platinum, other metals of the platinum group (SITC code 681) | 2 | Iron ore and concentrates (SITC code 281) | 1 |
| Cotton (SITC code 263) | 2 | Liquefied propane and butane (SITC code 342) | 1 |
| Fruits and nuts (excluding oil nuts), fresh or dried (SITC code 057) | 2 | Fruits and nuts (excluding oil nuts), fresh or dried (SITC code 057) | 1 |
| Total top 10 products | 54 | Total top 10 products | 65 |
| Total all products | 100 | Total all products | 100 |

**Source**: UNCTADStat (http://unctad.org/en/Pages/statistics.aspx).

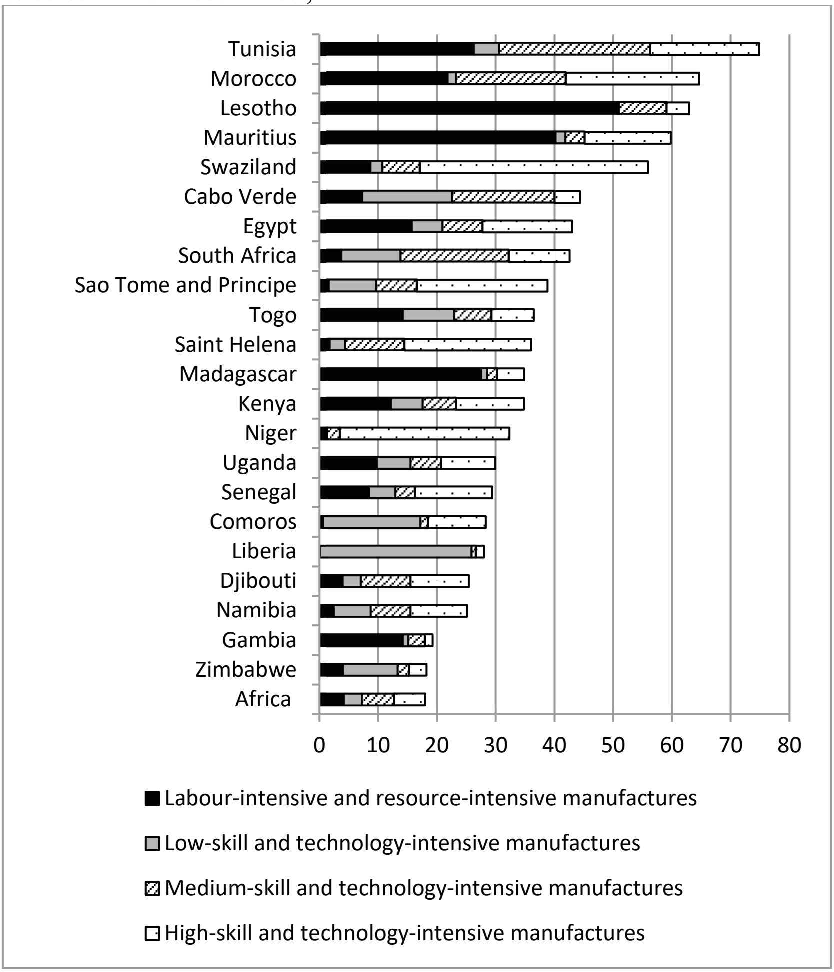
Another feature of Africa's commodity exports is their low level of processing, which reflects the fact that technological capacities for upgrading and value addition are low on the continent. In 2014, the share of un-processed commodities in Africa's total merchandise exports was 57 percent (UNCTAD 2016). The most vivid illustration of Africa’s low capacities in processing its natural resources is that of petroleum products. The continent exports petroleum in raw form, and re-imports it transformed into intermediary and finished products. The lack of local processing of Africa's resource exports leads to a loss of scarce foreign exchange and has important negative implications in terms of local employment, knowledge and technology acquisition.

This aggregate picture does not reflect the export patterns and experiences of all African countries. There are various countries in Africa where the share of manufactures in total merchandise exports is significant. Figure 6 shows that over the period 2010-2015, manufacture exports accounted for at least 30 percent of total merchandise exports in 15 African countries. In fact, the share was more than 50 percent in Tunisia, Morocco, Lesotho, Mauritius and Swaziland. That said, the bulk of the continent’s manufactures exports is concentrated in a few countries, with only four accounting for more than three quarters of the total in 2010-2015: South Africa (39 percent), Morocco (14 percent), Tunisia (12 percent) and Egypt (12 percent). Within the category of manufactures exports, medium skill- and technology-intensive manufactures had the highest growth rate (11 percent), while labour-intensive and resource-intensive manufactures had the lowest growth rate (5 percent) over the period 1995 and 2015 (see table 2 below).

Another interesting fact, observed in the data, is that Africa's intra-regional merchandise export has a different pattern from its total merchandise export to the world. Unlike the continent’s exports to the world, Africa's intra-regional exports are almost equally distributed between manufactures and commodities. That said, the share of commodities in Africa's intra-regional exports has increased from 51 percent in 1995-2000 to 56 percent in 2010-2015 (see figure 5), this being a consequence of the strong rise of commodity prices since the early 2000s. The implication of this is that intra-regional trade has the potential to foster economic diversification in Africa. Despite the modest share of intra-regional exports in Africa's total merchandise exports (14 percent in 2010-2015), it accounted for 35 percent of Africa’s total manufactures exports in 2010-2015 (up from 23 percent in 1995-2000).

Some African countries (see figure 6) have relatively high shares of manufactured exports. The countries listed in figure 6 are those whose share of manufactures in total merchandise exports is higher than Africa's average share.

**Figure 6: Share of categories of manufactures in total merchandise exports in selected African countries[1], 2010-2015**




[1] These countries are those whose share of manufactures in total merchandise exports is higher than Africa's average share. Data used for computation of shares of each category are in current prices.

**Source**: UNCTADStat database (http://unctad.org/en/Pages/statistics.aspx).

Although still at low levels, countries like Equatorial Guinea, Uganda and Sierra Leone are leading in terms of growth of manufacturing exports (see table 2).

**Table 2: Growth of Africa's manufacturing exports by components (%), 1995-2015**

| | Average annual growth rate between 1995 and 2015 | | | | |
|---|---|---|---|---|---|
| | Total manufactures | Labour-intensive & resource-intensive | Low-skill & technology-intensive | Medium-skill & technology-intensive | High-skill & technology-intensive |
| Equatorial Guinea | 28 | 3 | 46 | 19 | 49 |
| Uganda | 26 | 30 | 28 | 22 | 23 |
| Sierra Leone | 24 | 17 | 40 | 19 | 22 |
| Angola | 23 | 13 | 38 | 13 | 12 |
| Congo | 22 | 3 | 45 | 19 | 10 |
| Rwanda | 21 | 21 | 24 | 22 | 18 |
| Gambia | 18 | 25 | 14 | 13 | 10 |
| United Republic of Tanzania | 18 | 16 | 30 | 19 | 21 |
| Burundi | 17 | 15 | 20 | 16 | 21 |
| Zambia | 16 | 7 | 22 | 19 | 23 |
| Benin | 16 | 6 | 38 | 22 | 12 |
| Sao Tome and Principe | 16 | 12 | 22 | 9 | n.a. |
| Gabon | 16 | 13 | 29 | 20 | 13 |
| Egypt | 16 | 12 | 16 | 20 | 21 |
| Mozambique | 15 | 3 | 22 | 10 | 20 |
| Togo | 14 | 14 | 17 | 13 | 14 |
| Nigeria | 13 | 10 | 24 | 13 | 13 |
| Mali | 13 | 8 | 24 | 12 | 14 |
| Ethiopia | 13 | 13 | 26 | 24 | 11 |
| Saint Helena | 13 | 8 | 15 | 14 | 11 |
| Dem. Rep. of the Congo | 12 | 2 | 10 | 12 | 20 |
| Namibia | 12 | 8 | 20 | 13 | 9 |
| Seychelles | 11 | 10 | 26 | 9 | 11 |
| Niger | 11 | 1 | 6 | 4 | 13 |
| Burkina Faso | 10 | 6 | 9 | 14 | 13 |
| Kenya | 10 | 10 | 9 | 12 | 11 |
| Chad | 10 | 20 | 9 | 10 | 8 |
| Cameroon | 10 | 4 | 16 | 12 | 14 |
| Ghana | 9 | 4 | 17 | 18 | 11 |
| Cabo Verde | 9 | 1 | 14 | 12 | 5 |
| Madagascar | 9 | 8 | 9 | 11 | 11 |
| Malawi | 8 | -2 | 10 | 15 | 23 |
| Morocco | 8 | 4 | 12 | 19 | 8 |
| Lesotho | 8 | 7 | 5 | 34 | 10 |
| Eritrea | 8 | 6 | 9 | 5 | 9 |
| South Africa | 8 | 3 | 7 | 9 | 8 |

Continued on next page

Continued from previous page

| | Average annual growth rate between 1995 and 2015 | | | | |
|---|---|---|---|---|---|
| | Total manufactures | Labour-intensive & resource-intensive | Low-skill & technology-intensive | Medium-skill & technology-intensive | High-skill & technology-intensive |
| Senegal | 7 | 15 | 15 | 9 | 4 |
| Mauritania | 7 | 5 | 9 | 9 | 8 |
| Tunisia | 7 | 3 | 12 | 13 | 10 |
| Côte d'Ivoire | 6 | 1 | 9 | 7 | 7 |
| Algeria | 6 | 6 | -4 | -3 | 9 |
| Sudan (...2011) | 6 | -1 | 14 | 9 | 14 |
| Botswana | 6 | 4 | 6 | 5 | 6 |
| Comoros | 5 | -1 | 29 | 1 | 0 |
| Djibouti | 5 | 1 | 4 | 4 | 7 |
| Swaziland | 4 | -1 | 2 | 3 | 7 |
| Central African Republic | 3 | 3 | 2 | 4 | 3 |
| Libya | 3 | -1 | 3 | 4 | 3 |
| Somalia | 2 | 7 | -5 | 3 | 2 |
| Mauritius | 1 | -1 | 9 | 7 | 9 |
| Zimbabwe | 0 | -2 | 1 | 2 | 0 |
| Guinea | 0 | 8 | 5 | 10 | -3 |
| Guinea-Bissau | -1 | 6 | 6 | 0 | -5 |
| Liberia | -3 | -5 | -3 | 7 | 1 |
| **Africa** | **8** | **5** | **9** | **11** | **9** |

**Source**: UNCTADStat database (http://unctad.org/en/Pages/statistics.aspx).

## 4 What do we know about Inclusive Development in Africa?

This section discusses Africa's performance in achieving the goal of building inclusive societies which is one of the priorities in the SDGs. It does this by focusing on three key drivers of inclusive growth: the distribution of income; financial inclusion; and social progress. The focus on these indicators reflects our view that fostering inclusive development requires addressing both economic and non-economic factors which foster exclusion. When economists talk about making growth and development more inclusive than in the past the focus tends to be on income inequality; this is due to the assessment that a high level of income inequality is considered as unfair and has undesirable effects in an economy. Especially, studies have shown that inequality can have a negative effect on political stability, investment and growth in an economy (Alesina and Perotti 1996; Ravallion 2001). It can also lead to an inefficient use of resources and can increase the risks of financial crises (Dabla-Norris et. al. 2015). While the prevalence of high inequality in an economy is an indication that the development process is not inclusive, inequality is only one of the varied manifestations of exclusion in a society and so there is the need to discuss trends in other indicators as well.

Recent studies on inequality suggest that relative to other developing country-groups, income inequality is quite high in SSA and that the recent high growth experienced by countries in SSA did not result in significant changes in inequality in the sub-region. Table 3 presents recent estimates of various measures of income inequality in SSA over the period 1975 to 2010. The coefficient of variation and the Gini coefficient are relative measures of income inequality while the standard deviation and the absolute Gini are absolute measures of inequality. Although many economists use relative measures of inequality in their analyses, economic theory does not provide guidance on which should be the preferred measure. Furthermore, surveys have shown that individuals care about absolute differences in incomes and so it is an aspect of inequality that should not be ignored (Nino-Zarazua et. al. 2016). The key message from table 3 is that both absolute and relative measures of inequality suggest that income inequality in SSA increased significantly between 1975 and 2010. In other words, Africa's growth and development has gone hand in hand with an increase in inequality, indicating that it has not been inclusive. But, also other drivers of inclusion are lacking in SSA.

**Table 3: Income inequality estimates for Sub-Saharan Africa, 1975-2010**

| **Inequality measure** | **1975** | **1985** | **1995** | **2000** | **2005** | **2010** |
|---|---|---|---|---|---|---|
| Coefficient of variation | 1.40 | 1.66 | 3.32 | 2.70 | 3.24 | 3.14 |
| Standard deviation | 2337.86 | 1770.68 | 5288.44 | 5021.64 | 5574.38 | 7627.56 |
| Gini | 0.54 | 0.54 | 0.68 | 0.67 | 0.63 | 0.63 |
| Absolute Gini | 889.91 | 581.41 | 1090.04 | 1252.41 | 1083.35 | 1535.17 |

**Source**: Nino-Zarazua, Roope and Tarp (2016)

Access, use and quality of financial services are crucial factors in building an inclusive society. They permit individuals and firms to exploit opportunities and to contribute to, as well as benefit from, the growth and development process. Therefore, the degree of financial inclusion in a society is an important driver of inclusive growth. Available data on the three main indicators of financial inclusion (ownership of a bank account, saving at a financial institution, and the use of bank credit) indicate that some progress was made in fostering financial inclusion in Africa over the period 2011 and 2014, but the degree of financial inclusion on the continent is still relatively low (see table 4 below). In 2014, the percentage of the population in SSA that had an account at a financial institution was 28.9 percent compared with a global average of 60.7 percent. Furthermore, only 15.9 percent of the population in SSA had savings at a financial institution compared with a global average of 27.4 percent. Regarding the use of bank credit, only 6.3 percent of the population in SSA borrowed from a financial institution compared with a global average of 10.7 percent. Within SSA, there is a wide variation across countries in the degree of financial inclusion. For example, in 2014, the share of the population with an account at a financial institution was as high as 82 percent in Mauritius, 75 percent in Kenya, and 70 percent in South Africa. But it was only 9 percent in Madagascar and 7 percent in Burundi. Zins and Weill (2016) examined the determinants of financial inclusion in Africa and found that gender, income, education, and age are important factors. Especially, being a man, more educated, richer, and older has a positive impact on financial inclusion in Africa. There is also some evidence suggesting that financial innovation is crucial in promoting financial inclusion and that the development of financial systems is a necessary but not sufficient condition for financial inclusion (Beck, Senbet and Simbanegavi, 2015). These facts underscore the need for adapted financial inclusion policies; it is necessary to consider differences across groups and to better exploit the role of technology and innovation than in the past.

**Table 4: Indicators of Financial Inclusion (%), 2011 and 2014**

| Share of population | World | | Sub-Saharan Africa | |
|---|---|---|---|---|
| | 2011 | 2014 | 2011 | 2014 |
| With an account at a financial institution | 50.6 | 60.7 | 23.9 | 28.9 |
| Saved at a financial institution in the past year | 22.6 | 27.4 | 14.3 | 15.9 |
| Borrowed from a financial institution in the past year | 9.1 | 10.7 | 4.8 | 6.3 |

**Source**: Based on data from World Bank (2015)

The degree of social progress achieved in a society is another important driver of inclusive growth. The Social Progress Imperative has developed a methodology for computing an index of social progress that captures the social performance of countries. The Social Progress Index (SPI) measures the capacity of a society to meet basic human needs, build the foundations of well-being of its citizens, and provide opportunity for its citizens (Porter, Stern and Green, 2016). Two key attractive features of this index are that: (a) it is an outcome-based rather than an input-based index and; (b) it focuses on non-economic dimensions of social progress, thereby permitting an analysis and understanding of the linkages between economic development and social progress. The index was developed in 2014 and ranges from 0 to 100, with higher numbers indicating a higher level of social progress. The SPI is a simple average of the three dimensions of social progress mentioned above, namely: basic human needs; foundations of wellbeing; and opportunity. Based on the 2016 index, at the global level the countries with very high levels of social progress are: Finland (90.09), Canada (89.49), Denmark (89.39), Australia (89.13), Switzerland (88.87), Sweden (88.80), Norway (88.70), Netherlands (88.65), United Kingdom (88.58), Iceland (88.45), New Zealand (88.45), and Ireland (87.94). Table 5 presents information on the 2016 index and its components for African countries which are included in the sample. It shows that, in general, African countries have relatively low SPI values which is consistent with the widely-held view that the recent growth in Africa has not been inclusive. There is a wide variation across African countries in terms of the level of social progress achieved. For example, countries such as Mauritius, Tunisia, South Africa, and Botswana have higher levels of social progress than other African countries. It should be noted that some African countries that have relatively high SPI values also show weaknesses in some components of the SPI. For example, although Mauritius and Tunisia have relatively high overall SPI values, they have low scores in the component of the index reflecting opportunity provided to citizens. This configuration may have substantial impact on political stability.

Although the SPI focuses on non-economic aspects of social performance, as shown in figure 7 there is a positive correlation between the index and economic indicators such as income per capita. This may reflect the fact that African countries with higher income levels have more resources to invest in the social sectors and so tend to have better social indicators. But this does not mean that having higher income is a sufficient condition for social progress because there are some countries with high levels of income which have low levels of social progress and vice versa. For example, Angola has much higher levels of income than Malawi and Rwanda, yet the latter countries have achieved higher levels of social progress than the former (figure 7). This indicates that income or economic development in general does not automatically translate into higher levels of social progress, and that policies which promote growth need to be complemented by other policy measures to foster social inclusion.

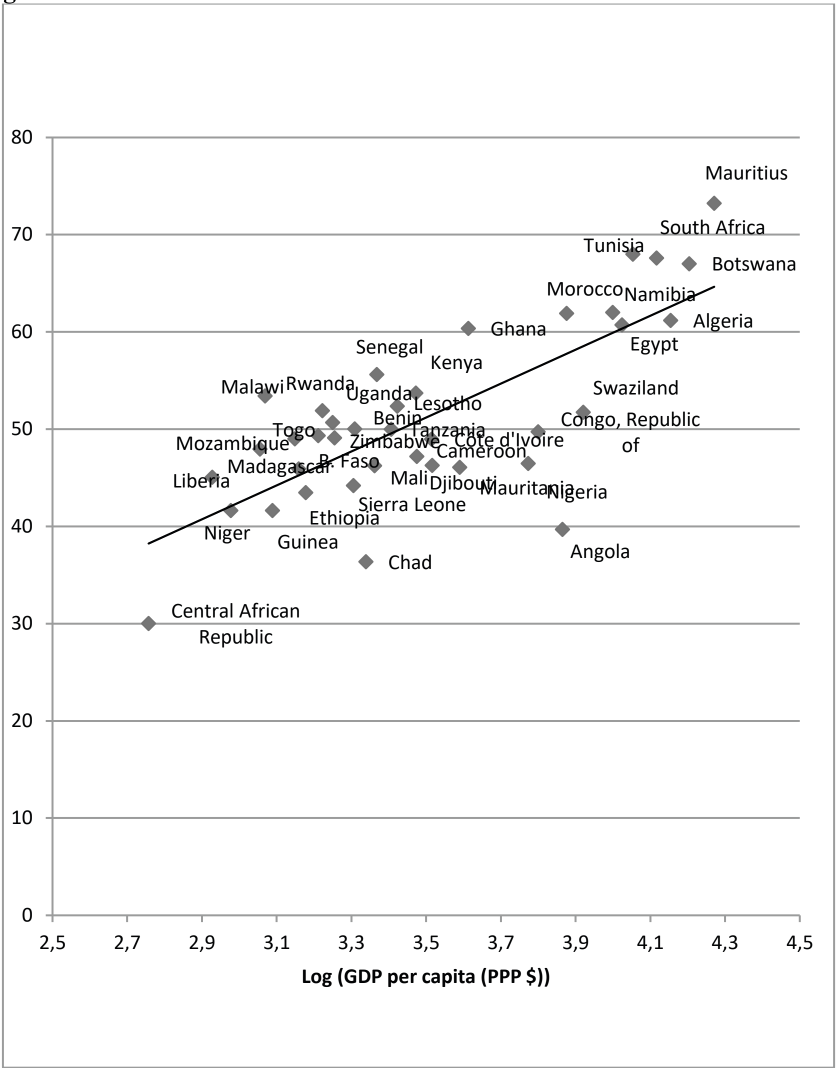
In sum, data on the three drivers of inclusive development analysed in this section suggest that, although African countries have made modest progress in promoting inclusion, they are still a long way from achieving their overall objective of creating an inclusive society. In this context, there is the need for African governments to ratchet-up efforts to engender inclusive growth, and this would require addressing both economic and non-economic factors that affect inclusive development.

**Table 5: Measuring Social Progress in Africa, 2016**

| Country | Social Progress Index | Components | | |
|---|---|---|---|---|
| | | Basic human needs | Foundations of well-being | Opportunity |
| Mauritius | **73.24** | 89.44 | 72.84 | 57.46 |
| Tunisia | **68.00** | 82.17 | 74.6 | 47.23 |
| South Africa | **67.60** | 66.95 | 68.23 | 67.61 |
| Botswana | **67.03** | 71.94 | 70.37 | 58.77 |
| Namibia | **62.01** | 61.75 | 66.14 | 58.14 |
| Morocco | **61.92** | 78.09 | 69.89 | 37.8 |
| Algeria | **61.18** | 79.58 | 69.54 | 34.41 |
| Egypt | **60.74** | 82.07 | 65.49 | 34.66 |
| Ghana | **60.37** | 60.41 | 68.59 | 52.12 |
| Senegal | **55.64** | 65.31 | 58.6 | 43.01 |
| Kenya | **53.72** | 52.4 | 67.96 | 40.79 |
| Malawi | **53.44** | 54.62 | 57.82 | 47.87 |
| Lesotho | **52.39** | 53.44 | 51.56 | 52.17 |
| Rwanda | **51.91** | 57.26 | 59.25 | 39.21 |
| Swaziland | **51.76** | 58.08 | 56.33 | 40.87 |
| Uganda | **50.69** | 52.13 | 60.21 | 39.72 |
| Benin | **50.03** | 53.35 | 58.26 | 38.47 |
| Tanzania | **49.99** | 47.13 | 60.95 | 41.90 |
| Congo, Republic of | **49.74** | 45.88 | 64.19 | 39.16 |
| Burkina Faso | **49.34** | 51.77 | 53.46 | 42.80 |
| Zimbabwe | **49.11** | 51.29 | 62.33 | 33.72 |
| Togo | **49.03** | 50.19 | 56.53 | 40.38 |
| Côte d'Ivoire | **48.97** | 54.24 | 57.37 | 35.31 |
| Mozambique | **47.96** | 45.5 | 58.76 | 39.62 |
| Cameroon | **47.22** | 52.7 | 56.19 | 32.75 |
| Nigeria | **46.49** | 46.63 | 60.47 | 32.38 |
| Djibouti | **46.3** | 64.65 | 42.63 | 31.63 |
| Mali | **46.24** | 53.46 | 50.89 | 34.38 |
| Mauritania | **46.08** | 55.26 | 52.97 | 30.01 |
| Madagascar | **45.91** | 43.76 | 56.91 | 37.05 |
| Liberia | **45.07** | 45.99 | 48.97 | 40.24 |
| Sierra Leone | **44.22** | 41.05 | 55.2 | 36.39 |
| Ethiopia | **43.50** | 50.57 | 52.25 | 27.68 |
| Guinea | **41.66** | 45.58 | 51.23 | 28.18 |
| Niger | **41.63** | 48.11 | 45.15 | 31.64 |
| Angola | **39.70** | 43.74 | 49.73 | 25.65 |
| Chad | **36.38** | 36.75 | 45.27 | 27.11 |
| Central African Republic | **30.03** | 29.84 | 41.42 | 18.83 |

**Source**: Based on data from SPI: http://www.socialprogressimperative.org/global-index/

**Figure 7: Relationship between Income per capita and the 2016 Social Progress Index**




**Source**: Based on data from UNCTADStat database (http://unctad.org/en/Pages/statistics.aspx); and data from SPI: http://www.socialprogressimperative.org/global-index

## 5 What is the State of Technology and Innovation in Africa?

Technology and innovation will play a vital role in poverty reduction and development in Africa. Especially, it is crucial to addressing the challenges of low productivity and lack of structural transformation required to achieve the SDGs in Africa. Over the past few decades, African governments have strengthened efforts to promote technology and innovation on the continent. At the continental level, in 2005 the African Union (AU) has adopted Africa's Science and Technology Consolidated Plan of Action (CPA) covering the period 2005-2014. This has now been superseded by the Science, Technology and Innovation Strategy for Africa (STISA), adopted at the 23$^{rd}$ African Union Summit in June 2014 to cover the period 2014-2024. African regional economic communities (RECs) have also developed regional visions on science and technology. For example, in 2011 the Economic Community of West African States (ECOWAS) has adopted the ECOWAS Policy on Science and Technology, and the Southern African Development Community (SADC) has a protocol on Science, Technology and Innovation dating back to 2008. At the national level, many countries have either developed or revised their Science, Technology and Innovation (STI) policy over the past decade (Box 1). For example, Angola has adopted an STI policy document in 2011, while the United Republic of Tanzania has revised its 1996 science and technology policy in 2010 (UNESCO, 2015). However, not all regions and countries in Africa are active in this regard.

**Box 1: UNCTAD's Science, Technology and Innovation Policy Reviews in Africa**

The experiences of developed countries and emerging markets show that technology and innovation are crucial drivers of productivity and sustained growth in an economy. In recognition of this important role of technology and innovation in the development process, UNCTAD assists developing countries in building and strengthening domestic capabilities in the field of Science, Technology and innovation (STI). Over the past decade, it has conducted and published STI policy reviews in four African countries: Angola (2008), Ghana (2011), Lesotho (2010) and Mauritania (2010). The Reviews provide an independent and constructive assessment of STI capabilities and policies, identify major areas of weakness, and suggest concrete policy actions that should be implemented to better harness the potential of STI for development, given each country's specific circumstances.

Three of the four African countries reviewed (Angola, Ghana, and Lesotho) had established formal institutional arrangements and an elaborated national STI policy and strategy at the time of the review. Mauritania, however, had no public body mandated to oversee STI issues, and had no clear STI strategy at the time of the review. While there are differences among the four countries, the Reviews suggest that there are weak links and an inadequate coordination among the different stakeholders of the STI system (ministries and other governmental bodies, research institutes, and the private sector). Another interesting finding in the Reviews is the supply-driven character of these countries' STI system, reflecting the fact that there is over-reliance on the public budget and donors. One consequence of this funding mechanism is that funding allocations for STI do not reflect the priorities of key domestic actors such as the private sector, research institutes, and universities. It is also one of the reasons why STI systems in Africa often do not adequately address countries' socio-economic needs. Especially the links of the STI system with the private enterprises are weak.

The Reviews underscored the need to strengthen efforts to convert STI policies into implementable initiatives. They also emphasized the need to better integrate STI policies into national development strategies for coherence and to ensure that these policies support the development of productive capacities and promote economic diversification and structural change. Other recommendations of the reviews include: identifying STI needs at the national and sector levels; establishing mechanisms for monitoring and evaluation; forecasting technology needs and foreseeing STI directions; placing emphasis on the growth of the science, engineering and technical workforce through investing in education and training to meet the needs of a modernized economy; and establishing support mechanisms for private-sector innovation, technology absorption, and industry-driven research.

**Sources**: UNCTAD (2008); UNCTAD (2010a); UNCTAD (2010b) and UNCTAD (2011)

There is no doubt that the recent measures taken by African countries at the national, regional and continental levels have had an impact on the state of technology and innovation in Africa. Over the past few decades, there have been noticeable improvements in some technology and innovation indicators. For example, the number of researchers in SSA per million inhabitants increased from 65.8 in 1996 to 91.4 in 2013 (table 6). Similarly, domestic expenditure on research and development (R&D) in SSA has increased from 0.37 to 0.42 percent of GDP over the same period (table 7). However, it should be noted that when compared to the world average, SSA is not doing well on these indicators. One of the interesting findings from the data on the number of researchers is that there is a gender gap in all regions of the world. For example, in 2013 female researchers as a percentage of the total number of researchers was 28.4 percent for the world, 36.8 percent for the Arab States, 39.9 percent for Central and Eastern Europe, 47.1 percent for Central Asia, 22.6 percent for East Asia and the Pacific, 44.3 percent for Latin

America and the Caribbean, 32.0 percent for North America and Western Europe, 18.9 percent for South and West Asia, and 30.0 percent for SSA. Closing this gender gap is necessary and urgent to enhance prospects for meeting the SDGs by the 2030 target date.

**Table 6: Researchers per million inhabitants, 1996-2013**

| | 1996 | 2000 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|
| World | 784.7 | 803.5 | 1022.8 | 1050.4 | 1069.6 | 1083.3 |
| Arab States | 406.9 | 394.7 | 382.5 | 397.1 | 409.5 | 416.3 |
| Central and Eastern Europe | 2209.5 | 1950.9 | 1975.3 | 2002.8 | 2030.5 | 2049.9 |
| Central Asia | 580.5 | 476 | 480.3 | 484.9 | 557 | 583.9 |
| East Asia and the Pacific | 653.6 | 720.5 | 1168.9 | 1231.3 | 1274.3 | 1311.8 |
| Latin America and the Caribbean | 281.1 | 284.8 | 459.3 | 464.4 | 469.2 | 467.9 |
| North America and Western Europe | 2685 | 3024.4 | 3757.3 | 3843.7 | 3904.5 | 3952 |
| South and West Asia | 144.4 | 112.9 | 170.1 | 169.3 | 170.3 | 171.2 |
| Sub-Saharan Africa | 65.8 | 71.2 | 89.5 | 90.6 | 91.7 | 91.4 |

**Source**: Based on data from the UNESCO Institute for Statistics (UIS.Stat) database (http://data.uis.unesco.org/).

Most important is the role of private enterprises in R&D, and the numbers of researchers in and finance through such enterprises. SSA is very weak in this regard, but also the respective situation in North African countries needs improvement.

Patent applications are another useful indicator of innovation. Unlike expenditure on R&D that captures innovation input, patents are the output of innovation activities, and so it is an indicator of the extent to which an economy has made progress in the field of technology and innovation. Table 8 presents information on the total number of patents filed (based on the applicants' origin). It shows that there has been a significant increase in the number of patent applications filed by applicants from African countries over the past decade. For example, in Algeria the number of patent applications has increased from 46 in the period 2006-2010 to 120 in the period 2011-2015. In Benin, it increased from 3 to 103, in Cameroon from 5 to 509, in Kenya from 62 to 164, and in Tunisia from 108 to 190 over the same period. In fact, of the 50 African countries for which there are such data available, only 6 (Cabo Verde, The Gambia, Libya, Madagascar, Sudan and Zambia) have experienced a decrease in the number of patent applications over the periods 2006-2010 to 2011-2015. Within the continent, there is a high degree of concentration in patent applications, with South Africa, Egypt and Cameroon accounting for the bulk of patent applications filed by the continent in the period

2011-2015. While many African countries have made progress in terms of the number of patents filed, it is worth noting that the large economies in the continent (Algeria, Egypt, Nigeria, and South Africa) file far less patent applications than developing countries such as, for example, China, India, and Mexico. In the period 2011-2015 the average number of patent applications was 120 for Algeria, 657 for Egypt, 53 for Nigeria, and 2,008 for South Africa. In contrast, China filed an average of 715,979 applications, India 20,259, and Mexico 2,195 applications.

**Table 7: Domestic expenditure on R&D (% of GDP), 1996-2013**

| | 1996 | 2000 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|
| World | 1.42 | 1.53 | 1.63 | 1.65 | 1.68 | 1.7 |
| Arab States | 0.22 | 0.22 | 0.26 | 0.27 | 0.27 | 0.3 |
| Central and Eastern Europe | 0.79 | 0.81 | 0.94 | 0.95 | 1.01 | 1.01 |
| Central Asia | 0.27 | 0.22 | 0.2 | 0.2 | 0.21 | 0.23 |
| East Asia and the Pacific | 1.41 | 1.54 | 1.9 | 1.96 | 2.03 | 2.1 |
| Latin America and the Caribbean | 0.52 | 0.53 | 0.65 | 0.64 | 0.66 | 0.67 |
| North America and Western Europe | 2.05 | 2.2 | 2.36 | 2.39 | 2.43 | 2.43 |
| South and West Asia | 0.51 | 0.58 | 0.7 | 0.71 | 0.71 | 0.71 |
| Sub-Saharan Africa | 0.37 | 0.39 | 0.41 | 0.41 | 0.41 | 0.42 |

**Source**: Based on data from the UNESCO Institute for Statistics (UIS.Stat) database (http://data.uis.unesco.org/).

Patent applications can also be analysed from the perspective of the filing office rather than the applicant's origin. Based on this indicator, there has been an increase in total patent applications filed in Africa from 10,900 in 2005 to 14,800 in 2015. Available data also shows that among developing-country regions, Asia accounts for a large percentage of global patent applications, with as much as 61.9 percent in 2015 (table 9). Interestingly, there has been a significant decline in the share of global patent applications received by high-income countries, from 80.4 percent in 2005 to 53.4 percent in 2015, reflecting largely the increasing role of Asia in the field of patent applications.

**Table 8: Total patent applications by applicants' origin, 2006-2015**

| | **2006-2010** | **2011-2015** |
|---|---|---|
| Algeria | 46.80 | 120.60 |
| Angola | 1.00 | 2.80 |
| Benin | 3.00 | 103.00 |
| Botswana | 1.50 | 15.80 |
| Burkina Faso | 2.00 | 61.00 |
| Burundi | 2.50 | 8.00 |
| Cabo Verde | 3.00 | 1.00 |
| Cameroon | 5.40 | 509.25 |
| Central African Republic | 1.33 | 38.00 |
| Chad | 1.00 | 52.20 |
| Comoros | | 17.00 |
| Congo | 2.00 | 64.25 |
| Côte d'Ivoire | 2.00 | 259.00 |
| Democratic Republic of the Congo | 1.33 | 1.50 |
| Djibouti | | 3.00 |
| Egypt | 494.60 | 657.00 |
| Ethiopia | 5.50 | 7.33 |
| Gabon | 1.75 | 41.00 |
| Gambia | 2.00 | 1.00 |
| Ghana | 1.80 | 9.67 |
| Guinea | 1.50 | 22.67 |
| Kenya | 62.00 | 164.60 |
| Lesotho | | 1.00 |
| Liberia | | 1.40 |
| Libya | 1.75 | 1.67 |
| Madagascar | 8.20 | 4.80 |
| Malawi | | 5.25 |
| Mali | 4.00 | 46.80 |
| Mauritania | 2.00 | 28.33 |
| Mauritius | 42.20 | 81.80 |
| Morocco | 184.00 | 286.60 |
| Mozambique | 8.60 | 16.00 |
| Namibia | 2.60 | 9.00 |
| Niger | 1.00 | 93.00 |
| Nigeria | 15.00 | 53.60 |
| Rwanda | | 17.67 |
| Sao Tome and Principe | 3.00 | 3.00 |

Continued on next page

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| | **2006-2010** | **2011-2015** |
|---|---|---|
| Senegal | 1.33 | 235.00 |
| Seychelles | 50.20 | 99.20 |
| Sierra Leone | 1.00 | 1.75 |
| Somalia | | 2.00 |
| South Africa | 2007.00 | 2008.60 |
| Sudan | 4.00 | 3.50 |
| Swaziland | 44.75 | 27.80 |
| Togo | | 41.50 |
| Tunisia | 108.20 | 190.80 |
| Uganda | 6.33 | 6.80 |
| United Republic of Tanzania | 1.25 | 3.50 |
| Zambia | 12.80 | 8.40 |
| Zimbabwe | 2.80 | 4.80 |

**Source**: Based on data from the WIPO statistics database (http://ipstats.wipo.int/ipstatv2/index.htm?tab=patent)

**Table 9: Share of global patent applications by filing office (%), 2005-2015**

| | Africa | Asia | Latin America and the Caribbean | Europe | High-income |
|---|---|---|---|---|---|
| **2005** | 0.64 | 50.19 | 2.92 | 19.14 | 80.41 |
| **2006** | 0.71 | 49.68 | 3.02 | 18.60 | 78.28 |
| **2007** | 0.75 | 49.75 | 3.06 | 18.10 | 76.44 |
| **2008** | 0.72 | 50.80 | 3.06 | 17.93 | 74.01 |
| **2009** | 0.66 | 50.88 | 2.79 | 17.43 | 72.62 |
| **2010** | 0.62 | 51.52 | 2.76 | 17.19 | 70.04 |
| **2011** | 0.67 | 54.62 | 2.79 | 15.48 | 65.59 |
| **2012** | 0.62 | 56.06 | 2.69 | 14.67 | 62.64 |
| **2013** | 0.57 | 58.39 | 2.48 | 13.49 | 58.84 |
| **2014** | 0.56 | 59.96 | 2.39 | 12.91 | 56.81 |
| **2015** | 0.51 | 61.85 | 2.27 | 12.46 | 53.45 |

**Source**: Based on data from the WIPO statistics database (http://ipstats.wipo.int/ipstatv2/editIpsSearchForm.htm?tab=patent)

Information and communication technology (ICT) has been identified as another important enabler of innovation. For example, Spiezia (2011) found that it is an enabler of both product and marketing innovation in manufacturing and services. He also found that ICT contributes to innovation through enabling firms to adopt innovation rather than increasing their inventive capabilities. Table 10 shows that significant progress was made in the use of the internet in SSA over the past decade. In the year 2000, the number of internet users in the region per 100 people was 0.5 and by 2015 it had increased to 22.4. Similar increases were also experienced in other regions of the world. For example, in Latin America and the Caribbean the number of internet users per 100 people has increased from 3.9 in 2000 to 54.5 in 2015, and in the Middle East and North Africa it increased from 1.7 to 43.7 over the same period. When compared to other regions of the world, SSA has the lowest number of internet users in 2015 followed by South Asia. North America is the region with the highest number of internet users in 2015 (table 10).

**Table 10: Internet Users (per 100 people), 2000-2015**

| | **2000** | **2005** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** |
|---|---|---|---|---|---|---|---|---|
| Sub-Saharan Africa | 0.5 | 2.0 | 9.8 | 12.1 | 14.6 | 17.1 | 19.6 | 22.4 |
| North America | 43.9 | 68.3 | 72.5 | 71.0 | 75.5 | 72.8 | 74.4 | 75.9 |
| Middle East & North Africa | 1.7 | 9.8 | 24.9 | 27.7 | 31.3 | 34.7 | 39.7 | 43.7 |
| Europe & Central Asia | 13.2 | 35.2 | 56.1 | 58.9 | 63.5 | 66.3 | 69.5 | 71.7 |
| East Asia & Pacific | 5.6 | 14.7 | 34.2 | 37.4 | 40.8 | 44.2 | 46.7 | 49.8 |
| Latin America & Caribbean | 3.9 | 16.6 | 34.7 | 39.3 | 43.2 | 46.3 | 48.8 | 54.5 |
| South Asia | 0.5 | 2.5 | 7.2 | 9.4 | 11.5 | 13.7 | 19.3 | 23.6 |

**Source**: Based on data from the WDI database (http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators)

Africa has also experienced an increase in ICT trade. In the year 2000, the share of ICT goods in total exports of Africa was 0.53 percent and in 2014 it was 0.84. Developing Asia has the highest share of ICT goods in total exports, recording 23.4 percent in 2014. Both developing Asia and developing America experienced a decline in the share of ICT goods in total exports between 2000 and 2014 (table 11).

In sum, over the past few decades modest progress has been made in promoting technology and innovation, as evidenced by the fact that the number of researchers on the continent has increased, patent filings by African countries have gone up, and the number of internet users has also increased. Nevertheless, significant challenges remain. For example, the level of technology and innovation in Africa remains low relative to what is observed in other continents and as well low relative to the development needs of the continent. In addition, there are still very limited resources devoted to R&D, and there is a gender gap in research which needs to be addressed. Also, the internet penetration rate for SSA is very low relative to that of other developing country-regions, thereby making it difficult for the region to fully exploit opportunities which are created by the rapid growth of ICT.

**Table 11: Share of ICT goods as a percentage of total exports, 2000-2014**

| | 2000 | 2005 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|
| Developed Economies | 13.61 | 9.68 | 6.89 | 6.1 | 5.72 | 5.42 | 5.54 |
| Developing Africa | 0.53 | 1.13 | 0.75 | 0.71 | 0.7 | 0.77 | 0.84 |
| Developing America | 11.14 | 7.92 | 7.51 | 6.07 | 6.19 | 6.2 | 6.81 |
| Developing Asia | 27.8 | 25.71 | 23.27 | 20.73 | 21.59 | 21.38 | 23.42 |
| Developing Oceania | 0.23 | 0.24 | 0.21 | 0.14 | 0.19 | 0.48 | 1.77 |

**Source**: UNCTADStat database (http://unctad.org/en/Pages/statistics.aspx).

## 6 Policies to Foster Technological Innovation for Transformation and Inclusive Development in Africa

This paper has argued that structural transformation and inclusive growth are crucial for achieving the SDGs and that promoting technological innovation is necessary to address both, challenges of low structural transformation and inclusive development in Africa. A crucial question therefore is how can African countries effectively promote technological innovation to foster transformation and inclusion and to achieve better development outcomes than in the past? This section highlights some policy measures that African countries could adopt to effectively promote technological innovation in the continent.

*Develop coherent STI policies.* A first step to effectively promoting technology and innovation in Africa is for African governments to develop coherent STI policies. Over the past decade many African countries have either developed or revised their STI policies.[3] However, there is often incoherence between STI policies and other development policies. For example, UNCTAD (2015) reviewed STI policies of three countries (Ethiopia, Nigeria, and the United Republic of Tanzania) and found that there was a lack of coordination between STI and industrial development policies in these countries. Other areas where there is disconnect between STI policies and other development policies include gender and education. It is well-known that technological progress tends to be gender and skill-biased (Naude and Nagler 2015). In particular, new technologies tend to favour skilled workers and men (more than unskilled workers and women), what has negative consequences for income distribution and the quest for inclusive development. Despite the importance of these issues and the associated linkages, STI policies in

[3] In SADC, for example, only three countries (Democratic Republic of Congo, Mauritius and Seychelles) out of the 15 member States did not have an STI policy document in 2014 (UNESCO 2015).

Africa are developed independently of gender policy and educational policy. To enhance policy coherence, there is the need for STI policies to go hand in hand with educational policies geared towards enhancing the skills of unskilled workers and women to enable them to take better advantage of technological progress and to make the growth process more inclusive than in the past. There is also the need for African governments to strengthen efforts to align national and regional STI strategies for better development outcomes.

*Increase domestic expenditure on R&D.* It is a well-known fact that R&D is an important component of any effective package to promote technology and innovation. Yet African countries spend a relatively small percentage of their GDP on R&D (less than 1 percent). In 2014, for example, gross domestic expenditure on R&D as a percentage of GDP was 0.68 percent in Egypt, 0.27 percent in Togo, and 0.64 percent in Uganda. These numbers are far below the 1 percent target set by the African Union (AU), and so R&D expenditure needs to be scaled-up. A related issue is the low investment rates in tertiary education in Africa which is a disincentive to R&D, and this factor also constrains technology transfer through foreign direct investment (FDI). African governments should prioritize tertiary education to stimulate R&D and should also promote knowledge spillovers from foreign to domestic firms. Studies have shown that, when domestic workers have the required skills, this facilitates knowledge spillovers to domestic firms, and this also enhances the local capacity to absorb foreign technology (Farole and Winkler 2014). While we emphasize the need to increase spending on R&D, it is also important to point out that R&D is useful to the extent that it can effectively foster technological learning and the building of innovation capacities in a country. It is therefore important for African governments to pay attention to the kinds of research activities they promote to ensure that they address the technology and innovation needs of the country. Furthermore, in seeking to promote innovation through R&D, there is also the need for governments to have a comprehensive view of innovation in the sense that the focus should not be solely on the product side, but focus should also cover other dimensions of innovation as well (for example, process, marketing and organisational innovation). It is by adopting such a holistic approach to technology and innovation and directing government policy towards promoting the creation, transfer, adoption, adaptation, and diffusion of knowledge that African countries can effectively use technological innovation to foster inclusive development (Oyelaran-Oyeyinka, 2014).

*Strengthen university-industry collaboration*. Universities are major producers of knowledge. But for this knowledge to have impact on diversification and structural transformation, it should address the needs of industry and should be transferred or disseminated to the productive sectors. Unfortunately, in many African countries the educational curriculum is not geared towards addressing the challenges facing industries, resulting in a mismatch between university output and the labour demands of the private sector. One way to reduce this mismatch and to make the growth process more inclusive is to develop effective linkages between institutions of higher learning and the industrial sectors in Africa, through for example, appointing Chief Executive Officers (CEOs) of strategic industries to sit on the boards of universities. This would encourage university administrators to involve the private sector in the design of education curricula in universities. It would also enhance the likelihood that university graduates have the skills they need to access and participate in the labour market. Governments can also incentivise industries to collaborate with universities through, for instance, providing grants for joint research to enterprises and universities which form R&D partnerships.

*Enhance implementation of existing STI policies.* A major challenge facing African countries is the lack of full implementation of policies and plans at both the national and the continental levels. As indicated earlier, many countries have developed an STI policy document over the past decade. Yet, some of these policies have not been implemented. In Lesotho, for instance, several of the policies contained in the National Science and Technology Policy for 2006-2011 have not been implemented. Similarly, in Malawi, the Science and Technology policy framework, revised and adopted in 2002, has not been fully implemented (UNESCO 2015). These facts underscore the need for African policymakers to pay more attention to the implementation of policies than in the past. Some of the measures they can take to enhance implementation of policies include: developing an implementation plan for STI policies; prioritizing data collection and introducing a monitoring and evaluation system; and making appropriate provisions for STI policies in national budgets to ensure adequate funding.

*Promote innovation at the enterprise level.* The creation of an environment conducive to entrepreneurship is necessary to achieve sustained progress in technology and innovation. Governments can unleash the innovation potential of entrepreneurs through providing better infrastructure, building a skilled labour force, and eliminating regulatory obstacles that drive some entrepreneurs into the informal sector. They can also encourage entrepreneurs to innovate through setting up technology parks (of different formats, origins of establishment, and sizes) and providing incentives (such as the establishment of innovation prizes and entrepreneurship awards) to young potential entrepreneurs. While governments have a major role to play in promoting innovation, it is not the responsibility of governments alone. Firms also have an important role to play but they can do so more effectively if they adopt a systemic as opposed to a reactive innovation strategy.[4]

*Increase awareness of intellectual property rights (IPRs).* Lack of awareness of existing IPRs can create a disincentive for firms to invest in R&D, and this can

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[4] Interestingly, in a survey of executives of companies in different regions of the world, it was found that firms can also foster innovation through having a diverse workforce; diversity and innovation are related via various mechanisms (Forbes Insight, 2011).

militate against innovation. It can also make young potential innovators reluctant to innovate for fear that their novel ideas could be stolen, patented and used by potential competitors (Ezeanya 2013). African governments can play a crucial role in addressing this issue by increasing awareness of existing IPRs in their countries, through the organisation of information dissemination events and through exploiting opportunities created by the rapid growth and use of social media. Intellectual property offices in Africa should also be encouraged by governments to play a more active role in facilitating access to information on IPRs, and these offices can also play a role in disseminating technological information in support of local innovative activities.

## 7 Conclusions and Policy Recommendations

This paper examined the state of structural transformation, innovation and inclusive development in Africa and showed that although modest progress has been made in each of these areas over the past decade, more needs to be done to enhance the likelihood that African countries will meet the SDGs adopted by world leaders in 2015. The paper argued that fostering technological innovation is crucial for addressing the challenges of structural transformation and inclusion in Africa. It has also identified and delineated mechanisms through which technological innovation could be linked to transformation and inclusion. Transformation, Inclusion and Innovation are analysed in context. Also, the chapter shows that diversification of African economies depends on domestic policies which pro-actively exploit the interrelationships between Transformation, Inclusion and Innovation.

Finally, the paper made policy recommendations on how to foster technological innovation to trigger transformation and to build inclusive societies on the continent. The policy recommendations discussed in the paper include: developing coherent STI policies; increasing domestic expenditure on R&D; strengthening university-industry collaboration; enhancing implementation of existing STI policies; promoting innovation at the enterprise level; and raising awareness of intellectual property rights.

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# Science, Technology and Innovation (STI) Development in Selected African Countries - A UNESCO Experience Perspective

**Nazar M. Hassan***

## 1 Introduction

Science, technology and innovation (STI) are of critical significance for sustainable development in all its dimensions – economic, social and environmental.[1] Through research, sciences buttress all technological innovation and engineering solutions needed to address contemporary challenges, such as environmental degradation and restoration, water issues, and energy needs. The example of Malaysia is often cited by decision-makers as a developing country that has achieved the desired economic success, thanks in part, to the contribution of S&T. In 1992, the former prime minister of Malaysia, Dr Mahathir Muhammad, announced that the sole objective of the Malaysian S&T policy was to help Malaysia to become fully developed by the year 2020. By 2015, this objective had already been achieved to some extent. Following suit, the scientific and technological communities in the developing countries strongly recommend a paradigm shift to enhance the STI role concerning a practical roadmap that will achieve sustainable development.

Since its creation in 1945 UNESCO was mandated with the development of scientific knowledge and its utilization to spur economic transformation in developing countries.[2] At that time, a strong belief existed that through application of scientific knowledge and technology transfer from the industrialized to the developing countries, it is possible to quickly raise welfare of society and spur economic

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* Regional Adviser, UNESCO Regional Office for Science and Technology for the Arab States, Cairo, Egypt; Professor Karl Wohlmuth from the University of Bremen and Chief Editor of the African Development Perspectives Yearbook has made some editorial extensions, changes and adaptations to the text which are thankfully acknowledged by the author. The ideas and opinions expressed in this article are those of the author and do not necessarily represent the views of UNESCO.

[1] See: Kotchetkov, 2005, web content at http://www.eolss.net/; Chapter on "SCIENCE AND TECHNOLOGY POLICY IN UNESCO: A HISTORICAL OVERVIEW", Summary

[2] See on UNESCO's activities in Africa and for the implementation of the Sustainable Development Goals (SDGs): http://www.unesco.org/new/en/africa/ and http://en.unesco.org/sdgs

transformation of the newly independent countries in need. Developing the science and technology potential and designing a strong STI policy became the important priorities of each government. The fully-fledged programme on Science and Technology Policy was adopted in 1964. The evolution of UNESCO's approaches, operations and formal mandate in science policy can be traced by reference to the science policy resolutions adopted by the UNESCO Bi-annual General Conferences. These programmes contributed in paving the path for the orientation of science towards national socially-oriented outcomes.

Science, Technology and Innovation (STI) policies are most effective when they are closely linked to the political and socio-economic evolution of any state; policies should enable the state to forge a set of institutions and processes to cultivate scientific and technological endeavour that is needed to contribute to its national development. This is evident when reviewing the chronological history that accompanied the evolution of STI policy around the globe:

1. There was first the need for Science Policy linked to the necessity of doing good science;
2. Then Science Policy evolved into Science & Technology (S&T) policy, linking knowledge (science) to its application (technology);
3. The "Science for Technology for Development" policy then became the focus to harness S&T for national development; this gave rise to S&T for development and the development of science by measures to strengthen the S&T capacity;
4. The STI policy started to focus on the means to translate science into innovative technologies in the marketplace, making STI a part of the economic transformation process/system; i.e. Science for Policy and Policy for Science notions were adopted.

While the above has been the general theme for STI policy design and utilization, the creation of technological districts, for example in the early 1960s and largely through the 1970s, occurred spontaneously; this was not a result of the active promotion of technology policies. The famous case of Silicon Valley was quickly taken as an ideal for further policies in this direction. Usually created around some university or large research facilities, technological districts are exploiting the "positive externalities" created by the close connection of firms in the same region. Technological interactions in a single region can be created between firms that are linked as sub-contractors of some larger organization or, more generally, in a pattern of linkages established between users and providers of a given technology. And, the circulation of the technological and economic information in a region creates technological opportunities for production and specific demands for training and technological equipment.

This paper aims to provide a synthesis of the key characteristics of the science, technology and innovation (STI) national platforms in selected countries in Africa. The different sub-regions of Africa have generally failed to catalyse knowledge production effectively or to add value to products and services. Some of the failures were: insufficient government commitments for STI and research, including financing of technology and capacity; a disconnect between policymakers, scientists and society in generating, sharing and utilizing scientific knowledge; poorly designed national STI policies and/or lack of adequate organizational capacities to implement policies; and ineffective government measures to ease doing business. These factors have exacerbated the cycle of marginalization of the science communities in these countries. This paper tries to answer the questions why it is that in most cases developing countries, especially in Africa, are falling behind in efficiently utilizing the STI platform, and how the STI agenda and related policies could become robustly effective to reap the socio-economic development objectives desired in these countries. In section 2 after the Introduction the STI Policies in Africa are reviewed. Section 3 presents various case studies of African STI development. Section 4 is on shortcomings of STI development in Africa. Section 5 is devoted to preconditions for sustainable STI policies in Africa. The paper concludes in section 6 with a set of "must-have" national mechanisms to patch these deficiencies towards knowledge-based economies.

## 2 STI Policies Development in Africa

### 2.1 Historical Background

Probably the most known UNESCO activities in the field of science and technology policy in the late 1970s were the regional ministerial conferences. These conferences were regarded as important fora for information exchange between the countries of one region and as vehicles for the general political recognition of the importance of science and technology to national development. Through promoting the application of scientific knowledge and technology transfer from the developed to the developing countries, these conferences supported the Member States to begin the development of their STI potential by devising a strong STI policy as an important priority for building their welfare.

One of the achievements after the first Conference of Ministers Responsible for the Application of Science and Technology in Africa (CASTAFRICA I) was the establishment of the African Network of Scientific and Technological Institutions (ANSTI) in January 1980. It was a network conceived by UNESCO to facilitate the cooperation among African institutions for national capacity building in science and technology. The purpose was to help African universities and research organizations engaged in training and research to establish such linkages among themselves to enable them to pool together their human and material resources, and thereby to contribute more effectively to the application of science and technology for the development in Africa. The network disseminated information on

S&T activities to ninety-one faculties of science and engineering in thirty-three African countries.[3] Among the important activities of ANSTI was the identification of strategic issues of scientific and technological education in Africa. Some observers considered that it was probably the biggest scientific regional network in the world in terms of the number of countries involved and the intensity of the activities carried out.

During the period 1988-1993, UNESCO's Science & Technology Policy Programme (STP) evolved into a Programme on Science, Technology and Society (STS), with the following main components:

1. Promoting scientific and technological cultures in society, which included the organization of the first World Conference on Science Journalists and of the international seminars on planning science museums;
2. Assisting in the management of science and technology policies and training of personnel, with emphasis on the provision of policy advice and the establishment of regional networks for training and research in this field; and
3. Emphasizing Science Ethics; the programme for the Ethics of Science and Technology was entrusted to UNESCO's Sector for Social and Human Sciences in 2000.

In the early 1990s, worldwide consensus has been built that science and technology are the main drivers of industrial, economic and social development, and that university-industry linkages are vital to this process. UNESCO's University-Industry-Science Partnership (UNISPAR) programme was launched in 1993 to improve the quality of universities in developing countries and for encouraging them to become more involved in the process of industrialization of their country. The UNESCO General Conference, which brings together all of UNESCO's Member States every two years to approve the programme and budget for the coming biennium, decided at its 27th session in 1993 to terminate the Programme on Science Technology and Society.[4] The main reason cited was the need to concentrate UNESCO's resources on a smaller number of priority areas. The same General Conference, however, adopted a resolution inviting the Director-General to promote the reflection in UNESCO's programme of the questions relating to science, technology and society. The Director-General at that time, Federico Mayor, nominated a group of experts to advise him on the issue. This group submitted its

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[3] See: Kotchetkov, 2005, web content at http://www.eolss.net/; Chapter on "SCIENCE AND TECHNOLOGY POLICY IN UNESCO: A HISTORICAL OVERVIEW", Section Four

[4] See: Kotchetkov 2005, web content at http://www.eolss.net/; Chapter on "SCIENCE AND TECHNOLOGY POLICY IN UNESCO: A HISTORICAL OVERVIEW", Section Seven

conclusions in July 1994. It recommended that '…steps be taken as soon as possible to launch a programme on science and society, including the allocation of resources and the establishment of an appropriate supporting structure, so that it can be fully operational in the next medium-term plan for 1996 to 2001'.

Ultimately, it was in 2002 that the Division of Science Analysis and Policies came into being, thereby heralding the re-entry of UNESCO to the international science policy community. Today, the programme is helping universities in developing countries to forge partnerships with industry, and to strengthen their capacity for innovation, so that they can embrace the knowledge economy and sustainable development. UNESCO has also substantively contributed to Africa's Science and Technology Consolidated Plan of Action within its African STI Policy Initiative (2008-2013), by involving: an assessment of the status of S&T policy formulation in Africa; technical advice and support for national STI policy reviews; development of common African STI Development indicators; creation of an African STI Observatory; and the launch of a pilot science park in Africa.

Today, UNESCO contributes to many international STI policy initiatives, working in close collaboration with other UN agencies and development organizations, such as the UN Commission on Science and Technology for Development (UN-CSTD), the Organization for Economic Cooperation and Development (OECD), the United Nations Conference on Trade and Development (UNCTAD), the World Bank, the Swedish International Development Cooperation Agency (SIDA), and the International Development Research Centre (IDRC). In recent years, UNESCO has collaborated with sister agencies and other partners on assessments of the science policy systems in Botswana, Congo, Nigeria, Morocco, among others. The period of 1993-2002 has also given leeway to many international organizations to the STI arena to work solo on offering technical support to the different member states in different capacities. UNESCO is collaborating with other UN organizations towards STI development in Africa.

As one of the main UN organizations giving socio-economic support to the African Continent, United Nations Economic Commission for Africa (UNECA) works with the African Member States to promote the use of science, technology and innovation (STI) to achieve sustainable socio-economic development in Africa.[5] The STI Programme offers policy advice on new and emerging trends and technical assistance in designing policies, measures and projects to promote, nurture and harness Africa's creative minds and entrepreneurial talents. The programme benefits from the expertise and the inputs of the members of the Science

[5] See: http://www1.uneca.org/istd/sti.aspx

and Technology Advisory Group (STAG), the Committee on Development Information Science and Technology/CODIST[6], and the Science with Africa Conference[7], among others.[8] UNECA has also been involved in the production of the Africa Science, Technology and Innovation Review (such as for 2013) that is intended to provide sound data and evidence to enable member States to make informed policy decisions in the areas of science, technology and innovation as drivers of economic growth.[9] The review is also designed to be a powerful and useful resource for researchers, analysts, civil society, and media wishing to understand the levels of technological and industrial development as well as to inspire national, regional and international agencies and other organizations to collect and share data to help policy-making in this key area. The Review series highlights some examples of strategic policy designs, implementation and evaluation drawn from within and outside Africa that can be used to unleash such a transformation of the continent. Africa is perhaps the continent that most needs science and technology to meet its education, energy, food, health, and employment challenges, among others, within its limited resources.

UNECA is also the convener of the Senior Experts Dialogue (SED) on Science, Technology and Innovation and the African Transformation Agenda.[10] The "Senior Experts Dialogue on Science, Technology and Innovation and the African Transformation Agenda" is an initiative of the United Nations Economic Commission for Africa (UNECA), designed to support Member States to leverage science, technology and innovation (STI) to drive the structural transformation of their economies. The impetus for the SED comes from two principal sources: a) the general recognition that most of Africa's development challenges are amenable to resolution through the careful and purposeful application of STI; and b) the recognition by the international community that STI is an important means of implementation of the outcomes of recent UN summits, including the Addis Ababa Action Agenda of the Third International Conference on Financing for Development; Rio+20; the United Nations 2030 Agenda for Sustainable Development (SDGs); the Istanbul Programme of Action for Least Developed Countries; and the African Union's long-term plan for the structural transformation of the continent – Agenda 2063 (African Union/AU 2014), along with the continental Science Technology and Innovation Strategy for Africa 2024 (Science Technology and Innovation Strategy for Africa/STISA 2024). That, among other things, is aimed

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[6] See: http://repository.uneca.org/codist/

[7] See: http://www.uneca.org/sciencewithafrica/main.html; see also about the conference: http://allafrica.com/stories/200801220001.html

[8] See: http://www1.uneca.org/istd/sti.aspx

[9] See: http://www.uneca.org/publications/africa-science-technology-and-innovation-review-2013

[10] See: http://www.uneca.org/sed-sti2016

to help African countries identify the main opportunities and challenges at different policy and organizational levels for leveraging and maximizing the drive innovation and invention.

Building on the experience of the implementation of the African Information Society Initiative (AISI) and the African Innovation Framework (AIF), UNECA is focusing on assisting African countries and Regional Economic Communities (RECs) in the formulation, adoption and implementation of new technology and innovation policies. All this will help them to accelerate the transformation process to improve the competitiveness of their firms, the welfare of their citizens, including ensuring their collective and individual security.[11] UNECA also conducts research on national and regional innovation systems, technology transfers, and on new and emerging technologies likely to support economic transformation; this is taking place in key areas such as agriculture and social service delivery, where innovations and new technologies can support economic transformation and human resource development.

Despite of the fact that it has been a UN Conference since its inception, UNCTAD was among the first UN entities to indulge in the STI policy arena at the time when UNESCO's STI programme seized to exist in 1993.[12] Today, UNCTAD has various programmes that tackle STI policies in the different member countries from different lenses and perspectives. UNCTAD's work in STI Policy for Development focuses on supporting the integration of STI Development into national development strategies and building-up a stronger STI policy-making capacity in developing countries. Activities are implemented in collaboration with other UN entities, multilateral development institutions, and national counterparts. The programme of Science, Technology and Innovation Policy Reviews is its main instrument in this area, which is complemented with other capacity-building programmes. Some of the STI review reports have specific areas of focus. For example, in one report the focus was on the contribution to the sustainable urbanization discourse by addressing the specific role of science, technology and innovation.[13] It is based on literature review and an analysis of cities in developed and developing countries that provide examples which can be reapplied elsewhere. In another report, the focus was on the transfer of technology and on knowledge-sharing for development; this report addressed important STI issues for developing countries.[14]

Among the many international organizations being involved in promoting STI for development, the African Development Bank (AfDB) has also been engaging

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[11] See: http://www.uneca.org/pages/about-innovation-technology

[12] See: http://unctad.org/en/Pages/DTL/STI_and_ICTs/STI4D.aspx

[13] See: http://unctad.org/en/pages/newsdetails.aspx?OriginalVersionID=991

[14] See: http://unctad.org/en/pages/PublicationWebflyer.aspx?publicationid=1093

with various African countries to support the Higher Education, Science and Technology (HEST) systems in terms of human capital skills development and capacity building — particularly in education, science and technology — to respond to labour market demands, and to spur productivity nationally. The AfDB is currently implementing such a project in Uganda, and this venture involves six public universities (including Mbarara University of Science & Technology/MUST and two degree-awarding tertiary institutions).[15]

Co-organized by the African Development Bank (AfDB), the African Union (AU), the United Nations Economic Commission for Africa (UNECA), and the Association for the Development of Education in Africa (ADEA), UNESCO in 2012 did organize the first Africa Forum on Science, Technology and Innovation (STI) being held in Nairobi, Kenya.[16] Among the main objectives of the Forum, the stakeholders aimed at:

- Supporting African countries by providing a forum for the exchange of knowledge and ideas on STI, bringing together key stakeholders and experts in the field to present latest research results and important programmes;
- Creating an Africa-focused global network of development innovators and problem solvers;
- Reinforcing North-South and South-South collaboration in STI;
- Strengthening public-private partnerships between governments, industry and technology companies; and
- Fostering regional cooperation on STI among higher education institutions to cater to an increasingly demand-driven education system;

Two years later, the African Development Bank (AfDB) and its partners again organized the second Ministerial Forum on Science, Technology and Innovation (STI) in Africa, in Rabat, Morocco.[17] The Forum gathered over 40 Ministers of Higher Education, Science and Technology, and successfully put STI at the centre of a policy dialogue in Africa, this to achieve the following main objectives:

1. Showcasing global best practices and innovations in Water, Energy, Natural Resources, Education, Health, Agriculture, and Climate Change;
2. Making informed choices about applications of ICT to improve development effectiveness;

[15] See: https://www.afdb.org/en/projects-and-operations/project-portfolio/p-ug-iad-001/ and http://www.must.ac.ug/afdb-hest

[16] See: https://www.afdb.org/en/news-and-events/afdb-organises-the-first-africa-forum-on-science-technology-and-innovations-sti-for-youth-employment-human-capital-development-and-inclusive-growth-8263/

[17] See: https://www.afdb.org/en/news-and-events/rabat-to-host-2nd-ministerial-forum-on-science-technology-and-innovation-in-africa-13358/

3. Developing skills (especially in science, technology, engineering and mathematics/STEM, teaching/reading, and job creation); and
4. Building strategic partnerships to move the STI agenda forward.

The Food and Agriculture Organization (FAO) has also been supporting many new programmes to investigate the best modalities for how science, technology and innovation are supporting sustainable development in agriculture and natural resources management.[18] To be able to achieve its mandates, FAO makes STI to reach their full potential, and this can only be achieved by developing STI to be adaptable to the specific needs of different communities. It needs to build up from local systems and from the knowledge that exists in local communities. It is also essential to build partnerships with the communities, the civil society, the private sector, the governments, and other actors and stakeholders. For example, FAO has gone into partnership with various farmers' foundations, and the partnership supports the delivering of smartphones and the relevant capacity-building for farmers to be able to access information which is specifically tailored to family farmers on agricultural technologies and practices, animal and crop production, food prices, weather conditions, and other issues. Technology also allows them to share their knowledge with other farmers. In another example, at COP 21 (21st Conference of the Parties) in Paris, FAO and Google launched a strategic partnership on remote sensing. One of the results of this partnership is the integration of Google Earth to improving environmental monitoring instruments such as the Open Foris FAO-led Initiative[19]. This is a set of open-source software tools which facilitate flexible and efficient data collection, analysis and reporting. Another major area that FAO is working on is to facilitate the utilization of STI to achieve gender parity through making available greater opportunities for rural women's empowerment. In collaboration with the AfDB, FAO has been developing an Action Agenda for Science, Technology and Innovation (STI) in driving an Agriculture-led Economic and Social Transformation of Africa, through properly identifying the role of science, technology and innovation (STI) in ensuring food security by 2030 and as well the technology means needed to implement it.

For the New Partnership for Africa's Development (NEPAD) and the STI Observatory which it had been developing and maintaining, the African Union Commission (AUC)[20] has launched five Science, Technology and Innovation (STI) hubs across universities in Africa, which will focus on specialised areas to drive

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[18] See: https://www.afdb.org/fileadmin/uploads/afdb/Documents/Events/DakAgri2015/An_Action_Agenda_for_Science_Technology_and_Innovation__STI__in_driving_an_Agriculture-led_Economic_and_Social_Transformation_of_Africa.pdf

[19] See: https://www.google.de/search?q=Open+Foris+&ie=utf-8&oe=utf-8&client=firefox-b&gfe_rd=cr&ei=yAM9WamYLO7G8Aft8a_QDw

[20] See: https://www.au.int/web/en/commission

the socio-economic sector and development on the continent.[21] These centres have been decided at the Jomo Kenyatta University Of Agriculture And Technology (JKUAT) in Nairobi[22], which will focus on STI, while the University of Ibadan (UI), Nigeria, will cater for Life and Earth Sciences. The others will be the University of Yaoundé, Cameroon, another one in the Southern Africa region, and the University of Algiers in Algeria for the Northern Africa region.[23] NEPAD has also been the main driver behind the development of the Science, Technology and Innovation (STI) Strategy for Africa for the year 2024.

The World Bank has also initiated a project that involves a series of STI reviews in developing countries. The project, whose activities are occasionally undertaken in collaboration with the OECD, aims at strengthening the STI system in the targeted countries that between 2014 and 2017 included Colombia, Vietnam and Peru.[24] For different countries, the focus is quite different to match the national requirements and the needs of the STI system. For example, in the case of Colombia, the review focused on strengthening the capacity of the Administrative Department of Science, Technology and Innovation (COLCIENCIAS) to promote human capital for the knowledge economy, especially for research and development (R&D) and innovation; and to raise the awareness of science, technology and innovation in the Colombian society. In the case of Peru, the project focused on mechanisms to improve research skills and firm-level innovation capabilities. In the case of Vietnam, the review focused on looking at the key elements, the relationships, and the dynamics that drive the Vietnamese innovation system and the opportunities to enhance it through government policy. For African countries, such an analytic approach may be highly relevant too.

In 2015, the Inter-Agency Group, comprised of UNDESA, UNEP, UNIDO, UNESCO, UNCTAD, WIPO, ITU, and the World Bank Group, resolved to support the building of the national STI capacity, and to facilitate technology development, transfer and dissemination for inclusive sustainable development.[25] The initiative was launched in response to the high level of importance attributed to STI Development in the emerging Addis Ababa Accord (AAA), both as means of implementation for realizing the future post-2015 sustainable development agenda (SDA), and as objectives in their own right. Innovative and affordable technology solutions will have to be harnessed at an unprecedented scale to eradicate poverty and achieve sustainable development by the year 2030.

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[21] See: http://www.nepad.org/content/nepad-agency-set-science-technology-and-innovations-sti-hubs-across-five-universities

[22] See: http://www.jkuat.ac.ke/

[23] See: http://www.nepad.org/content/nepad-agency-set-science-technology-and-innovations-sti-hubs-across-five-universities

[24] See: http://projects.worldbank.org/P117590/science-technology-innovation?lang=en

[25] See: http://en.unesco.org/news/agencies-join-forces-promote-science-technology-and-innovation-reaching-new-development-goals

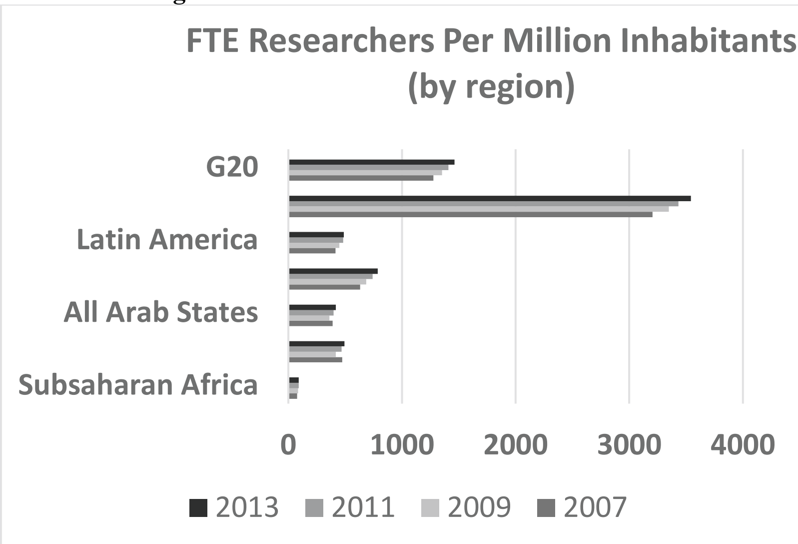
## 2.2 Status Quo of STI Development in Africa

In the 1970s, many African countries had been fully involved in setting up national policy mechanisms for science and technology and in developing explicit national science and technology policies. Côte d'Ivoire, as an example, set up a Ministry of Scientific Research (MoSR) in 1970, while Senegal had created a General Directorate for Scientific Research and Technology (DGRST) by 1974. Ethiopia's Science and Technology Commission (ESTC) was established in 1975, while Ghana, Mali, and Niger had all set up their national research councils (NRCs) by the end of the 1970s. Somalia inaugurated an Academy of Sciences and Arts (AoSaA) in 1979. However, the efforts to develop an African scientific and technological potential have fallen short of expectations. The dormancy of governmental efforts may be ascribed mainly to unfavourable economic conditions, lack of finance, absence of long-term commitments on the part of political forces and, sometimes, and to a rather superficial understanding of the role of science and technology in the socio-economic transformation of society.

The first Conference of Ministers Responsible for the Application of Science and Technology in Africa (CASTAFRICA I) was held in Dakar, Senegal in January 1974.[26] One of the 86 recommendations, adopted by CASTAFRICA I, to give an example, urged the African States to take measures needed to attain, if possible, before 1980, the target of between 1,000 to 2,000 scientists and engineers per million inhabitants; of them 10 percent (100-200 persons) should be engaged in R&D activity. Yet, statistical evidence indicated that this target had never been reached. The average number of African specialists engaged in research and development (R&D) activities in 1980 was of an order of 45 persons per million inhabitants only. Another CASTAFRICA I recommendation, which called upon the African States to devote by 1980 one percent of their Gross National Product (GDP) to R&D and to scientific and technological public services (STPS), has also proved difficult to achieve. In fact, it was only 0.36 percent in 1980. Today, the situation is not much different in terms of both, the number of full-time equivalent (FTE) researchers per million and/or the Gross Expenditures on R&D (GERD), as a percentage of GDP, as depicted in figures1 and 2 respectively

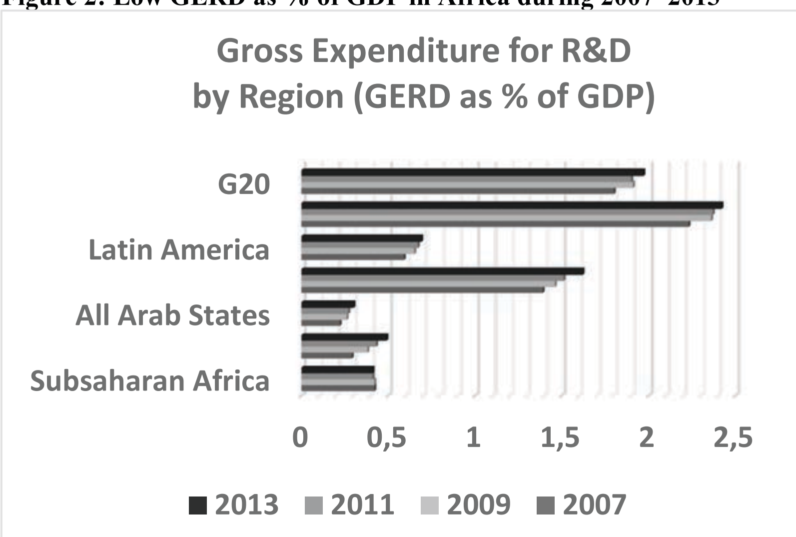
[26] See: Kotchetkov, 2005, web content at http://www.eolss.net/; Chapter on "SCIENCE AND TECHNOLOGY POLICY IN UNESCO: A HISTORICAL OVERVIEW", Section Four

**Figure 1: Stagnant Low Levels of FTE Researchers per Million Inhabitants in Africa during 2007–2013**




**Source**: UNESCO Science Report 2015

**Figure 2: Low GERD as % of GDP in Africa during 2007–2013**




**Source**: UNESCO Science Report 2015

A study which was undertaken by UNESCO in 1981-1982 in West Africa revealed that many of the national science policy-making bodies, though in existence for many years, had not been able to perform the functions for which they were created.[27] Reasons were the lack of qualified personnel, of equipment, and of financial resources. CASTAFRICA II was held in Arusha, Tanzania from 6 to 15 July 1987, thirteen years after CASTAFRICA I. By then, 18 African nations had already established national science and technology policy bodies at the ministerial level. However, such an increase in numbers does not necessarily imply adequate efficiency levels. Some countries established science policy bodies without having any scientific tradition or even a scientific infrastructure.

All African countries suffered from the absence of reliable social, cultural and economic data which are indispensable for a realistic science policy; that made it difficult to undertake efficient planning of scientific and technological activity.[28] Despite of continuous efforts from the side of institutions such as the UNESCO Institute of Statistics (UIS) and the African Observatory for Science, Technology and Innovation (AOSTI), Africa's ability of measuring and monitoring science, technology and innovation (STI) information is still underdeveloped; in some cases information is generated through estimates of STI data which are based on indirect forms of measurement, such as in the areas of technology-related use, trade and investment, and education and training. The absence of a robust common set of STI Development Indicators has also limited the continent's ability to make evidence-based decisions regarding STI development. And, although the Frascati Manual recommends the collection of primary data through direct surveys, many of these countries have adopted the use of secondary data from national budgets and budgetary records of public R&D performing units.

In the case of North Africa, the Conference of Arab Ministers Responsible for the Application of Science and Technology to Development (CASTARAB I) that was held in Rabat, Morocco in August 1976 concluded the first round of the UNESCO regional ministerial conferences. CASTARAB I was organized by UNESCO with the co-operation of the Arab League Educational, Cultural and Scientific Organization (ALECSO).[29] The Conference brought together ministers (though they all were from the educational field) from 18 Arab States, and called upon the strengthening of regional cooperation; they also outlined some scientific programmes and adopted a resolution in which it was proposed to establish an

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[27] See: Kotchetkov, 2005, web content at http://www.eolss.net/; Chapter on "SCIENCE AND TECHNOLOGY POLICY IN UNESCO: A HISTORICAL OVERVIEW", Section Four

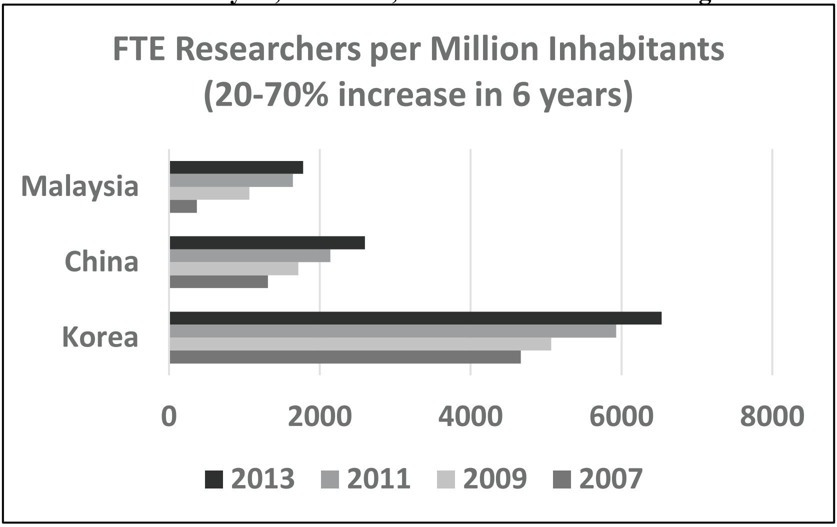
[28] African Observatory for Science, Technology and Innovation (AOSTI); http://aosti.org/index.php/actualites/55-astii-aosti-policy-brief-series-july-2013-no-02-monitoring-africa-s-progress-in-research-and-experimental-development-r-d-investments

[29] See: UNESCO/ALESCO/ECWA 1976

Arab Fund for financing scientific research. A target of $ 500 million dollars was set for this purpose. A working group was entrusted to carry out a feasibility study for this fund. Although the well-grounded feasibility study came up with positive conclusions, the Fund had never been implemented, not because of a lack of funds, but rather owing to a lack of political will. Furthermore, despite of intensive preparations made by UNESCO, the Cast-Arab Continuing Committee (CCC) and the CASTARAB II never came up and took place for similar reasons. This fiasco is one of the reasons why by the end of the 1980s very few Arab countries had national science and technology policies. Only Egypt and Iraq had formulated five-year plans of science and technology strategies, while Sudan has formulated its 10-year S&T Strategy and its S&T Plans. Most other countries in the Arab States region did not have national research plans for science and technology, as they were lacking the required policies and the necessary strategies for this field at the time.

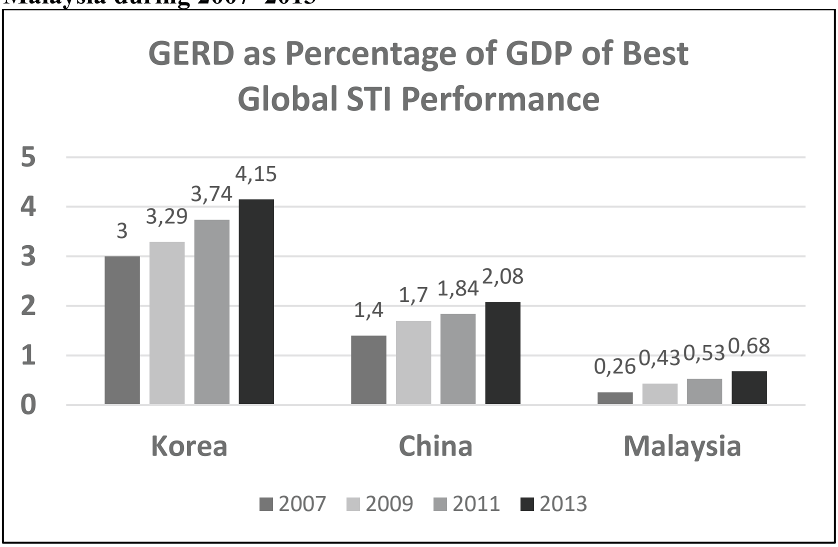
As investment in research and innovation is a policy choice, this type of investment is greatly affected in countries where the State has a control over the research circles. The political control of the knowledge sphere in many countries in the region has diminished the role of science and technology and its contribution towards achieving sustainable development and building the knowledge-based economy. This is not the case with countries, for example, such as China, South Korea, and/ or Malaysia, which are demonstrating a long-term commitment to research and development, and where multiple national actors/ enterprises are seriously engaged in research, development and innovation. A good national R&D system will usually possess a wide range of specialists and a substantive level of research diversification, a significant portion of which is typically related to experimental development activities. Figures 3 and 4 illustrate how countries such as China, South Korea and Malaysia have succeeded in building robust R&D programmes through both, a “critical mass of researchers” and a “critical mass of investment”. Both factors matter for a strong and diversified R&D system and for an expanding and sustainable STI infrastructure.

**Figure 3: Increase in the Number of FTE Researchers per Million of Inhabitants in Malaysia, China, and Korea during 2007–2013**




**Source**: UNESCO Science Report 2015

**Figure 4: Consistent Increase in GERD as % of GDP in Korea, China and Malaysia during 2007–2013**




**Source**: UNESCO Science Report 2015

Many of the African countries face common problems and constraints when it comes to the STI platform. Much STI Development Investment in many of these countries has been made during the last three decades for building the national infrastructure to produce goods and services, and indeed visible progress has been made in the various infrastructure subsectors. However, the rate of progress remains small due to various built-in inefficiencies of the development process which are mainly due to the weakness of the indigenous capacity in science and technology and the weak linkages to the production and service sectors, which resulted in the technological dependence of these countries on external sources. As a result, the levels of technical know-how which are applied in production remain low, leading to small rates of technological progress and economic growth.

Many recent reports have indicated that some countries are losing their winning ticket to development and progress; the motives may be economic or political, but the result is the same. There is an exodus of experts and researchers from countries which have spent millions of dollars at educating them. The biggest migratory flows from Africa to the United States are from Egypt, Ghana, and South Africa, with more than 60 percent of the immigrants from those three countries having a tertiary education, while migration of Africans with only a primary education is almost nil.[30] Researchers are not the only ones fleeing these countries, and there is no reason for them to remain hostages of governments which do not care for them or do not know how to use their talents. And if scientists will seek greener pastures to exercise their talents, it is the governments' task to offer better conditions to retain their technical workforce and their research staff. In many of these countries, there is a lack of a well-functioning innovation system with a clear governance and policy framework, compounded by a poor ICT infrastructure that hampers access to information and limits opportunities to create knowledge and wealth.

The transformation of the African countries into science-based societies is hence a long and a difficult process; however, some efforts can be made through national programmes for the popularization of science, especially among the youth all through their education years. Much experience has been accumulated elsewhere in this field, and the region can benefit from this experience through training of multipliers and the exchange of information on how to accelerate the popularization of the science process through the educational system. Supporting such endeavour with national large-scale projects is needed and is possible as country cases in Africa show.

It should be also noted that there is more to developing a national innovation system than putting in place material institutions. Intangible considerations and

[30] Carrington, W. and Detragiache, E.: How Extensive Is the Brain Drain?, Finance & Development Journal; Volume 36, Number 2; A quarterly magazine of the IMF June 1999

values are vital, too. These include transparency, rule of law, intolerance of corruption, reward for initiative and drive, a healthy climate for business, respect for the environment, and the dissemination of the benefits of modern science and technology to the general population, including the under-privileged. Employability and placement in public institutions should depend solely on the expertise and seniority of the individual, rather than on political considerations.

Hassan et al. (2016: page 466) concluded that the poor state of the innovation systems in the Arab States, and similarly in Africa, can be attributed to the following main factors:

1. Despite the Heads of State having committed to raising the GERD share to 1% of GDP more than 25 years ago, not a single Arab country has yet reached that target, leading to the region's low spending levels on R&D as illustrated in Figure 2;
2. Many countries are embracing the notion of economic diversification without building a critical mass of experts, technicians and entrepreneurs, while they currently possess a relatively small pool of qualified experts and research scientists and engineers;
3. The skills given to the graduates are a clear mismatch with labour market demand, causing employability problems among tertiary graduates and leaving the market without skilled labour;
4. In most countries, the education system is still not turning out graduates who are motivated to contribute to a healthier economy, while a relatively small number of tertiary students are enrolling in scientific disciplines;
5. Higher education curricula are mostly fact-heavy and lecture-based, with a limited use of ICT tools and hands-on learning and little contextualization; such an environment favours students' ability to memorize knowledge and curriculum content rather than enhancing their ability to develop the necessary analytical skills and the creativity to innovate; and the higher education teachers are not really facilitators in the learning process.

All this requires that a more inclusive STI development process is envisaged but based on clear objectives of STI development and the identification of country-specific factors of the prevailing national innovation system (NIS).

## 3 STI Opportunities and Challenges in Selected African Countries

The events of the past few years in North Africa may have stirred the cooking pot but real progress will only be measured against collective structural change at the economic, social and political levels. From the examples of the following country profiles, we can see that some countries are losing their winning ticket to development and progress; the motives may be economic or political, but the result is the same. These countries see an exodus of experts and researchers, although they have spent millions of dollars for educating them. Researchers are not the only ones fleeing these countries; as well entrepreneurs leave the countries. There is no reason for them to remain hostages of governments which do not care for them or do not know how to use their talents. And, if scientists and entrepreneurs will seek greener pastures to exercise their talents, it is the task of the governments to offer better environmental conditions and remunerations to retain their technical workforce, their researchers, and their entrepreneurs. In many of these countries, there is a lack of a well-functioning innovation system with a clear governance and policy framework, compounded are these problems by a poor ICT infrastructure which hampers access to information and limits opportunities to create knowledge and wealth.

## 3.1 STI Development in East and Central Africa[31]

Half the region is 'fragile and conflict-affected', whereas other development challenges for the region include civil strife, religious militancy, and the persistence of killer diseases such as malaria and HIV, which sorely tax national health systems and economic productivity. Poor governance and corruption undermine economic activity and foreign investment in several countries. Interestingly, both the indices of the Transparency International's Corruption Perceptions Index and of the Ibrahim Index of African Governance consider Rwanda as having the best governance record in East and Central Africa. The following represents the latest STI development account in selected countries in East and Central Africa.

*STI Development in Cameroon*[32]
In September 2007, the National Agency for Information and Communication Technologies[33] published the National Policy for the Development of Information and Communication Technologies (Republic of Cameroon, 2007). The policy's implementation has nevertheless been hampered by a lack of financial resources, the inadequate synergy between the government and external partners, and the weak state capacity for project management. Between 2007 and 2013, internet penetration spread only from 2.9% to 6.4% of the population. Despite this, two innovation hubs have been set up in recent years. The government is also supporting companies and is fostering linkages between research and professional communities, to develop an indigenous ICT sector to realize the country's Vision 2035, which was adopted in 2009, with the main aim to turn Cameroon into a newly

[31] See the evidence in the UNESCO Science Report 2015, Chapter 19: Urama et al. 2016: pages 498-533
[32] See on Cameroon: Urama et al. 2016: pages 517-518
[33] See: http://www.antic.cm/

industrialized country by 2035. It is anticipated to achieve this by raising the share of manufacturing from 10% to 23% of GDP (it had almost reached 14% by 2013), and by raising investment from 17% to 33% of GDP to drive technological development, while raising the share of secondary and tertiary students specializing in S&T subjects from 5% to 30%. However, all these data on objectives are based on plans, expectations and ideas and wait for implementation.

*STI Development in Ethiopia*[34]

For the past decade, Ethiopia has enjoyed some of the fastest economic growth in Africa among agrarian economies. The government is now focusing on modernization and industrialization to realize its ambition of turning Ethiopia into a middle-income economy by 2025. The government efforts are focused on sustainable technology transfer in medium and large-scale manufacturing industries to improve their export capacity, fostered through privatization and measures to attract foreign investors. By 2012, this sub-sector had registered growth of 18.6%, close to the target of 19.2%. There was a 13.6% growth in value-added industrial production by 2012, but export earnings from textiles, leather goods, pharmaceuticals and agro-processing sub-sectors have been disappointing. This was due to factors such as low productivity, inadequate technological capability, a lack of inputs, and other structural problems.

Policy has been revised and made operational since 2010. So far, the GERD/GDP ratio has risen to 0.61% of GDP in 2013, according to the UNESCO Institute for Statistics, which also reported a steep increase in the proportion of women researchers from 7.6% to 13.3% between 2010 and 2013. Currently, two programmes stand out, namely the National Priority Technology Capability Programmes which were launched in 2010 in the areas of agricultural productivity improvement, industrial productivity and quality programmes, biotechnology, energy, construction and material technologies, electronics and microelectronics, ICT, telecommunications and water technology; and the ongoing Engineering Capacity-Building Programme which was launched in 2005, and which is jointly financed and implemented by the governments of Ethiopia and Germany within the Ethiopian–German Development Co-operation. Priority sectors include textiles, construction, leather, agro-processing, pharmaceuticals/chemicals, and metal. In 2014, it was decided to support universities which are specializing in science and technology, especially those universities which have already ties with industry. This is done under the umbrella of the new Ministry of Science and Technology and is aimed to promote innovation in academia and to stimulate technology-driven enterprises. The first two universities in Addis Ababa and Adama were

[34] See on Ethiopia: Urama et al. 2016: pages 520-521

transferred from the Ministry of Higher Education in 2014 to the Ministry of Science and Technology. However, Ethiopia awaits more in concrete terms of STI strategy building.

*STI Development in Kenya*[35]

STI policy in Kenya has been given a major boost by the Science, Technology and Innovation Act which was passed in 2013. The Act contributes to the realization of the Kenya Vision 2030, which foresees the country's transformation into a middle-income economy by 2030, then endowed with a skilled labour force for sophisticated production. Kenya already hosts several hubs for training and research in life sciences, including the Biosciences Eastern and Central Africa Network and the International Centre for Insect Physiology and Ecology. In line with Vision 2030, Kenya is participating in the East Africa's Centres of Excellence for Skills and Tertiary Education in Biomedical Sciences programme[36] which is supported by the AfDB. Flagship projects within Vision 2030 include the following:

- Five industrial parks are being established for small and medium enterprises (SMEs) in key urban centres, the majority in agro-processing;
- The Nairobi Industrial and Technology Park is being developed within a joint venture with Jomo Kenyatta University of Agriculture and Technology;
- Konza Technology City is under construction in Nairobi; and
- Geothermal energy is being developed in the Rift Valley, within a programme to increase energy generation to 23,000 MW by mobilizing private capital for the development of renewable energy.

Nairobi is also home to the African Network of Scientific and Technological Institutions (ANSTI), an NGO hosted by UNESCO since its inception in 1980. ANSTI awards PhD and Master scholarships and travel grants. Since 2010, ANSTI has awarded 45 L'Oréal-UNESCO Fellowships for Women in Science to foster research and innovation. Nairobi is also home to m:lab East Africa[37], which provides a platform for mobile entrepreneurship, business incubation, developer-training and application-testing. The Act has further empowered the National Commission for Science, Technology and Innovation (NACOSTI)[38] to establish advisory research committees to counsel the Commission on specific programmes and projects, to maintain a database of these, and to foster R&D and education in

[35] See on Kenya's STI policy: Urama et al. 2016: pages 523-525

[36] See on Phase 1 of the programme: https://www.afdb.org/en/documents/document/multinational-east-africas-centers-of-excellence-for-skills-and-tertially-education-in-biomedical-sciences-phase-1-49867/

[37] See on this initiative: http://mlab.co.ke/

[38] See on this institution: https://www.nacosti.go.ke/

relevant areas. The Act has also created the National Research Fund[39] and made provisions for the fund to receive 2% of Kenya's GDP each financial year. This substantial commitment of funds should enable Kenya to reach its target of raising GERD from 0.79% of GDP in 2010 to 2% by 2014. Kenya has reviewed its Science, Technology and Innovation Policy in 2012, but the revised policy is still before parliament. The draft is nonetheless serving as a reference document for the Ministry of Education, Science and Technology. Also, Kenya is still working on a more coherent STI policy.

*STI Development in Rwanda*[40]

In a context of rapid economic and demographic growth, STI holds one of the keys to Rwanda's sustainable development process. This conviction is embodied in Rwanda's Vision 2020 for becoming a middle-income country by 2020, and in its National Policy on Science, Technology and Innovation[41], which was published in October 2005 with the support from UNESCO and the United Nations University (UNU). There is no dedicated Ministry for Science and Technology in Rwanda, but in 2009 the Directorate-General of Science, Technology and Research was established under the umbrella of the Ministry of Education to implement the National Policy on Science, Technology and Innovation. In 2012, the government had officially launched the National Commission for Science and Technology (NCST)[42]. The NCST has been strategically positioned in the Prime Minister's Office to serve as an advisory body on matters related to STI across all economic sectors. It became operational in 2014. The National Industrial Research and Development Agency (NIRDA)[43] was established in June 2013, in line with the National Industrial Policy of April 2011. The main mission of this research body is it to produce home-grown technological and industrial solutions to meet national and regional market needs.

In the past five years, Rwanda has put infrastructure in place to enable it to become an ICT hub in Africa. This infrastructure includes the Kigali Metropolitan Network (KMN)[44], a fibre-optic network linking all government institutions with a high-capacity national backbone which is connecting the whole country. The national backbone also links Rwanda with neighbouring countries, including

[39] See on the activities: http://www.researchfund.go.ke/

[40] See on Rwanda's STI policy: Urama et al. 2016: pages 525-527

[41] See on the policy framework: http://www.ncst.gov.rw/index.php?id=16&tx_ttnews%5Btt_news%5D=13&cHash=5085c5d4317ef19e52c7b64bdbec178a

[42] See on this institution: http://www.ncst.gov.rw/index.php?id=22

[43] See on this agency: http://www.nirda.gov.rw/index.php?id=2

[44] See on the launch of the Kigali Wireless Broadband (WiBro) Network and the Kigali Metropolitan Network (KMN): https://www.telegeography.com/products/commsupdate/articles/2009/12/11/kigali-wibro-network-launched/

Uganda and Tanzania, and through them to the submarine cables SEACOM[45] and EASSy[46]. In 2012, the Carnegie Mellon University[47] has established in Rwanda a regional centre of excellence in ICT. It is the first US research institution to offer degrees in Africa through an in-country presence. The government decided to partner with this leading private research university in the USA to produce ICT engineers and industry leaders who understand the balance between technology, business and innovation to meet the needs of industry. In October 2013, UNESCO's Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste (Italy)[48] established a branch in Rwanda. Hosted by the College of Science and Technology at the University of Rwanda[49], ICTP Rwanda aims to increase the number of scientists who are graduating at master's and PhD levels in strategic areas of science, technology, engineering, and mathematics (STEM). In 2012, the government adopted a policy of allocating 70% of university scholarships to students who are enrolled in S&T fields to increase the number of graduates.

The Rwanda Innovation Endowment Fund (RIEF) was established in 2012 by the Ministry of Education, in partnership with UNECA[50]. The Fund supports R&D to develop innovative market-oriented products and processes in three priority sectors of the economy: manufacturing, agriculture, and ICT. For the initial phase, a seed funding of US$ 650,000 was provided: US$ 500,000 were donated by the government and the remainder by UNECA. In January 2013, the Ministry of Education in Rwanda had established on a larger scale the Knowledge Transfer Partnership (KTP) programme, while the Kigali Institute of Science and Technology (KIST) benefitted from this initiative already since 2008[51]; the wider programme was established in collaboration with the AfDB to foster industrial development in Rwanda[52]. So far, the programme has sponsored five partnerships between private companies and the University of Rwanda's two Colleges of Science and Technology and Agriculture and Veterinary Medicine. The companies contribute its ideas for product or service development and the universities provide the appropriate expertise. The STI programme for Rwanda has strong political support and is on the way to more policy coherence.

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[45] About SEACOM: http://seacom.mu/about/

[46] EASSy stands for: Eastern Africa Submarine Cable System

[47] See about the CMU Africa programme: http://www.cmu.edu/africa/

[48] See on ICTP: https://www.ictp.it

[49] See on this College: http://www.cst.ur.ac.rw/

[50] See on the Rwanda Innovation Endowment Fund (RIEF): http://www1.uneca.org/ArticleDetail/tabid/3018/ArticleId/645/Rwanda-Officially-Launches-the-Rwanda-Innovation-Endowment-Fund.aspx

[51] See on the early implemented KTP programme: http://www.newtimes.co.rw/section/article/2008-10-13/48108/

[52] See on the wider KTP programme for Rwanda: http://www.hope-mag.com/index.php?com=news&option=read&ca=1&a=1186

### 3.2 STI Development in North Africa[53]

The Arab Strategy for Science, Technology and Innovation (ASSTI)[54], adopted by the Council of Ministers of Higher Education and Scientific Research in the Arab World in 2014, proposes an ambitious agenda. Countries are urged to engage in greater international co-operation in 14 scientific disciplines and strategic economic sectors, including nuclear energy, space sciences, and convergent technologies such as bio-informatics and nano-biotechnology. The Strategy advocates involving scientists from the diaspora and urges scientists to engage in public outreach; it also calls for greater investment in higher education and training to build a critical mass of experts and to staunch brain drain. The Strategy nevertheless eludes some core issues, including the delicate question of who will foot the hefty bill of implementing the strategy. How can heavily indebted countries contribute to the platform? What mechanisms should be put in place to combat poverty and to offer greater equity of access to knowledge and wealth at national levels? Without pondered answers to these questions, coupled with innovative out-of-the-box solutions, no strategy will be able to exploit the region’s capabilities effectively.

The poor state of Arab countries’ innovation systems can be attributed to many factors. The present UNESCO Science Report 2016[55] has highlighted, for instance, the region’s low spending levels on R&D, the relatively small pool of qualified experts and research scientists and engineers, the small number of tertiary students enrolling in scientific disciplines, the poor institutional support, and the effects of the inimical political and social perspectives on the promotion of science. Despite Heads of State having committed to raising GERD to 1% of GDP more than 25 years ago, not a single Arab country has yet reached that target. In most countries, the education system is still not turning out graduates who are motivated to contribute to a healthier economy. Why not? Governments should ask themselves whether the fault lies solely with the education system, or whether other impediments are stifling innovation and an entrepreneurial culture, such as a poor business climate.

How can Arab countries embrace economic diversification without building a critical mass of experts, technicians, and entrepreneurs? Higher education curricula are mostly fact-heavy and lecture-based, with a limited use of ICT tools and hands-on learning and little contextualization. This environment favours passive learning and examination-based assessments that measure students’ ability to memorize knowledge and curriculum content rather than their ability for creative

[53] See on the North Africa cases: Hassan et al. 2016: pages 430-469
[54] See on the strategy: http://www.universityworldnews.com/article.php?story=20140314113756
[55] See: http://en.unesco.org/unesco_science_report

work. Several Arab governments are setting up observatories to improve the monitoring of their science systems through data collection and analysis. Others should follow suit, to monitor the effectiveness of national policies and to form a network of observatories to ensure information-sharing and the development of common indicators. Some Arab countries are already taking this course of action, and are linking their observatories of STI.

There is more to developing a national innovation system than putting in place material institutions. Intangible considerations and values are vital, too. These include transparency, rule of law, intolerance of corruption, reward for initiative and drive, a healthy climate for business, respect for the environment, and the dissemination of the benefits of modern science and technology to the general population, including the underprivileged. Employability and placement in public institutions should depend solely on the expertise and seniority of the individual, rather than on political considerations. The following entries represent the latest STI development accounts for selected countries in North Africa.

*STI Development in Algeria*[56]

In 2008, Algeria adopted a plan to optimize its national innovation system. Piloted by the Ministry of Higher Education and Scientific Research (MoHEaSR), the plan proposed a reorganization of science, coupled with the development of infrastructure, human resources, and research, as well as greater scientific co-operation and funding. Algeria had devoted just 0.07% of GDP to GERD in 2005; although these data are partial, they suggest an extremely low R&D intensity in the years prior to the plan's adoption. The National Commission for the Evaluation of Permanent Researchers was launched in 2000 to give scientists a boost by allocating more financial resources to research and by introducing incentives for them to make better use of the results of their research. The aim was also to enhance collaboration with the Algerian diaspora. The National Commission met for the 12th time in February 2012. More recently, the MoHEaSR has announced plans to establish a National Academy of Sciences (NAS) in 2015, and this project became operational in 2016. Algerian scientists have published mostly in the areas of engineering and physics between 2008 and 2014. Their output has progressed steadily, doubling between 2005 and 2009, and then doubling again between 2010 and 2014. Over the seven years to 2014, 59% of the Algerian scientific papers had foreign co-authors. Although some progress can be seen, the way of Algeria to a coherent and effective STI system will be long.

[56] See: Hassan et al. 2016: page 447

*STI Development Egypt*[57]

For decades, science and technology in Egypt were highly centralized and dominated by the public sector. R&D was carried out mostly by state-run universities and research centres which were supervised by the Ministry of Higher Education and Scientific Research (MoHEaSR); this ministry has split into the Ministry of Higher Education (MoHE) and the Ministry of Scientific Research (MoSR) a few times and was merged again together in 2016. Egypt's research centres are scattered across the different ministries with little coordination with the Supreme Council of Scientific Research Centres and Institutes, which belongs to the Ministry of Higher Education and Scientific Research (MoHEaSR). The Academy of Scientific Research and Technology (ASRT) was founded in 1972. It is not an academy of sciences in the conventional sense of the word as, until 2007, it controlled the budget for R&D in universities and research centres. Today, it acts as a think-tank and policy advisor to the ministry and co-ordinates the country's research programmes.

In early 2015, the Ministry of Scientific Research (MoSR) began putting the final touches to Egypt's Strategy for Science, Technology and Innovation. In February 2015, UNESCO provided the ministry with technical assistance in organizing a Policy Dialogue on STI Development in the presence of international experts. A report commissioned subsequently by UNESCO proposed a series of recommendations for nurturing scientific research in Egypt (Tindemans, 2015). These recommendations included the following actions:

- A platform should be established at cabinet level with stakeholders from the economy and society to devise a vision and strategy for enhancing the role played by STI Development in socio-economic development;
- To improve the monitoring and co-ordination of policy implementation and to facilitate evaluation, the MoHEaSR should also head a high-level permanent committee of civil servants from ministries and NGOs entrusted with the responsibility for collecting and validating basic information on the national innovation system;
- The Ministry should develop close ties to the Ministry of Industry of Trade; and government departments need to be much more knowledgeable about the needs and aspirations of the private sector; they need to engage more to levels of large-scale pilot project implementation;
- A national innovation funding agency should be set up to support private sector research and public–private research co-operation, with the provision of competitive funding being its core task;
- The Egyptian Science, Technology and Innovation Observatory (ESTIO), which was launched in February 2014, should consider it a priority to obtain information on both public and private sector investment in R&D;

[57] See: Hassan et al. 2016: pages 448-450

current data on GERD and on the pool of researchers need to be subjected to critical analysis to ensure their reliability; the establishment of a panel of independent international experts could help with this critical analysis; and the ESTIO was requested to collect data for the business enterprise sector, but ESTIO also reported a rise in GERD from 0.43% to 0.68% of GDP between 2009 and 2013.

The Egyptian government has announced a US$ 5.87 billion reform plan for higher education to produce market-ready graduates being able to contribute to a knowledge economy. The plan runs from 2014 to 2022 and will be implemented in two phases. The plan is financed by the new constitutional entitlements that require the state to allocate at least 4% of the budget to education, 2% to higher education, and 1% to scientific research (Articles 19–21 of the 2014 Constitution). Many constitutional and institutional changes have taken place since, and the required different tasks have been assigned to different institutions. These changes have made it difficult to monitor and to assess the progress achieved so far. Egypt needs to accelerate its reforms of the STI system, as it is not yet coherent and effective, especially in regard of the private sector.

*STI Development in Mauritania*[58]

The main finding of the Science Technology and Innovation Policy Review of Mauritania[59], undertaken by the United Nations Conference on Trade and Development (UNCTAD) and by UNESCO in 2010, was that current capabilities were inadequate to address the challenges faced by the country. The report indicated that most public and private enterprises lack the capacity to innovate that would make them internationally competitive. The skills base needs to be developed, particularly in scientific and technical disciplines, as well as in entrepreneurship and management fields. Also needed are a more rapid technology diffusion and a greater absorptive capacity of technology. To address the above deficiencies, the Ministry of Higher Education and Scientific Research (MoHEaSR) has adopted in April 2015 an ambitious Three-Year Plan for Higher Education, covering the years 2014–2017. This plan has four main objectives:

- Strengthening institutional management and governance of tertiary institutions;
- Improving the relevance of the curricula, the quality of training, and the employability of graduates;
- Broadening access to tertiary study programmes; and
- Promoting scientific research on major national development issues.

With the technical assistance of UNESCO, Mauritania has recently adopted a new national STI strategy. The new strategy's focus is on developing skills and

[58] See: Hassan et al.2016: page 456

[59] See: http://unctad.org/en/pages/PublicationArchive.aspx?publicationid=1448

physical infrastructure, as well as on improving the co-ordination of private sector development policies, education reform, and trade and foreign investment policies. To effectively increase the odds of the successful implementation of the plan, the Government declared an STI presidential initiative through which a high-level STI council was formed which is headed by the president himself. Reforms will also need to build strong productive capacities in agriculture and fisheries, the mining industry, and the services sector, to take advantage of any improvement in macro-economic conditions.

For the first time, the administration of the current Ministry of Higher Education and Scientific Research (MoHEaSR) has managed to collect relatively comprehensive data on higher education and scientific research across the country. These data should enable the Ministry of Higher Education and Scientific Research (MoHEaSR) and the line ministries to identify the main obstacles to research. The newly developed STI Development indicators were the basis of the reviewed National STI Strategy which was adopted in early 2016. Mauritania needs to speed up the development of its STI system to involve the economic actors in the country.

*STI Development in Morocco*[60]

Morocco has managed to navigate the fallout from the global financial crisis relatively well, with average growth of over 4% between 2008 and 2013. The economy is diversifying but remains focused on low value-added products; the latter still represent about 70% of the manufactured goods and 80% of the exports. Unemployment remains high, at over 9%, and about 41% of the labour force lacks any qualification. Morocco's S&T system is essentially centred around the Ministry of Higher Education and Scientific Research (MoHEaSR) and the Inter-Ministerial Permanent Committee on Scientific Research and Technological Development (established in 2002), together with the Hassan II Academy of Science and Technology (established in 2006). The National Centre for Scientific and Technical Research (CNRST) is another key player; it runs the National Support Programme for Sectorial Research, for instance, which issues calls for research proposals to public institutions.

The Moroccan Innovation Strategy (MIS) was launched at the country's first National Innovation Summit in June 2009 by the Ministry of Industry, Commerce, Investment and the Digital Economy. It has three main thrusts: to develop domestic demand for innovation; to foster public–private linkages; and to introduce innovative funding mechanisms. The National Strategy for the Development of Scientific Research to 2025 (developed in 2009) recommended raising the secondary enrolment rate from 44% to at least 80% and the tertiary enrolment rate for the 19 – 23 years-old persons from 12% to over 50% by 2025. The Moroccan Innovation

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[60] See: Hassan et al. 2016: pages 457-458

Strategy (MIS) fixed the target of producing 1,000 Moroccan patents and of creating 200 innovative start-up companies by 2014. In parallel, the Ministry of Industry, Commerce and New Technologies (as it had since become the new name) has created a Moroccan Club of Innovation in 2011, in partnership with the Moroccan Office of Industrial and Commercial Property[61]. The idea is to create a network of players in innovation, including researchers, entrepreneurs, students and academics, to help them develop innovative projects.

Morocco's third techno-park was scheduled to welcome its first start-ups and SMEs in September 2015. Like its two predecessors in Casablanca and Rabat, the new techno-park in Tangiers will be hosting companies specializing in ICT, green technologies, and cultural/creative industries. Through a public–private partnership, offices in an existing building have been converted for an estimated cost of 20 million dirhams (MAD/Moroccan Dirham, approx. equivalent to US$ 2 million). They should be able to accommodate up to 100 enterprises, which will be sharing the premises with some of the project's key partners, such as the Moroccan Entrepreneurial Network and the Association of Women Chief Executive Officers (CEOs) of Morocco. University–business partnerships remain very limited in Morocco. Nevertheless, various competitive funds fostering this type of collaboration have been renewed in recent years. The government has encouraged companies to contribute to the fund to support research in their sector. Moroccan telecom operators were persuaded to cede 0.25% of their turnover; today, they finance about 80% of all public research projects in telecommunications, supported through this fund. The financial contribution of the business enterprise sector to GERD has meanwhile risen to 30% (2010).

The government is also encouraging citizen engagement in innovation on the part of public institutions. For instance, the Moroccan Phosphate Office (OCP/Office Chérifien des Phosphates)[62] is investing in a project to develop a smart city, King Mohammed VI Green City, around the Mohammed VI University which is located between Casablanca and Marrakesh, at a cost of MAD 4.7 billion (approx. equivalent to US$ 479 million). The Hassan II Academy of Science and Technology has international scientific outreach. In addition to recommending research priorities and evaluating research programmes, it helps Moroccan scientists to network with their national and international peers. The academy has identified various sectors where Morocco has a comparative advantage and is equipped with skilled human capital, including mining, fisheries, food chemistry, and new digital and environmental technologies. It has also identified various strategic sectors, such as energy, with an emphasis on renewable energies such as photovoltaic, thermal solar energy, wind and biomass; as well as the water, nutrition and health sectors, and the environment and geosciences sectors. Morocco is expanding its

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[61] See: http://www.ompic.org.ma/en
[62] See: http://www.ocpgroup.ma/

investment in renewable energies. A total of MAD 19 million (approx. equivalent to US$ 2 million) has been earmarked for six R&D projects in the field of solar thermal energy, under agreements signed by the Institute for Research in Solar and New Energy (IRESEN), and in cooperation with scientific and industrial partners.[63] Moreover, IRESEN is currently financing research in the field of renewable energy that is being conducted by more than 200 engineers and PhD students and some 47 university teachers-cum-researchers. Morocco has made some progress with its STI system, but still lacks coherence and efficiency of the system.

*STI Development in Sudan*[64]

Sudan has been plagued by armed conflict in the past decade: the conflict in Darfur, which lasted from 2003 until the signing of a ceasefire agreement with rebel groups in 2010; and a longstanding conflict in the south of the country, which resulted in the establishment of South Sudan as an independent state in 2011. But armed conflicts continue in Sudan (in the West and in the South), disrupting further the society, the infrastructure and the economy. Sudan has had its own Academy of Sciences since 2006, but otherwise has struggled to consolidate its science system over the past decade. One impediment is the loss of young talent to brain drain: for example, during the period between 2002 and 2014, Sudan had lost more than 3,000 junior and senior researchers to migration, according to information from the National Research Centre (NRC) in Khartoum and the report by Jalal (2014). Researchers are drawn to neighbouring countries, such as Eritrea and Ethiopia, by the better pay.[65] In 2010, the privately-run Future University in Khartoum was upgraded from a college to a university. Established in 1991, it was the first college in the region to introduce an IT programme, offering degrees in a wide range of fields, including computer science, artificial intelligence, bio-informatics, electronics engineering, geo-informatics and remote sensing, telecommunication and satellite engineering, biomedical engineering, laser and mechatronics engineering, and architecture. While its board of directors is managing the operating tasks of the university, the university is also very active in raising funds from international donors to sustain its annual scholarship programme.[66] UNESCO is also cooperating with the Future University in many of its educational programs.

In 2013, the Ministry of Science and Communication (MoSaC) has embarked on a revision of its Science and Technology Policy (2003), supported with the technical assistance of UNESCO. Various consultation meetings were organized with high-level experts from around the world; these produced a series of recommendations, including those advocating:

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[63] See: http://maghrenov.eu/p/iresen

[64] See: Hassan et al. 2016: pages 461-462

[65] See on this issue the websites of the Future University: http://www.futureu.edu.sd/

[66] See on the various programmes: http://www.futureu.edu.sd/#

- The re-establishment of a Higher Council for Science and Technology, to be headed by the First Deputy President of the Republic, which would coordinate and oversee relevant institutions and research centres which are affiliated to various ministries, with the Ministry of Science and Communication (MoSaC) acting as a rapporteur of the Council;
- The establishment of a fund to finance public research, with a focus on employing the proceeds of Awqaf and Zakat; this measure should be combined with the adoption of legislation for increasing financial allocations to scientific research; envisaged are also exemptions from some or even from all the customs duties which are raised on imported goods and equipment that support research; these measures should enable GERD to rise to 1% of GDP by 2021; and
- The establishment of an Observatory of STI Development indicators, with the technical support of UNESCO.

Similar to the case of Egypt, Sudan has a fairly diverse institutional framework, with a number of major research centres and institutes such as the Agricultural Research Corporation (ARC)[67], the Industrial Research and Consultancy Centre (IRCC)[68], the Animal Resources Research Corporation (ARRC)[69], the Sudan Meteorological Authority (SMA)[70], and the Social and Economic Research Bureau, which have their own substantial financial resources, but do not fall under the umbrella of the Ministry of Higher Education and Scientific Research (MofHEaSR). Hence this is causing a serious lack of coordination within the R&D platform. Also, Sudan lacks a well-integrated STI strategy, although some positive changes have occurred at the national level.

*STI Development in Tunisia*[71]

The economy in Tunisia has proved relatively resilient over the past four years, thanks partly to its broad base, with well-developed agricultural, mining, petroleum, and manufacturing sectors. This has helped to cushion the drop in the tourism sector, which accounted for 18% of GDP in 2009, but only 14% four years later. Compared to most African and Arab states, the STI system in Tunisia is relatively advanced, and it enjoys strong government support. The Higher Council of Scientific Research and Technology is chaired by the prime minister himself. The body is responsible for formulating policy and implementation strategies. The Ministry of Higher Education, Scientific Research and Information, and Communication Technologies can count upon the expertise of both the National Consultative Council of Scientific Research and Technology and the National Evaluation

[67] See: http://www.arcsudan.sd/
[68] See: http://www.ircc.gov.sd/index_en.php
[69] See: https://www.asti.cgiar.org/node/1079
[70] See: http://www.ersad.gov.sd/index.php
[71] See: Hassan et al. 2016: pages 462-464

Committee of Scientific Research Activities. The latter is an independent body in charge of evaluating both public scientific research and private sector research programmes benefiting from the public purse. The National Observatory of Science and Technology is another vital component of the Tunisian STI system. It was established in 2006, two years before being placed under the Ministry of Higher Education and Scientific Research.

Despite restrictions, 48% of the scientific articles which were published by Tunisian researchers had foreign co-authors in 2009. This share had risen to 58% by 2014. In 2009, the government began negotiating an agreement for a joint research programme with the European Union (EU). The three-year programme was ultimately launched on 12 October 2011, with € 12 million in EU funding. The Tunisian National Agency for Scientific Research Promotion (ANPR)[72] was given responsibility for distributing the programme funds in accordance with the country's priority research areas: renewable energy, biotechnology, water, environment, desertification, micro-electronics, nanotechnology, health, and ICT.

Tunisia is investing heavily in techno-parks. Elgazala Techno-park in the Tunis region was the first, both for Tunisia and the Maghreb. Established in 1997, it specializes in communication technologies and now hosts about 80 companies, including 13 multinationals (Microsoft, Ericsson, Alcatel Lucent, etc.). Several other techno-parks have been established since, including those in Sidi Thabet (2002, for biotechnology and pharmaceuticals), Borj Cedria (2005, for environment, renewable energy, biotechnology, and materials science), Monastir (2006, for textiles), and Bizerte (2006, for the agro-industry). In 2012, the government announced the creation of a new techno-park in Remada which is specializing in ICT. Meanwhile, the Ecosolar Village of Zarzis–Jerba should soon be operational. It will create jobs in renewable energy production, seawater desalination, and organic farming; this techno-park also plans to position itself as a training platform for the entire Africa region. Tunisia intends to raise the share of renewables in the energy mix to 16% (1,000 MW) by 2016, and to 40% (4,700 MW) by 2030, within its Solar Plan which was adopted in 2009. However, there is a lot of criticism about the lack of integration of the techno-parks into the STI system of Tunisia. The STI system needs to be adapted to the new development model which is currently developed in Tunisia as the economic reforms in the country are unfolding.

### 3.3 STI Development in Southern Africa[73]

The Southern Africa Development Community (SADC) is home to 33% of sub-Saharan Africa's population and contributes about 43% of its GDP (US$ 684 billion in 2013). The region combines middle-income countries with some of the

[72] See: http://www.biotechpole.rnu.tn/en/page.aspx?id=41

[73] See: Scerri et al. 2016; pages 534-565

fastest growing economies in Africa and some of the poorest. Nothing underscores the region's diversity more than the fact that one country alone generates about 60% of GDP generated within the SADC and about one-quarter of the continent's GDP: South Africa. The SADC region enjoys relative political stability and democratic political processes, although internal fragmentation continues to characterize the ruling political parties in most countries. For the past six years, SADC membership has remained relatively stable, although the membership of Madagascar was suspended in 2009, following a coup d'état; then the country was reintegrated in January 2014 after its return to a constitutional government.

In 2014, five SADC countries held presidential elections – Botswana, Malawi, Mozambique, Namibia, and South Africa. The SADC aims to attain equal representation of men and women in key decision-making positions by 2015, through the SADC Protocol on Gender and Development, which became into force in early 2013 after being signed in 2008. The population is growing fast, at 2.5% per year on average, between 2009 and 2013. By 2013, the region counted a combined population of over 294 million. Human development varies widely, from a high of 0.771 on the UNDP's Human Development Index (HDI) in Mauritius to a low of 0.337 in the Democratic Republic of Congo (DRC). A promising trend is that ten countries advanced in the overall world ranking from 2008 to 2013. Madagascar, Seychelles and Swaziland, on the other hand, have slipped a few places. The following represents the latest STI development accounts in selected countries in Southern Africa.

*STI Development in Botswana*[74]

Along with Tanzania, Botswana has one of the longest post-independence histories of political stability in Africa. As a multi-party democracy, it is deemed the continent's best-performing country by the Corruption Perceptions Index (31st out of 175), and it ranks third in Africa in the Ibrahim Index of African Governance. Real GDP per capita is relatively high and growing, but the country nevertheless ranks second in the SADC for inequality and there is widespread poverty in the country. Botswana's incidence of HIV (18.5% of the population) is also among the highest in the world, according to the Botswana AIDS Impact Survey of 2013.

The centrepiece of the government's strategy to utilize STI for development is the building of six innovation hubs. The first of these was established in 2008 to foster the commercialization and diversification of agriculture. The second to be set up was the Botswana Diamond Hub. In 2009, a Diamond Technology Park in Gaborone was set up as a hub for the local cutting and polishing of diamonds, as well as for the manufacture of diamond jewellery. By 2012, the government had licensed 16 diamond polishing and cutting companies. Innovation hubs are also

[74] See: Scerri et al. 2016: pages 546-547

being put in place for innovation[75], transport and health sectors. In addition, an education hub has been approved by the Government Implementation Coordinating Office (GICO), with the objective of developing quality education, training and research to make Botswana a regional Centre of Excellence and to promote economic diversification and sustainable growth. High unemployment (18.4% in 2013) has been linked to the mismatch between skills development and labour market needs, together with slow private-sector growth. The Botswana Education Hub will be coordinating its activities with those of the other five hubs in agriculture, innovation, transport, diamonds, and health.

The 2011 STI policy is a revision of the country's first Science and Technology Policy (1998). The 2011 policy has been consolidated with the 2005 Botswana Research, Science and Technology Plan (2005), following the recommendations of a review conducted by UNESCO in 2009. The main reason for the review was to align Botswana's policy with Vision 2016[76] which was outlined in the Tenth National Development Plan (TNDP) 2009 - 2016. The review concluded that the same obstacles to R&D persisted in 2009, implying that the 1998 policy had made little impact on job and wealth creation. So, the STI policy of Botswana is ambitious, but it needs more coherence and more intensive links with private business.

*STI Development in Malawi*[77]

Malawi has been a multi-party parliamentary democracy since 1994. For the past 10 years, the economy has grown annually by 5.6% on average, making it the sixth fastest growing economy in the SADC region. It is projected that, between 2015 and 2019, annual growth in real GDP will range from 6% to 5%. The economy is heavily dependent on agriculture, which accounts for 27% of the GDP and 90% of the export revenues. The three most important export crops are tobacco, tea, and sugar – with the tobacco sector alone accounting for half of Malawi's exports. Malawi spends more on agriculture (as a share of GDP) than any other African country. Over 80% of the population is engaged in subsistence farming, with manufacturing earning just 10.7% of the GDP. Despite being one of the poorest countries in the world, Malawi devoted 1.06% of its GDP to GERD in 2010, according to a survey by the Department of Science and Technology (DST)[78]. This is one of the highest ratios in Africa. Also noteworthy is that Malawian scientists publish more in mainstream journals – relative to GDP – than any other country of a similar population size. Enrolment in higher education, however, struggles to keep up with rapid population growth. Despite a slight improvement, only 0.81% of the age cohort was enrolled in a university by 2011. Moreover, although the number

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[75] See on this hub for defining future innovation and developing technologies: http://www.bih.co.bw/

[76] See on the Vision 2016: http://www.vision2016.co.bw/

[77] See: Scerri et al. 2016: pages 550-551

[78] It is a Department in the Ministry of Education, Science and Technology of Malawi.

of students choosing to study abroad increased by 56% between 1999 and 2012, their proportion decreased from 26% to 18% over the same period.

Malawi's first science and technology policy from 1991 was revised in 2002. Despite being approved, the 2002 policy has not been fully implemented, largely due to the lack of an implementation plan and an uncoordinated approach to STI. This policy has been under revision in recent years, with UNESCO assistance, to re-align its focus and its approaches with the second Malawi Growth and Development Strategy (MGDS) II for 2011-2016 (of 2013)[79] and with international development instruments to which Malawi is a party. The National Science and Technology Policy (NSTP) of 2002 envisaged the establishment of a National Commission for Science and Technology (NCST) to advise the government and other stakeholders on science and technology-led development. Although the Science and Technology Act of 200317 made provision for the creation of this commission, it only became operational in 2011, with a secretariat resulting from the merger of the Department of Science and Technology (DST) and the National Research Council (NRC). Among the notable achievements stemming from the implementation of national STI policies in Malawi in recent years is the establishment, in 2012, of the Malawi University of Science and Technology (MUST)[80] and of the Lilongwe University of Agriculture and Natural Resources (LUANAR)[81] to build an enlarged STI capacity for the country. This brings the number of public universities to four, with the University of Malawi (UNIMA)[82] and the Mzuzu University (MZUNI)[83]. Malawi has interesting STI development paths, but more coherence is needed to reap better dividends from the expansion of the STI system.

*STI Development in South Africa*[84]

South Africa is currently Africa's second-largest economy after Nigeria. Despite having a population of only 53 million, it generates about one-quarter of the African GDP. It is classified as a middle-income country and has a relatively solid national innovation system (NIS). With its regional political influence and a growing economic presence in Africa, the country has the potential to drive economic growth across the continent. For the moment, its weight is felt mostly by its immediate SADC neighbours, through the development of trading partnerships, political agreements, business linkages, and movements of people.

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[79] It is the Malawi Growth and Development Strategy (MGDS) II for 2011-2016. A Final Assessment Report appeared in 2016.

[80] See: http://www.must.ac.mw/

[81] See: http://www.bunda.luanar.mw/luanar/

[82] See: https://en.wikipedia.org/wiki/University_of_Malawi

[83] See on this country expertise: http://www.mzuni.ac.mw/

[84] See: Scerri et al. 2016: pages 555-558

The vision of the National Development Plan 2030 (with documents from 15 August 2012) is for South Africa to become a diversified economy firmly grounded in STI by 2030.[85] This transition is guided by the Ten-Year Innovation Plan (2008–2018)[86] and its five ‘grand challenges’: biotechnology and the bio-economy (formerly pharmaceuticals); space; energy security; global change; and understanding of social dynamics. The decision in 2012 to host the € 1.5 billion project to build the world’s largest radio telescope in South Africa and Australasia is bringing significant opportunities for research collaboration, attracting leading astronomers and researchers at all stages of their careers to work in Africa; it is worth noting that South African astronomers co-authored 89% of their publications with foreign collaborators during 2008–2014. It is a possibility that this project has significant spillovers to other research disciplines.

South Africa’s GERD/GDP ratio (of 0.73% in 2012) has dropped from a higher ratio of 0.89% in 2008. This has been mostly due to a sharp drop in private sector R&D, despite of rising public spending on R&D. However, South Africa’s research output still comprises about 85% of Southern Africa’s total research output. To help reach the target of a GERD/GDP ratio of at least 1%, the Sector-Specific Innovation Fund was launched in 2013. This fund targets specific industrial sectors to support the industry’s specific research, development and innovation needs, through a co-funding arrangement. This funding instrument also addresses one of the recommendations from the 2012 Ministerial Review Report[87], which called for greater interaction between the Department of Science and Technology (DST) and the private sector.

The National Development Plan 2030 (with documents of 2012) has fixed a target of producing 100,000 PhDs by 2030 to improve the country’s capacity for research and innovation. The DST has significantly increased its funding for post-graduate students. By 2014, 34 PhDs were being produced per million inhabitants, but this is still below the target of 100 PhDs per million inhabitants fixed by the Plan. Altogether, the plans are ambitious, but the links between the research system, the education and training system, the labour market system, the government agencies, and the private sector actors in South Africa are weak. The STI policy is not coherent.

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[85] See: http://www.gov.za/issues/national-development-plan-2030

[86] The Innovation Plan has the title “Innovation Towards A Knowledge-Based Economy”

[87] This report gives a valuable business perspective of South Africa’s NSI and highlights the role of the DST to link more than in the past the research community and the private sector.

*STI Development in the United Republic of Tanzania*[88]

An economic adjustment programme (EAP) which was launched in the 1990s had reduced state economic control and has nurtured the private sector; it was supported by the World Bank, the IMF, and by bilateral donors. This programme has contributed to average annual economic growth rates in Tanzania of between 6.0% and 7.8% since 2001. This impressive growth has however not significantly altered the country's economic structure, which is still based on agriculture. The latter sector accounted for 34% of GDP in 2013, compared to 7% for the manufacturing sub-sector. GDP per capita remains low by SADC standards, but nevertheless progressed between 2009 and 2013. Tanzania's low level of human development has improved somewhat in recent years. The country has the lowest level of income inequality within the SADC region, and has little (open) unemployment (just 3.5%), but its poverty rate is the highest among the SADC countries. The Vision 2025[89] document adopted in 1998 aspires to 'transform the economy into a strong, resilient and competitive one, buttressed by science and technology'. Tanzania's first National Science and Technology Policy (of 1996)[90] was revised in 2010, and it was renamed the National Research and Development Policy[91]. The new policy of 2010 recognizes the need to improve the process of prioritization of research capacities, international co-operation in strategic R&D areas, and planning for human resources; it also makes provisions for the establishment of a National Research Fund (NRF). This policy was, in turn, reviewed in 2012 and 2013[92].

Even though Tanzania has eight public institutions of higher education and a plethora of private institutions, fewer than half of the secondary school-leavers obtain a place at a university. The establishment of the Nelson Mandela African Institution of Science and Technology (NM-AIST) in Arusha in 2011 should augment Tanzania's academic capacity considerably.[93] This university has been designed as a research-intensive institution with postgraduate programmes in science, engineering, and technology. Life sciences and bio-engineering are some of the initial niche areas, taking advantage of the immense biodiversity in the region. However, despite of some highlights, the STI system in Tanzania is not coherent and is not effective enough.

[88] See: Scerri et al. 2016: pages 559-560

[89] See: http://fortuneofafrica.com/tanzania/tanzania-vision-2025/

[90] This document (of 1996) is rich in suggestions and policy proposals.

[91] There is also an implementation plan in the document (of 2010).

[92] The National Agriculture Policy of Tanzania from 2013 shows that there are repercussions from the new STI policy document to the new R&D system for agriculture; it is intended to make it more client-based and pragmatic.

[93] See on this institution: http://www.nm-aist.ac.tz/

*STI Development in Zambia*[94]

Zambia's economic growth has been derived mainly from the boom of commodities (especially copper), fuelled by the demand from China. However, growth has not resulted in job creation and poverty reduction, as Zambia has not yet managed to diversify its resource-based economy by developing a strong manufacturing sector and by adding value to its commodities. And, although agriculture employs about 85% of the labour force, it contributes only 10% of the GDP. Productivity is low, with agriculture representing only about 5% of Zambia's exports, mostly due to its weak linkages with processing and manufacturing. The combination of poor infrastructure, an inappropriate regulatory and tax regime, limited access to finance, a low level of skills, and the generally high cost of doing business are all major impediments to an economic transformation in Zambia.

The higher education sector consists of three public universities, the University of Zambia, the Copperbelt University and, since 2008, the Mulungushi University. There are also 32 private universities and colleges and 48 public technical institutes and colleges. Demand nevertheless far outstrips supply, as there are only enough student places for one-third of the number of qualifying school-leavers. The low remuneration of academic staff relative to other SADC countries has also resulted in an exodus of qualified academics. Zambia's GERD/GDP ratio is modest (0.28% in 2008), and it counts just 49 researchers per million inhabitants. No significant improvements have occurred since then with regard of these ratios.

A fund to spur research Zambia's National Science and Technology Policy[95] dates from 1996 and the Science and Technology Act from 1997[96]. These milestones have given rise to three key science and technology institutions, the National Science and Technology Council (NSTC), the National Technology Business Centre (NTBC, established 2002), and the National Institute for Scientific and Industrial Research (NISIR, a research body which replaced the National Council for Scientific Research/NCSR dating from 1967). The NSTC provides grants through the Strategic Research Fund (SRF), the Youth Innovation Fund (YIF), and the Joint Research Fund (JRF). It also administers the Science and Technology Development Fund (STDF) which was instituted by the Science and Technology Act (1997). Although Zambia is rich in STI-related institutions, the STI system lacks coherence and effectiveness.

*STI Development in Zimbabwe*[97]

Between 1998 and 2008, the Zimbabwean economy contracted by a cumulative 50.3%, sending GDP per capita plummeting to less than US $400. In July 2008,

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[94] See: Scerri et al. 2016: pages 561-562

[95] See: http://www.wipo.int/wipolex/en/text.jsp?file_id=209528

[96] See: http://www.wipo.int/wipolex/en/details.jsp?id=8801

[97] See: Scerri et al. 2016: pages 562-563

inflation peaked at 231,000,000%. By this time, 90% of the population was unemployed, and 80% were living in poverty. Infrastructure had deteriorated, the economy had become more informal, and there were severe food and foreign currency shortages. However, Zimbabwe has a long tradition in STI policy development. The Second Science and Technology Policy was launched in June 2012, after being elaborated with UNESCO assistance.[98] It replaces the earlier policy dating from 2002 and has cited sectorial policies with a focus on biotechnology, ICT, space sciences, nanotechnology, indigenous knowledge systems, technologies yet to emerge, and scientific solutions to emergent environmental challenges. The 2012 Science and Technology Policy asserts the government commitment to allocating at least 1% of GDP to GERD, focusing at least 60% of university education on developing skills in science and technology, and ensuring that school pupils devote at least 30% of their time to studying science subjects.

Zimbabwe has a long research tradition that dates back a century. However, the economic crisis has precipitated an exodus of university students and professionals in key areas of expertise (medicine, engineering, etc.) that is of growing concern. More than 22% of Zimbabwean tertiary students are completing their degrees abroad. In 2012, there were just 200 researchers employed in the public sector, one quarter of whom were women. Despite the turbulence of recent years, Zimbabwe's education sector remains in quantitative terms sound. In 2012, 91% of youth aged 15–24 years were literate, 53% of the population aged 25 years or more had completed secondary education, and 3% of the adults held a tertiary qualification. The government is planning to establish two new universities with a focus on agricultural science and technology: Marondera State University[99] and Manicaland State University[100]. The long-standing University of Zimbabwe is particularly active in research, producing more than 44% of Zimbabwe's scientific publications in 2013. Productivity is low, but the number of publications has grown since 2005. The past decade has seen an extraordinary rise in the number of co-publications with foreign partners, which now represent 75–80% of all Zimbabwean publications in the Web of Science. Despite of the severe economic and political crisis, there are positive developments in the STI sector. Public–private sector linkages remain weak. An exception is the long-standing STI cooperation with the tobacco industry and other industries which are oriented towards agriculture, but there has traditionally been little collaboration between industry and academia in Zimbabwe. The current regulatory framework hampers the transfer of technology to the business sector, and as well the development of industrial R&D, despite the commercialization of research results being one of the major goals of

[98] See on the UNESCO assistance projects to Zimbabwe: http://en.unesco.org/countries/zimbabwe

[99] See: https://zimguide.com/marondera-new-university-opening

[100] See: http://ww4.msu.ac.zw/manicaland-college-of-applied-sciences/

the Second Science, Technology and Innovation Policy. Although STI has a great tradition in Zimbabwe, the long years of crisis have affected the quality and effectiveness of the national innovation system (NIS).

### 3.4 STI Development in West Africa[101]

Most West African countries are striving to achieve lower or upper middle-income status within the next 15 years. This goal is enshrined in the current development plans and economic policies of Côte d'Ivoire, Gambia, Ghana, Liberia, Mali, Senegal, and Togo, for instance. Nigeria even plans to join the world's top 20 economies by 2020. Yet, for two-thirds of the West African countries middle-income status remains an elusive goal: annual GDP per capita remains below US$ 1,045 in all of Benin, Burkina Faso, Gambia, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Sierra Leone, and Togo. The Economic Community of West African States (ECOWAS) has experienced strong economic growth in recent years, despite a series of crises, with projected sub-region's prospects of growth of 7.1% in 2014 compared to 6.3% in 2013. The following represents the latest STI development accounts in selected countries in West Africa.

*STI Development in Benin*[102]
In Benin, the STI regulatory framework has evolved since 2006 when the country's first science policy was prepared. This has since been updated and complemented by new texts on science and innovation (the year of adoption is between brackets; see below):

- A manual for monitoring and evaluating research structures and organizations (2013);
- A manual on how to select research programmes and projects and how to apply to the National Fund for Scientific Research and Technological Innovation (2013) for obtaining competitive grants;
- A draft act for funding scientific research and innovation and a draft code of ethics for scientific research and innovation were both submitted to the Supreme Court (in 2014); and
- A strategic plan for scientific research and innovation (which was still under development in 2015).

The priority areas for scientific research are health, education, construction and building materials, transportation and trade, culture, tourism and handicrafts, cotton/textiles, food, energy, and climate change. The main research structures are the Benin Centre for Scientific and Technical Research (CBRST), the National

[101] See: Konte et al. 2016: pages 470-497
[102] See: Konte et al. 2016: pages 482-483

Institute of Agricultural Research of Benin (INRAB)[103], the National Institute for Training and Research in Education, the Office of Geological and Mining Research, and the Centre for Entomological Research. The University of Abomey-Calavi[104] also deserves mention for having been selected by the World Bank as a Centre of Excellence in Applied Mathematics. The main challenges facing R&D in Benin are:

- The unfavourable organizational framework for R&D: weak governance, a lack of co-operation between research structures, and the absence of an official document on the status of researchers;
- The inadequate use of human resources and the lack of any motivational policy for researchers; and the mismatch between R&D activities and development needs.

STI policy in Benin is developing its potentials, but still the sector lacks policy coherence.

*STI Development in Burkina Faso*[105]

Since 2011, Burkina Faso has clearly made S&T a development priority. The first sign was the creation of the Ministry of Scientific Research and Innovation (MRSI) in January 2011[106]. In 2012, Burkina Faso adopted a National Policy for Scientific and Technical Research, the strategic objectives of which are to develop R&D and the application and commercialization of research results. The policy also makes provisions for strengthening the ministry’s strategic and operational capacities. One of the key priorities is to improve food security and self-sufficiency by boosting the capacity in agricultural and environmental sciences. The creation of a Centre of Excellence at the International Institute of Water and Environmental Engineering (2iE) in Ouagadougou[107] within a World Bank project provides essential funding for capacity building in these priority areas.

In 2013, Burkina Faso passed the Science, Technology and Innovation Act establishing three mechanisms for financing research and innovation, a clear indication of high-level commitment.[108] These mechanisms are the National Fund for Education and Research, the National Fund for Research and Innovation for Development, and the Forum of Scientific Research and Technological Innovation. Burkina Faso however faces various challenges in developing R&D:

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[103] See on the role of this institution: http://www.ifpri.org/publication/agricultural-rd-benin-assessment-national-institute-agricultural-research-benin

[104] See: http://www.uac.bj/

[105] See: Konte et al. 2016: page 483

[106] See: http://www.mrsi.gov.bf/

[107] See: http://www.2ie-edu.org/en/

[108] See on the advisory role of UNESCO: http://www.unesco.org/new/en/natural-sciences/science-technology/sti-systems-and-governance/sti-policy-development/africa/burkina-faso/

- ➢ A small pool of researchers: only 48 per million population in 2010;
- ➢ A lack of research funding;
- ➢ Outdated research facilities;
- ➢ Poor access to information and internet: access only for 4.4% of the population in 2013; and
- ➢ An insufficient utilization of research results.

Although STI policy is advancing in Burkina Faso, there is still a lack of integration and coherence with regard of the various elements.

*STI Development in Cote d'Ivoire*[109]

With the political crisis now over, the incoming government of President Alassane Ouattara has vowed to restore the country to its former leading role in sub-Saharan Africa. The National Development Plan for 2012–2015[110] had two primary objectives: to achieve double-digit growth by 2014, and to turn Côte d'Ivoire into an upper middle-income country by 2020. A second national development plan is under preparation for 2016–2020. Key targets of the Plan requiring recourse to S&T include:

- ✓ Rehabilitation of the railway linking Abidjan to Burkina Faso's border; rehabilitation and extension of the ports of Abidjan and San Pédro; creation of a new airline company (infrastructure and transport);
- ✓ Increasing the productivity of yam, banana plantain, and manioc by at least 15% (agriculture);
- ✓ Creation of two transformation units for iron and manganese and one for gold refining (mining);
- ✓ Construction of the Soubré dam; electrification of 200 rural communities each year (energy);
- ✓ Establishment and equipping of three techno-poles to promote innovation; transformation of 50% of raw materials into value-added goods (industry and SMEs); and
- ✓ Expansion of the country's fibre-optic network as just 2.4% of Ivoirians had internet access in 2012; introduction of an e-education programme; establishment of cyber-centres in every municipality (post and ICTs).

Côte d'Ivoire does not yet have a dedicated STI policy. Related policies are implemented by the Ministry of Higher Education and Scientific Research (MESRS)[111]. The main planning body is the Directorate General of Scientific Research and Technological Innovation. For its part, the Higher Council for Scientific Research and Technological Development serves as a forum for consultation

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[109] See: Konte et al. 2016: pages 486-487

[110] See about this document: https://www.mindbank.info/item/5432; the National Development plan for 2016-2020 is following the National Development Plan 2012-2015.

[111] See: http://www.enseignement.gouv.ci/index.php?open=le_ministere

and dialogue with stakeholders and research partners. There are chances that Cote d'Ivoire advances with its STI policies in the next 5 to 10 years. Political stability will be a major precondition.

*STI Development in Ghana*[112]

The Ghana Shared Growth and Development Agenda 2014–2017[113] contextualizes the sector-specific policies for agriculture, industry, health, and education as defined by the National Science, Technology and Innovation Policy (from 2010)[114]. Ghana has one of West Africa's most developed national innovation systems (NISs). There is a Council for Scientific and Industrial Research (CSIR)[115], which was established in 1958, with 13 specialized institutes for research on crops, animals, food, water, and industry. The export of cocoa contributed over 40% of the country's foreign exchange earnings up until the 1980s and still contributes about 20%. The Cocoa Research Institute of Ghana (CRIG)[116] plays an important role in further developing the cocoa industry, through research into crop breeding, agronomy, pest management, and extension services, among others. Other scientific institutions include the Ghana Atomic Energy Commission, the Centre for Scientific Research into Plant Medicine, and the Noguchi Memorial Institute for Medical Research at the University of Ghana.

Ghana has however only a small pool of researchers (39 researchers per million population in 2010), but they are increasingly publishing in international journals. Ghana's scientific publication record has almost tripled between 2005 and 2014. This performance is especially noteworthy, as Ghana has devoted just 0.38% of GDP to GERD in 2010. Greater investment is needed to stimulate R&D. Between 2004 and 2011, Ghana has invested 6.3% of GDP in education, on average, and between one-fifth and one-quarter of this is invested in higher education. The number of students who are enrolled in degree courses shot up from 82,000 to 205,000 (what is 12% of the age cohort) between 2006 and 2012, and the number of PhD candidates rose in this period from 123 to 867.

Despite insufficient investment, some universities maintain high standards, such as the University of Ghana (created in 1948), the country's oldest, and Kwame Nkrumah University of Science and Technology (KNUST, being created in 1951). Both have been selected for the World Bank's African Centres of Excellence project. KNUST has developed a reputation for excellence in engineering, medicine, pharmacy, basic sciences, and applied sciences. In 2014, the government established a Centre of Excellence in Petroleum Engineering at KNUST in

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[112] See: Konte et al. 2016: pages 488-489

[113] See on the relevant documents for download: http://www.ndpc.gov.gh/downloads/2/

[114] See the document: http://www.ecowrex.org/document/national-science-technology-and-innovavion-policy

[115] See about the activities of the CSIR: http://www.csir.org.gh/

[116] See: http://crig.org.gh/

cooperation with the World Bank, which will serve as a hub for developing Africa's capacity in the oil and gas value chain. In all, seven public universities conduct extensive R&D in Ghana. Within the World Bank project, the West Africa Centre for Crop Improvement (WACCI) at the University of Ghana[117] is receiving US$ 8 million for research and the training of crop breeders at PhD and MSc levels over 2014–2019, as well as for the provision of other services. The West Africa Centre on the Cell Biology of Infectious Pathogens (WACCBIP)[118] within the University of Ghana and KNUST's Regional Water and Environmental Sanitation Centre[119] are also receiving similar support. So, Ghana is an example of a country with an advancing STI policy and an established national innovation system (NIS), despite of the low domestic funding base for R&D and the high dependence of the country on foreign funds.

*STI Development in Nigeria*[120]

Nigeria plans to use its Vision 20:2020 (from December 2009) to integrate STI Development into the development of key economic sectors.[121] One of the strategic targets of Vision 20:2020 was initially to set up a US$ 5 billion endowment fund to finance the establishment of a National Science Foundation. This fund was pledged by former President Olusegun Obasanjo (1999–2007) towards the end of his mandate and has not materialized. Progress towards other targets is hard to evaluate for lack of STI and socio-economic data. The STI policy of Nigeria also recommended a shift in research focus from basic research to innovation. The emphasis in STI is on space science and technology, biotechnology, and renewable energy technologies. Although Nigeria has had a National Biotechnology Development Agency (NABDA)[122] since 2001, the National Biosafety Management Agency Bill lingered in parliament for years; the bill was finally passed in 2011 but was still awaiting presidential consent in early 2015.

In 2012, an UNESCO International Centre for Biotechnology was established under the auspices of UNESCO at the University of Nigeria in Nsukka.[123] The institute provides high-level training (including at sub-regional level), education and research, particularly in areas related to food security, conservation of harvested crops, gene banking, and tropical diseases. In October 2011, the president launched the Youth Enterprise with Innovation in Nigeria (You Win) grant scheme

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[117] See on WACCI: http://www.educartis.co.ao/centros/west-africa-centre-for-crop-improvement

[118] See: http://www.waccbip.org/

[119] See: https://knust.edu.gh/events/academic/knust-regional-water-and-environmental-sanitation-kumasi-rwesck-short-courses

[120] See: Konte et al. 2016: pages 492-494

[121] See: http://www.nationalplanning.gov.ng/index.php/national-plans/nv20-2020

[122] See: http://www.nabda.gov.ng/

[123] See: http://unesco.unn.edu.ng/

to generate jobs.[124] By 2015, some 3,600 aspiring entrepreneurs between 18 and 45 years had received up to 10 million Naira each (US$ 56,000) to help them launch or expand their business, to mitigate start-up risks or to set up spin-offs from existing businesses.

Although Nigeria has the potential to advance in terms of STI development, lack of policy coherence and non-implementation of policies prevent that decisive steps to steady progress are taken.

*STI Development in Senegal*[125]

In 2012, Senegal adopted a National Strategy for Economic and Social Development for 2013–2017[126], based on the vision of its Plan for an Emerging Senegal (PES).[127] This is Senegal's development plan for becoming an upper middle-income country by 2035. Both documents consider higher education and research as a springboard to socio-economic development and thus as a priority for reform. In early 2013, a national dialogue was held on the future of higher education. It produced 78 recommendations that the Ministry of Higher Education, Universities, Regional University Centres and Scientific Research (MSR) has since translated into an action plan entitled Priority Programme Reform and the Development Plan for Higher Education and Research, 2013–2017 (PDESR). This action plan was adopted in stages by the Presidential Council on Higher Education and Research through 11 presidential decisions taken by the Head of State, including a funding commitment of US$ 600 million over five years.

The creation of a National Council of Higher Education, Research, Innovation, Science and Technology in 2015 should allow it Senegal to meet some of these challenges. It will act as a consultative committee to the Minister of Higher Education, Universities, Regional University Centres and Scientific Research (MSR) and as a monitoring body. The ongoing construction of Senegal's first planetarium and mini-astronomical observatory could also be a sign of a growing science culture. The Ministry of Higher Education, Universities, Regional University Centres and Scientific Research (MSR) also runs an extension programme called Centres for Research and Experimentation to promote technology transfer. These centres popularize innovative research that improves social welfare through various instruments within several research funds, including one targeting women. Although there are some reforms undertaken in the STI system of Senegal, the

[124] See: https://www.heysuccess.com/opportunity/The-Youth-Enterprise-with-Innovation-in-Nigeria-(You-WiN!)-13349

[125] See: Konte et al. 2016: pages 494-459

[126] See: https://www.africaportal.org/dspace/articles/sndes-strategie-nationale-de-developpement-economique-et-social-2013-2017-sndes

[127] See on the Plan for an Emerging Senegal (PES): http://www.presidence.sn/en/pse/emerging-senegal

lack of policy coherence is a great burden hindering progress towards fully using STI for development.

## 4 Addressing the Shortcomings of STI Policies in African Countries

The national STI Agenda, which STI policy must identify and deliver, is hence the optimal acquisition and management of the sum of total sciences, technologies and innovations required to achieve socio-economic transformation. And because of the above interrelationships, the STI policy should embrace the whole system approach towards attaining a knowledge-based or innovation-led economy. It is worth noting that there are various critical groups of technologies that each developing country should strive to develop and to possess. These technologies include the technologies for meeting basic needs and services, such as food, water, transportation, shelter (construction) and energy, as well as the technologies for improving the quality of life, e.g. education, healthcare, environmental sustainability, etc. These technologies and their knowledge spheres should be a top national priority and should be essential in the creation process of a country's national development agenda and/strategy. As a global standard in national planning, the National Developmental Strategy or Agenda (NDS/NDA) usually would specify the list of national priorities, and would clearly indicate a modular approach to attend to the list of national priorities selected. The NDS/NDA should hence be designed in such a way that it could be easily decoded into an Integrated Multi-Sectoral National Developmental Action Plan (MSNDAP), which contains a set of well-defined large-scale national programmes for the proper development of the different economic sectors.

Nour (2013: 166) has concluded that the problems hindering R&D in Sudan, as an example, are mainly the unavailability of sufficient finance and human resources in the field of R&D. But, unavailability of funds and of human resources are only intermediate results of the national R&D system design and the associated operational processes embedded in that system. This is basically the case for most of the developing countries that since the early 1970s have not been able to utilize STI for development. Many factors leading to such system failures are found within the creation process of the national developmental strategy or national developmental agenda (NDS/NDA). The NDS/NDA creation process, which should be the first step in the process of defining national R&D priorities (together with a R&D sector's needs assessment), in many of these developing countries is politically controlled and in isolation from the science communities, instead of being a high-level political coordination process that fully engages the science community. In many developing countries, this politically-controlled process also lacks the necessary coordination between different government sectors and institutions to ensure coherence between the sought NDS/NDA and the other strategies/policies of different economic sectors in any specific country. Of course, this also includes the non-involvement of the private sector, which resembles the backbone and industrial machine for any of these countries. Such a process and system design would only produce a blue print document that is in most cases unrealistic and impractical to implement.

A typical document of this type would usually lack: Specific, Measurable, Attainable, Replicable, and Time-bound (SMART) strategy/policy goals; the required normative planning strategies, i.e. there are no explicit goals to be achieved in any specific time in the future; the required policy interventions to address the STI supply side, i.e. there is neither a funding plan nor a human resources plan for R&D, and of course no policy interventions to bring in the private sector and to provide the necessary incentives to foster R&D within the private sector. And of course, a typical document will also lack a strategy of how to promote and to foster regional and international cooperation, the matter that could greatly help strengthen plans towards regional and sub-regional integration to create the necessary synergies with neighbouring countries to collaborate in building the national and regional economies.

A good illustration of the above is the Arab Strategy for Science, Technology and Innovation (ASSTI), adopted by the Council of Ministers of Higher Education and Scientific Research in the Arab region in 2014, that proposed an ambitious agenda. Countries are urged to engage in greater international co-operation in 14 scientific disciplines and strategic economic sectors, including nuclear energy, space sciences and convergent technologies, such as bio-informatics and nano-biotechnology. These are science and technology spheres that most of the Arab States do not have any capacities in. The Strategy advocates involving scientists from the diaspora and urges scientists to engage in public outreach; it also calls for greater investment in higher education and training to build a critical mass of experts and to reduce brain drain.

The Strategy (ASSTI) nevertheless eludes some core issues, including the delicate question of who will foot the hefty bill of implementing the strategy. How can heavily indebted countries contribute to the platform? What mechanisms should be put in place to combat poverty and to offer greater equity of access to knowledge and wealth at national levels? Without pondered answers to these questions, coupled with innovative “out-of-the-box” solutions, no strategy will be able to exploit the region’s capabilities effectively. For the Strategy to fly, the region’s scientific community needs a coherent agenda containing a portfolio of solution-oriented scientific projects and programmes that expressly serve the region’s needs, along with clearly identified SMART goals and the necessary sources of funding.

The production of modern manufactured goods and related services is the essence of the Knowledge-driven Economy or the Innovation-led Economy, and evidence-based research indicates that the backbone of developed knowledge-based economies is the existence of diversified manufacturing capabilities. Abdul Rahman (2010) indicated that the European manufacturing sector employs more than 35 million people in 2+ million enterprises in 20+ industrial sectors, while another 60+ million people are working in related service areas for manufacturing. The manufacturing sector and the related service areas contribute about 55% of Europe's GDP. It is no secret that the production of modern manufactured goods and related services is also dependent on the Total National Capacity (TNC) in Science, Technology and Innovation (STI) of any State or region. The TNC in STI therefore requires an STI Policy encompassing practical modalities to build the capacity to acquire technology (technology transfer), to develop it (via R&D) further, and to build the capacity to apply, utilize and localize technology (technology diffusion) for development. The "TNC in STI" concept is here considered as a value chain for building technological capabilities in a country.

Another example of a strong presence of a diversified manufacturing sector is China; and the evolution of this sector holds the secret to the economic success in China. In the last decades, China has been able to reform its R&D system with a focus on specific factors to reap a great deal through the development of its STI platform. Today, China alone has 19.1% of the global research labour force in 2013, this being almost equivalent to China's share of the global population (19.3%). China's share of the world's GERD rose from 10.2% in 2007 to 19.6% in 2013, and some 84.6% of the research spending in China consists of experimental development (2013), compared to 64.3% in the USA (in the year 2012). As of 2012, China has 58,492 doctoral students living abroad, offering a strong impetus for future international scientific co-operation. The acquisition of machinery and software is more widespread as a method of innovation (prevalent for 64% and 85% of the manufacturing firms) than in-house R&D in China compared with other countries (Schneegans et al. 2016: page 50).

From the previous sections, we can conclude that the poor impact or the lack thereof of effective STI policies could be attributed to a set of problems associated with the R&D systems currently existing in many African countries. Lemarchand (2015: page 140-141) enlisted the below issues as general examples of what R&D systems face in many of the African countries:

(a) Limited experience in R&D priority determination, programming and management, and their association as an integral part of the national developmental strategy or agenda (NDS/NDA);
(b) Absence of national R&D programmes in dealing with the main economic priorities such as water, energy, and agriculture;

(c) Dispersion of the limited R&D capacity within the same country among numerous scientific fields, disciplines and institutions, resulting in small units of limited capacity, being then unable to deal effectively with real problems on a multi-disciplinary basis;
(d) Weakness of the linkages between the R&D system and the production sector, together with the scarcity of R&D units in the firms of the production sector itself;
(e) Scarcity of experimental development activity (the D component of R&D), oriented to the transformation of results of applied research to processes, goods, and services; in other words, there is more scientific research than technological development; and
(f) No motivation to resolve issues around limited financial resources with "out-of-the-box" innovative solutions.

The management of any well-designed R&D system requires a multi-disciplinary approach utilizing management sciences, economics, systems theory, sociology, legislation, scientific disciplines, banking, marketing, etc. This also means that different groups involved in government, the private sector, and the scientific community should become well versed in the issues on a collective basis so that each group can play its proper role in enhancing and utilizing the indigenous STI capacity. Currently little is done in this respect and what is done is usually done in separate silos.

In the following section 5, we will attempt to spell out a few practical and attainable solutions that could lay the foundation for a successful utilization of the STI platform towards sustainable development in the Developing States of Africa. For all practical purposes, instead of (a) indicating the need to establish and strengthen government structures and mechanisms for planning, budgeting, coordinating, managing and promoting scientific research, it is instead illustrated how this could be best done in an environment of limited resources; (b) indicating the importance of maintaining a proper balance between the various types of research (fundamental, applied, and experimental development) and supporting the development of a creative national scientific community, the priorities among the various types of research are illustrated and as well how to utilize such priorities as leverage to reform the research system so that it can support the development of a creative scientific community; and (c) indicating the need to optimize human, financial, institutional and informational resources, it will be illustrated how to create the necessary critical mass of human resources and the critical mass of investment to implement attainable work plans despite the limited resources (financial and human resources).

Section 5 will also present various recommendations on how to assess and to promote productivity, relevance, and quality effectiveness of national research and scientific and technological services in various sectors, and how to remove successfully organizational and managerial difficulties encountered in the execution of scientific research.

## 5 STI Policies for Successful Inclusive Growth in Africa

Centuries ago, Arab States were the hub of ground-breaking science. Today, they spend less on research and development (R&D) than any other region (0.3% compared to 0.41% for the sub-Saharan region), such being one of the major reasons spurring young scientists to seek greener pastures in the West. In the face of increasing insecurity over food, water and energy, however, even those Arab States dependent on oil revenue will have no choice but to espouse science and technology (S&T) to attain sustainable development. If they do not want to be left behind by the knowledge economy, they need to invest and to build a techno-preneurship and an innovation culture. Strong national and regional capacities in STI will be essential to addressing the development priorities of the region.

### 5.1 The Policy-Making Cycle

To address the issue of limited experience in R&D priority determination, programming and management, and their association as an integral part of the national developmental strategy or agenda (NDS/NDA), decision makers need to realize that there exists a scientific approach to the design and development of STI agendas and/or strategies, and that there are a number of techniques to successfully carry out the required analysis to identify both the needs as well as the feasible solutions within the finite resources available. An example of one of the most effective strategic management techniques that are simple to use is known as the Dynamic Strategic Fit (DSF) concept that is defined as the match over time between external factors to a system (risks and opportunities) and its internal factors (resources and skills). This RORs-technique (Results Oriented Responses) is best utilized in the environment of finite or limited resources such as the cases in most African countries.

Lemarchand (2015: page xxiii) argued that the policy-making cycle is a dynamic process and usually involves the following 5 main stages:

1. *Developmental agenda-setting:* This stage refers to the process by which STI-related problems and the linkages between STI and both the society and the economy come to the government's attention. This is the first phase of the STI engagement process and is usually optimally done through: sensitization, a preliminary assessment and commitment with a strong science community engagement to properly allow for needs assessment and the selection and mapping of the appropriate national priorities in government and industry, to be reached with the

optimal resources management and utilization. In developing countries, the National Developmental Strategy or Agenda (NDS/NDA) should indicate a modular approach to attend to the list of national priorities selected. The NDS/NDA should be designed in such a way that it could be easily decoded into an Integrated Multi-Sectoral National Developmental Action Plan (MSNDAP), which contains a set of well-defined mega-projects for the different economic sectors.

2. *Policy formulation:* It refers to the process by which STI policy options are formulated by the government to support the implementation of the Multi-Sectoral National Developmental Action Plan (MSNDAP). STI policies are basically enablers for the implementation of a well-designed STI agenda for development, and they are meant to remove all anticipated institutional, regulatory, technical, and financial impediments, to identify and to close all related implementation gaps, and to create the necessary synergy by utilizing an integrated approach in achieving the multi-objectives developmental action plan which any government is trying to implement. The STI policy will only be as good as the developmental action plan that the policy is supporting in its implementation, and should be as concise and practical as possible to guide the implementation process with a set of clear strategies. Abdul Rahman (2013: 4) indicated that an STI policy should be an integral part of a national socio-economic transformation programme and should comprise at least the following five basic components: STI for Policy, Policy for STI; STI and the Private Sector; International Collaboration and STI; and STI and Governance.

3. *Decision-making process*: It refers to the process by which governments adopt a specific course of action or non-action. In developing countries, this stage is usually done through the process of Expert Group Decision-making, which is as good as the competence of the members of the expert group. The science community could play a substantive role in guiding this process by utilizing many of the existing scientific approaches and techniques such as the Strengths/Weaknesses/Opportunities/Threats (SWOT) analysis and the Combinatorial Optimization Method (COM)[128] to mention a few. When dealing with sustainable development, the formulated multi-objectives problem is usually complex and the number of feasible solutions are many, and without the use of such techniques, a great deal of error becomes possible.

4. *Policy Implementation:* It refers to the process by which governments put STI policies into effect. This implies that all the required policy instruments for implementation should be ready and able, including the qualified human resources as well as the financial resources. A high level of commitment for all stakeholders is needed to reap the fruits of such programmes, which should be large-scale in nature and which are multi-objective and multi-sectoral to maximize the synergies produced between collaborating economic sectors. The "Sending Man to the

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[128] See on this method: https://en.wikipedia.org/wiki/Combinatorial_optimization

Moon" project of the United States of America in 1961 is the best example to be followed in African countries that want to successfully cross the development bridge. The following excerpts from President John F. Kennedy's "Urgent National Needs" speech to the Congress in 1961 are enlightening, as the momentum of the speech paved the way to successfully commission the project in only six years:

a. I believe we possess all the resources and all the talents necessary. But facts of matter are that we never made the national decision or marshalled the national resources required for such leadership. We have never specified long-range goals on urgent time schedule, or managed our resources and our time to ensure their fulfilment;
b. Let it be clear that I am asking the congress and the country to accept a firm commitment to a new course of action – a course which will last for many years and carry heavy costs – an estimated \$7-9 billion additional over the next five years; (in total spent were \$20 billion!);
c. Let me stress also that more money alone will not do the job. The decision demands a major national commitment of scientific and technical manpower, material and facilities. New objectives and new money cannot solve these problems – unless every scientist, every engineer, every serviceman, every technician, contractor, and civil servant involved gives his personal pledge that this nation will move forward, in the exciting adventure of space;
d. If we were to go halfway, or reduce our sights in the face of difficulty, it would be better not to go at all…It means a degree of dedication, organization and discipline which have not always characterized our R&D efforts…It means we cannot afford undue work stoppages, inflated costs of material or talent, wasteful interagency rivalries, or a high turnover of key personnel; and
e. It will not be one man going to the moon – it will be an entire nation. For all of us must work to put him there.

The African countries need this level of commitment and resource mobilization to succeed. The "Sending Man to the Moon" project is also an excellent example that illustrates how technical knowledge itself comes through R&D, specialized education and training, and learning-by-doing. Learning-by-doing is generated in terms of developing new skills acquired from involvement in the production activities. Such acquired skills open the way for adopting newer and more efficient technologies for production. On the other hand, R&D is ultimately responsible for introducing these new technologies. Therefore, investment in R&D is not only viable for increasing the degree of self-reliance, but it is the main instrument available for charting the road for technical progress and hence sustained economic growth in developing countries. The "Sending Man to the Moon" example also highlights the importance of the experimental development type of research that is essential for creating the required level of innovation as in the case of China illustrated earlier; and

5. *Policy evaluation:* It refers to the process by which the results of STI policies are monitored by both the State and the societal actors. The result may be a re-conceptualization of policy problems and solutions, in which the effectiveness, efficiency, and continuing appropriateness of policies and policy instruments are assessed and the results fed-back into another round of agenda-setting and/or reforming the development action plan.

## 5.2 Approaches for Developing the STI Agenda

Abdul Rahman (2013: 17) argued that it is only with the Total National Capacity (TNC) that a nation's STI agenda can be achieved and the economy can become innovation-driven and private-sector-led. But for the developing countries of Africa with a limited number of FTE researchers not exceeding 300 FTE researchers per million inhabitants in many countries as indicated in Figure 1, the implementation of the TNC approach could be unattainable when considering the issues of unsustainable economies and high rates of brain drain of educated people. The TNC approach, which is seen by many policy makers as the approach that led to the successful experience of development in Malaysia, might not be the best in an environment lacking the relevant STI Development Infrastructure (well-equipped universities, research institutions, and laboratories, etc.). The TNC approach supports a push system that focuses on the supply side first (where jobs availability is anticipated, but is not definite, etc.). And hence, this approach requires a well-established industry to absorb human capital being developed. This approach has been successful in developed countries and in emerging countries such as Malaysia. As indicated before, this approach could only be effective in an environment with the relevant research infrastructure, including well-equipped research institutes and laboratories and a sustainable and sufficient funding system to operate these institutes and laboratories.

Following the model of the "Man to the Moon" project and observing the benefits of implementing experimental development research projects, strongly proposed are the design and the implementation of Multi-Objectives Programmes (MOPs) to translate the Large-scale Pilot Projects Direct Implementation (LPPDI) approach into action for setting-up the STI agenda in developing countries. Through hands-on training and learning by doing, countries will build the STI national capacities in a modular form through the implementation of a limited number of specific national project(s) in few selected priority economic sectors, what is a good match for economies with limited resources. Examples of these "large-scale national programmes" might be building an automotive industry; or building small commercial aircrafts; or even building a nuclear program, where the specializations are well-defined. Such programs that facilitate SMEs development could also be a nucleus for developing mass production facilities, developed specifically for the manufacturing system parts that will be required in big quantities to meet either national demand or demand for exportation. National Mega-Projects, also for basic infrastructure development, will be the destination to many experts in the Diaspora turning brain drain into brain gain (an effective way of building proud among the fellow nationals!), while such projects could be implemented to promote sub-regional integration and to foster resources-pooling and collaboration instead of competition.

## 5.3 The Sustainable Development Goals (SDGs) and STI Development

The 2030 Agenda for Sustainable Development, together with the Addis Ababa Action Agenda, successfully define “What” needs to be done over the next fifteen years in terms of national priorities to achieve global sustainable development. While the scene is not currently promising in developing African countries, the goal to achieve this 2030 agenda presents itself as a golden opportunity for these countries to catch up with the developed world and to leapfrog into Inclusive Growth, if things were done in a scientific fashion. The Sustainable Development Goals (SDGs) problem is indeed a mathematically complex problem with a total of 194 objectives to achieve, a situation that would require mathematical modelling techniques such as combinatorial optimization or the use of algorithms to solve. Even the attempt of addressing a set of inter-related 3-4 goals at a time in a specific country would mean the full co-operation and coordination of at least 4-5 ministries within a national government; this is one matter that is rarely seen in developing countries, where for most of the time wasteful inter-agency rivalries are prevalent.

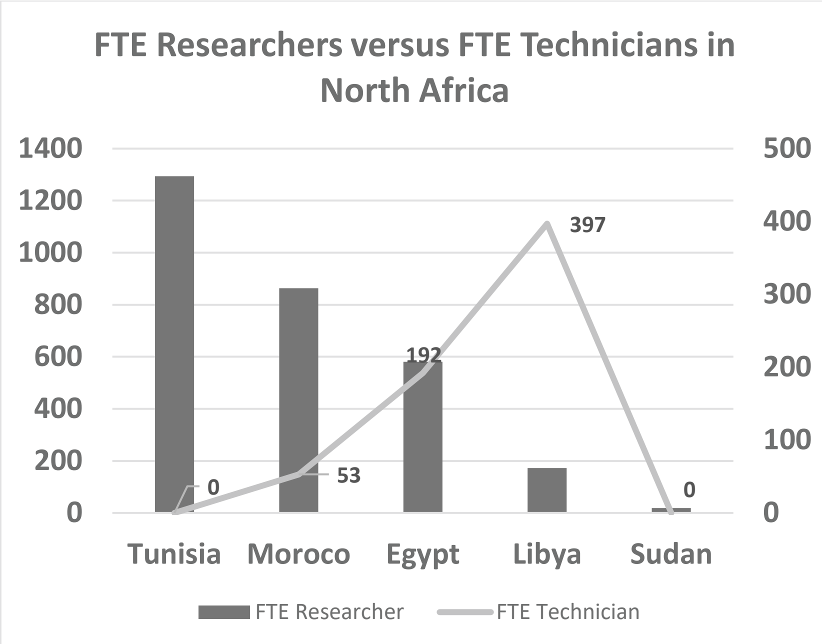
The nexus approach, for example the Water-Energy-Food (WEF) Security Nexus, would clearly articulate the practical benefits that an interdependent approach to these different sectors can offer - such as facilitating integrated planning and decision-making, informing the efficient allocation of resources between competing needs, and highlighting cross-sectional interactions that produce more synergy levels between these different actors. But the nexus approach shall in turn mandate the creation of a national Higher Council for Sustainable Development, to be led by the Head of State or the Prime Minister, to ensure that policies related to all these circles would interact more favourably and to achieve the status of an innovation-led economy which is sought. Moreover, the success of such an approach would not be guaranteed without the institutional framework that will ensure the proper identification of required measures for creating, funding and mobilizing private or public scientific and technological resources aiming at fostering and orienting the required knowledge- and innovation-producing activities. It is hence imperative that the STI policies are adapted to those needs to successfully adopt the nexus as a key enabler of sustainable development in the region, and to properly address the question of developing the required critical mass of human, institutional, and infrastructural prerequisites for relevant innovations. Using the 2030 SDG Agenda as a starting basis for a national developmental action plan will ensure the emergence of national R&D programmes dealing with the main economic priorities, such as water, energy, and agriculture.

With the overall education system in all its forms being central in forming the required "critical mass", galvanizing all these different education sectors, namely education, higher education, vocational training and education, technology development, science and innovation, for fostering an innovation and techno-preneurship culture in these countries, becomes a must. An integrated approach, clustering all the different education sectors into what could be called as the "Knowledge-Technology-Innovation" (KTI) Nexus, would again clearly articulate the practical benefits that an interdependent approach to these different education sectors can offer, such as facilitating integrated planning and decision-making, informing the efficient allocation of resources between competing needs, and highlighting cross-sectional interactions that produce more synergy levels between these different actors.

## 5.4 The "Critical Mass" of Human Resources for Development

Harnessing adequate technologies to produce modern quality goods and services of higher added value is the essence of an "innovation- and knowledge-based economy". Developing countries should hence be committed to create the required "critical mass" of experts and knowledge so that workers and entrepreneurs are becoming capable of developing and implementing nation-wide new and innovative technological programmes which are aligned with national developmental priorities. Currently, the technical and vocational education and training (TVET) programmes in many countries are very weak, and hence the numbers of technical workers (FTE technicians) are even much smaller compared to the number of researchers per million inhabitants as depicted in figure 5 below. This is a direct result of channelling those students who perform poorly into vocational education – rather than acknowledging the key role which qualified technicians play in the knowledge economy; the cases in Egypt and Sudan are just two examples for highlighting this negative trend. The negative selection of participants in vocational training programmes needs to be ended.

**Figure 5: Low Levels of FTE Technicians to Trigger the Required Economic Inclusive Growth Process in North Africa**



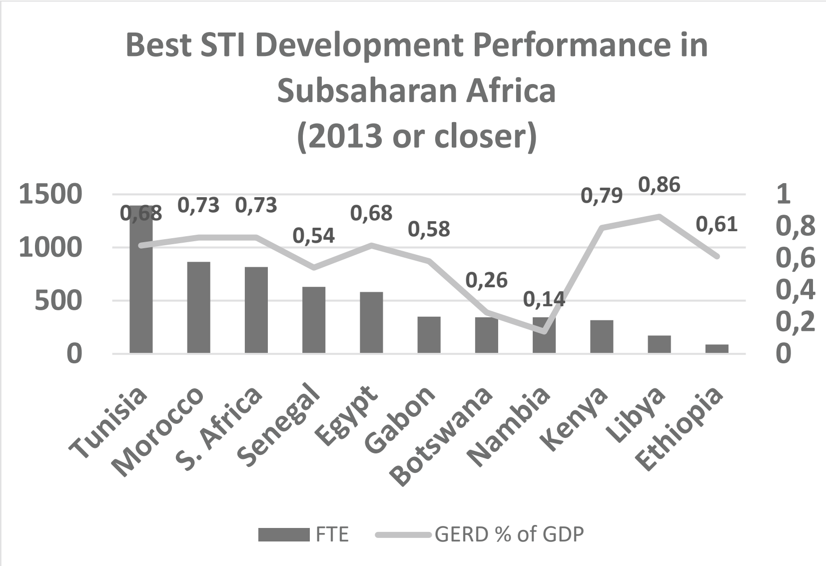

**Source**: UNESCO Science Report 2015
**Note**: Data for FTE Technicians for Sudan and Tunisia are not available.

As for the definition of the "critical mass", Lemarchand (2016) indicated that the "system" needs a critical mass of experts and a critical mass of investment to start showing results, which means that STI activities become visible within the economy. Below this minimum threshold, the empirical analysis of individual countries at global level shows little economic impact. This is well illustrated in figure 6, where it becomes obvious that African countries doing relatively better in terms of their economics are also doing well in terms of their numbers of FTE researchers per million inhabitants and/or the level of the GERD or both. When any country has around 1,200 FTE researchers per million inhabitants, this will scale a GERD investment of around 1% of GDP. This is empirically evident from the cases of South Korea, Singapore, and China in past decades, when at more than 1,000 FTE researchers per million inhabitants, these countries started obtaining results from their R&D work, by selling specific niches of technologies, or by specializing in specific know-how that makes their country more competitive at international level. Below that threshold, STI activities usually have little impact on the global economy of a given country. Other countries, for example Brazil or

Argentina, did not reach those thresholds yet (Brazil needs more FTE researchers and Argentina needs more GERD investment). This is consistent with the fact that it takes decades of continuous investment on STI activities by a given country to create qualified human resources and good laboratories (supply side), and to realize strong interactions with the "productive system of the country" (demand side). When countries have more than 1,200 FTE "researchers" per million inhabitants, the result is that the critical mass of researchers, who are working in the country, are spreading their knowledge into the society. One will also see that when a country is reaching the 1,200 FTE researchers per million inhabitants' milestone, the shares of the private sector investment on STI activities also start to match public sector investment levels. Similarly, countries with a strong manufacturing base indicate that they have a high ratio of FTE technicians.

Morocco has announced its intention of making education more egalitarian, through the institutionalizing of scholarship schemes to give rural and poor tertiary students the same opportunities as their peers from wealthier and urban backgrounds; other African countries could do likewise. This could be turned also into a good example of better resources management and resources utilization. Recent statistics show that in many developing countries, fresh university graduates remain unemployed for 2–3 years on average before landing his or her first job. This situation could be turned to an advantage. A national programme could be launched to recruit and to train fresh university graduates on leadership and interpersonal skills, and then to request them to teach for up to two years after graduation in rural areas where there is a chronic lack of primary and secondary school teachers. In addition to lifting the moral of these graduates during their unemployment period after graduation, they can inspire the young pupils in the rural areas to continue their education all through. This is an available and valuable resource that is never utilized despite the dire need for it. However, salary, organization and financing for these programmes may be a problem.

**Figure 6: Best STI Performing African Countries are below the required Thresholds to Show STI Results**




**Source**: UNESCO Science Report 2015

## 5.5 The “Critical Mass” of Investment for Development

As indicated earlier, any STI policy should comprise all the necessary identified measures for creating, funding and mobilizing private or public scientific and technological resources aiming at fostering and orienting knowledge-producing activities towards strengthening technological innovation through the build-up of robust National Innovation Systems (NISs). In a globalized knowledge-based economy, innovation is among the most critical drivers of advancement in all spheres, including social, economic, and environmental ones. To achieve such a goal, the people’s knowledge, talents and general skills need to be developed and strengthened with a focus on their mastering of science, technology, engineering and mathematics (STEM) education. It is hence critical to ensure adequate investments in STEM education at all levels. The development gap in Africa will hence need to be closed by covering the existing STI Development Investment gap. Ambitious national minimum target investments for STI need to be set up, using innovative “out-of-the-box” financial models, mostly depending on national resources.

The implementation of experimental development research projects acts as a “win-win-win” situation for developing countries, and should have priority over other types of research, as in the examples of China and other BRICS countries. Making use of the outcomes of the many nationally-applied research programmes being executed over the last decades, experimental development in these research areas could lead to a great deal of new products and/or industrial processes developed and marketed, especially if implemented in collaboration with the private sector. This could turn into the development of a series of spin-off companies that could generate a substantive cash flow which could support R&D activities. Implemented in the form of pilot projects, hands-on training and learning by doing for fresh college graduates would facilitate the building of a critical mass of experts in these selected fields, while making use of national experts from the Diaspora. Pilot development research projects could also bring on board academia, the private sector, and various ministries for an unprecedented inter-agency coordination and collaboration. Even regional and international cooperation become possible to allow for a better utilization of expertise and resources which one individual country does not possess. Developing countries could implement accelerator programmes for the development and testing of specific applications in any of the critical technology areas that are associated with basic services such as access to energy and water.

Most of the developing countries are paying heavy subsidies to ensure the supply and access of their constituents to basic clean energy and safe water services. Successful experimental development research projects in these economic sectors could also probe innovative solutions that are more cost effective and economic than the classic technologies used today. For example, implementing an energy-efficiency national programme could release substantive government funds spent today and have it directed towards an experimental development accelerator programme in promising renewable energy technologies.

At another level, the private sector could be encouraged to contribute to the R&D effort. An excellent example is how Moroccan telecom operators are currently supporting public research projects in telecommunications by ceding 0.25% of their turnover to a dedicated fund. This is a good approach to attract the private sector for such a growth via STI strategy. One could imagine a token amount being collected from large companies to finance R&D in their own sectors, especially in water, agriculture and energy. For the developing countries, it is imperative to create innovative funds to accelerate the transfer of innovative technologies by developing educational large-scale pilot projects in priority areas, including renewable energy systems. This will also help to build up a critical mass of experts and technicians in these countries.

The herewith discussed issues related to the role of STI in development, and the issues related to technology transfer, diffusion and management have become vital to the future development of Africa. Much experience has been acquired on the methods and options available to deal with such issues, but this experience remains in the hands of the few. Therefore, extensive capacity building and training is required for transferring knowledge in these areas to Africa. One of the major UNESCO's tasks over the last 60 years has been in the training of experts at all levels of a decision-making process. The UNESCO's activities in this field consisted mainly in supplementing the training of policy analysts in science and technology and in the management of scientific research by giving special attention to the problems of the developing countries. Training activities, even in restricted fields of policy-making in science and technology for development, call for flexible approaches to accommodate the needs of specific target groups. Currently, UNESCO Cairo[129] is working on developing training material for STI policy development in developing countries. The purpose of such exercises is the development of a critical mass of competent analysts, planners, and managers for the formulation of science and technology policies and plans in developing countries as well as the strengthening of institutional capacities for training and research in this area at the national, sub-regional and regional levels.

## 6 Conclusions and Policy Recommendations

Today, discoveries in life sciences and innovative technologies offer developing countries a golden opportunity to improve social welfare and productivity. By ensuring that they possess sufficient absorptive capacity to build on the backlog of unexploited technologies and to benefit from the associated lower risks, these countries can now leapfrog over the expensive investment in infrastructure. Value creation nowadays depends increasingly on a better use of knowledge, whatever its form and whatever its origin, and whether the process technologies used are developed domestically or not.

There are many lessons learned from UNESCO's long-term engagement and accumulated experience in STI policy development and reviews. In conclusion, sustained economic inclusive growth shall only be attained as a direct consequence of sustained technological progress through the application of technical knowledge in the production of goods and services. Lack of the human capital and of investment funds should not deter African countries from indulging to achieve such endeavour. We have seen that despite the African countries have started this STI development trip in the early 1970s, little has been achieved, mostly because these countries have been using the same STI model that developed countries have been using under the notion of one-size-fits-all. As indicated previously, the results were the status quo with insufficient government commitments for STI and research, including financing of technology and capacity; a disconnect between policymakers, scientists and society in generating, sharing and utilizing scientific

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[129] See: http://www.unesco.org/new/en/cairo

knowledge; poorly designed national STI policies lack of adequate organizational capacities to implement policies; and ineffective governments to ease doing business.

The following list briefly sums up the recommendations that could, as a starting basis, re-direct the march of these countries towards sustainable development:

1. For STI to live to their full scale and to be truly transformational in developing countries, STI activities need to be connected to all segments of the society; it is necessary to translate innovative and creative problem-solving approaches from global to national and local levels. To successfully achieve the above, these countries need to embrace best proven practices which are associated with already established networks of national and regional champions of STI, regional champions from business and from academia, from government and the political arena, and from the society at large. This is necessary to bring about the aspired change towards achieving sustainable development;
2. Developing countries should focus on building their diversified manufacturing capabilities, the backbone for developing knowledge-based economies, by using a modular approach;
3. The Large-scale Pilot Projects Direct Implementation" (LPPDI) approach is more suitable for African countries for developing the STI development agenda, as it facilitates the building of the basic manufacturing capabilities while utilizing the Diaspora in building international human capacities, and fostering sub-regional integration and collaboration;
4. Developing Countries can adopt the 2030 Agenda as their national STI Development Agenda and utilize the Nexus Approach as an interdependent approach to the different nexus sectors to facilitate integrated planning and decision-making, to inform the efficient allocation of resources between competing needs, and to highlight cross-sectional interactions that produce more synergy levels between these different actors. This could be the starting basis of solving some of the problems arising from limited resources. The Water-Energy-Food Security (WEF) Nexus & the "Knowledge-Technology-Innovation" (KTI) Nexus are examples that could be followed;
5. The policy-making cycle is a dynamic process that starts with the application of scientific techniques for the development of the national development agenda, and must engage the science community as a necessary condition for the success of such a process. The STI policy document would not be effective without Specific, Measurable, Attainable, Replicable and Time Bound (SMART) goals and explicit policy interventions to address both the supply and the demand side;
6. In terms of the R&D system, developing countries should follow the footsteps of China and of other BRICS countries and should focus heavily on experimental development types of research. There are various critical groups of tech-

nologies that each country should possess, and these priority technologies will ensure the access of the public to basic services such as clean water and modern energy;

7. To be effective, successful experimental development research projects in these economic sectors are a necessary condition to probe innovative solutions that are cost-effective and more economic than the classic technologies used today. For developing countries, they might prove more useful in sectors where the government is paying heavy subsidies that could be freed and support R&D instead. For example, implementing an energy-efficiency national programme could release substantive government funds spent today on energy subsidies and instead have it directed towards an experimental development accelerator programme (EDAP) in promising renewable energy technologies;

8. Each country should utilize its stock of applied research results to pursue the development of new products and processes in these research areas that possess some comparative advantages;

9. Investment in R&D is not only viable for increasing the degree of self-reliance, but it is the main instrument available for paving the road to technical progress and sustained economic growth;

10. Innovative “out-of-the box” modalities of funding and investing into research are in order. A good example is the US Government commitment shown in the implementation of the "Send the Man to the Moon" project in May 25, 1961[130];

11. Developing Countries can launch a national programme to make use of the existing qualified human resources by recruiting and training fresh university graduates from all academic disciplines on leadership and soft skills and request them to teach for up to two years after graduation in rural areas where there is a chronic lack of primary and secondary school teachers. In addition to lifting the moral of these graduates during their unemployment period, they can inspire the young pupils to continue their education all through. This is an available and valuable resource that is never utilized despite the dire need for it; it is possible to solve the financial and organizational problems of such a programme;

12. Developing countries are to follow the example of the Moroccan telecom operators, as well as many others in the private sector, to support public research projects in telecommunications by ceding 0.25% of their turnover to a dedicated fund. One could imagine a token amount being collected from large companies to finance R&D in their own sectors, especially in water, agriculture and energy; and

13. For the developing countries, it is imperative to create innovative funds to accelerate the transfer of innovative technologies by developing educational large-scale pilot projects in priority areas, including the renewable energy systems.

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[130] See: https://history.nasa.gov/moondec.html

This will also help to build up a critical mass of experts and technicians in these countries.

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# Successful Cases of Building Capacity in Africa's Science, Technology and Innovation Systems

**Emmanuel Nnadozie[1], Thomas Munthali[2], Robert Nantchouang[3], Samia Mohamed Nour[4], and Nicholas Ozor[5]**

## 1 Introduction

In this newly emerging economic system, which is characterized by both increasing globalization and the development of information and communication technologies (ICTs), science, technology and innovation (STI) are becoming more important for all countries (Nour, 2012, 2013). In September 2015, the United Nations (UN) have approved the Agenda 2030 on Sustainable Development Goals (SDGs) which have benefitted from a common position brought in from Africa. Africa is hence committed to achieving the SDGs, including sustainable development goals concerned with quality education, industry, innovation and infrastructure.[6] African countries recognize the importance of enhancing the STI capacity

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[1] Prof. Emmanuel Nnadozie, an economist and development expert, became the Executive Secretary of the African Capacity Building Foundation on Dec. 1, 2013.

[2] Dr. Thomas Chataghalala Munthali is the Director of Knowledge and Learning at the African Capacity Building Foundation (ACBF), a technical agency of the African Union on capacity development.

[3] Dr. Robert Nantchouang is an economist and a statistician from Cameroon, and the Senior Knowledge Management Expert in the Knowledge, and Learning Department, the African Capacity Building Foundation (ACBF).

[4] Prof. Dr. Samia Satti Osman Mohamed Nour, Full Professor at the University of Khartoum, Economics Department, Faculty of Economic and Social StudiesKhartoum, Sudan

[5] Nicholas Ozor, Ph.D., is the Executive Director of the African Technology Policy Studies Network, Nairobi, Kenya, a transdisciplinary network of researchers, policymakers, private sector actors, and civil society actors promoting the generation, dissemination, use and mastery of Science, Technology and Innovations (STI) for African development.

[6] The 17 new Sustainable Development Goals, also known as the Global Goals, aim to achieve sustainable development. They are the following: SDG 1: No poverty, SDG 2: Zero hunger, SDG 3: Good health and well-being, SDG 4: Quality education, SDG 5: Gender equality, SDG 6: Clean water and sanitation, SDG 7: Affordable and clean energy, SDG 8: Decent work and economic growth, SDG 9: Industry, innovation, infrastructure, SDG 10: Reduced inequalities, SDG 11: Sustainable cities and communities, SDG 12: Responsible consumption, and production, SDG 13: Climate action, SDG 14: Life below water, SDG 15: Life on land, SDG 16: Peace, justice and strong institutions, and SDG 17: Partnerships for realising the goals.

for the continent's transformation and its sustainable development and have reflected this accordingly in the Agenda 2063 which is the continent's 50-year development vision; in this context also the 10-year Science, Technology and Innovation Strategy for Africa (STISA-2024) is relevant that was adopted by the African Union (AU) Heads of State and Government Summit which was held in June 2014. STISA-2024 is part of the long-term people-centred AU Agenda 2063, which is underpinned by science, technology and innovation as multi-function tools and enablers for achieving continental development goals. The strategy places science, technology and innovation at the heart of Africa's socio-economic development and growth.[7] Analogues to the African Union Consolidated Plan of Action (AU-CPA), STISA-2024 focuses on three interrelated conceptual pillars, of STI capacity building, knowledge production, and technological innovation.

As demonstrated in the process of adoption of the STISA-2024, there is increasing recognition by African governments, scientists and policy makers on the important role of STI as a driver of economic growth and sustainable development (see for instance, NEPAD, African Innovation Outlook II, 2014, p. 9). This increasing recognition appears from the fact that many African countries have developed STI policies, strategies and plans. The increasing recognition of the importance of capacity building in STI is also demonstrated from the establishment of the Department of Human Resources, Science and Technology by the African Union (AU), the establishment of an African Conference of Ministers responsible for Science and Technology (AMCOST) by the African Union (AU), and the adoption of the African Science Technology and Innovation Indicators (ASTII) Initiative.

In view of the increasing international and African recognition of the importance of STI for enhancing sustainable development as mentioned above, the African Capacity Building Foundation (ACBF) produced also for 2017 the Africa Capacity Report/ACR (ACBF, 2017), which focuses on building capacity for science, technology and innovation for Africa's transformation. Particularly, it discusses key determinants and components of capacity building for STI in Africa, it highlights the importance and necessity of building the required capacity for STI in Africa for enhancing inclusive sustainable development in Africa to achieve the continent's transformation through STI and to achieve the AU development Agenda 2063 and the UN's Agenda 2030. It provides a broad analysis since it focuses not only on the general description of the importance of STI for development in Africa, but its main value addition is in its paying attention to the capacity dimensions of the STI in Africa.

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[7] See the African Union Commission/AUC (2014) "Science, Technology and Innovation Strategy for Africa (STISA-2024)", pp. 8, 10. Web Access: http://www.hsrc.ac.za/uploads/pageContent/5481/Science,%20Technology%20and%20Innovation%20Strategy%20for%20Africa%20-%20Document.pdf [Accessed on June 16, 2016]

Based on the above, this paper uses the main results of the ACR 2017 (ACBF, 2017) to present the required capacities and attendant challenges for developing STI in Africa while highlighting the possibilities through successful country cases, of building capacity in science, technology and innovation in Africa. Concerning the general structure, this paper comprises four sections organized as follows: section 1 provides an introduction. Section 2 explains key initiatives undertaken toward improving and building capacity in science, technology and innovation for Africa's transformation. Section 3 discusses successful country cases of building capacity in science, technology and innovation in Africa. And, section 4 provides the conclusions and policy recommendations.

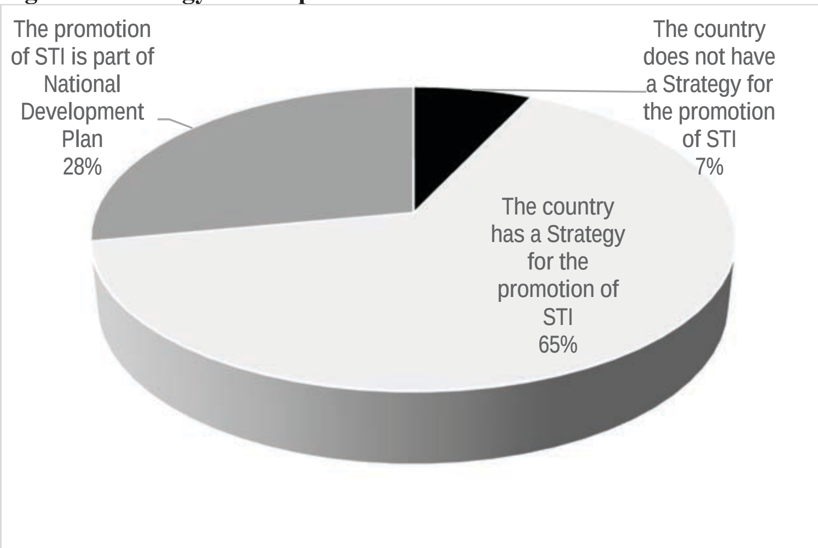
## 2 Building Capacity in Science, Technology and Innovation for Africa's Transformation

This section assesses the commitment to STI strategies and to capacity development, and explains key initiatives undertaken toward building capacity in science, technology and innovation for Africa's transformation, mainly, key STI initiatives in research and development (R&D) and in higher education in Africa, at national level before discussing commitments at continental level.

### 2.1 Commitment to STI strategies and capacity development at national level in Africa

The ACR 2017 (ACBF, 2017) illustrates that the main critical challenges confronting science, technology and innovation in Africa include, the lack of financial resources, the lack of human resources, the lack of efficient institutions, the huge brain drain, the lack of enabling political, social and economic conditions, the lack of awareness, the lack of incentives, and the small contribution from the private and business sector. Despite the critical challenges confronting building capacity for STI in Africa, African countries show commitment to adopt STI strategies. Findings from the ACR 2017 confirm the increasing recognition of the importance of STI strategies and of capacity development in African countries. The report reveals that the majority and nearly two third of African countries surveyed have a strategy for the promotion of STI (65%); and for more than a quarter of the African countries included in the survey, the promotion of STI is part of the National Development Plan (28%); whereas few and less than tenth of the African countries surveyed indicated the absence of a strategy for the promotion of STI (7%) (figure 1).

**Figure 1: Strategy for the promotion of STI in African countries**

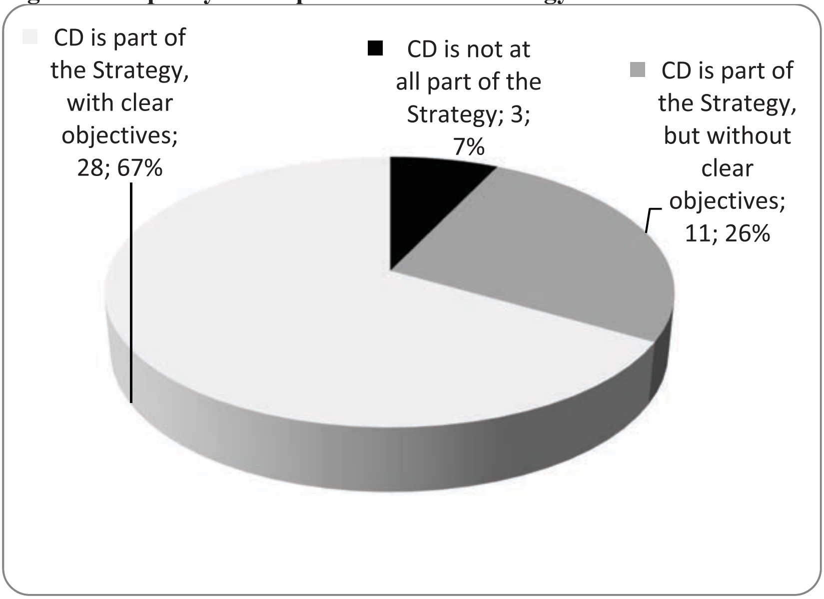



**Source:** ACBF/Africa Capacity Building Foundation STI Survey (2016)

Moreover, the results of the survey indicate that for the majority and nearly two third of African countries, capacity development (CD) is part of the strategy with clear objectives (67%); for more than a quarter of the African countries included in the survey, capacity development (CD) is part of the strategy, but without clear objectives (26%); whereas few and less than tenth of the African countries indicated that capacity development (CD) is not part of the strategy for the promotion of STI (7%) (figure 2).

Hence, these results imply an increasing recognition and commitment of a major share of the African countries to improve the institutional and regulatory framework for STI by the adoption of a strategy for the promotion of STI and by incorporation of capacity development (CD) in the strategy. However, in almost all the countries, the allocation of resources for STI capacity development (CD) and the extent of implementation of the strategies remain lacklustre. This implies that further efforts are needed by all stakeholders to improve the implementation of STI strategies and capacity development (CD) strategies in all African countries.

**Figure 2: Capacity development and STI Strategy in African countries**




**Source:** ACBF/Africa Capacity Building Foundation STI Survey (2016)

## 2.2 STI initiatives in higher education

At the national level, since long, African higher education institutions play a significant role in capacity building and in socio-economic development. Both, the typical African universities with specialized programmes in science, technology and engineering and the African universities specialized in S&T play significant roles in capacity building (CD) in STI on the continent. Recognizing that many specialized S&T universities and higher education institutions exist in several African countries (see Annex 1), the longstanding presence of specialized S&T programmes and universities implies that several African countries place S&T at the heart of higher education institutions to achieve sustainable development and inclusive growth. The widespread existence of specialized S&T universities in Africa provides evidence that investment and training in specialized S&T in higher education and research institutions remain significant in many African countries. It also emphasizes the importance of universities and higher education institutions in capacity building in S&T in Africa.

For a very long time, S&T education in many African countries has been mainly provided by public specialized S&T universities. However, there is a growing trend of S&T education being provided by private specialized institutions in some African countries (e.g. Benin, Cameroon, Congo, Togo, and Zambia). Other

African countries, such as Egypt, Kenya, Nigeria, Sudan, and Tanzania, seem to be relatively reliant on a combination of public and private specialized S&T universities, with growing emphasis on public-private partnership. On the one hand, the Nelson Mandela African Institution of Science and Technology which was inaugurated in 2012 in Tanzania is a public educational and research institute that focuses on education, training and research in the fields of science, engineering, and technology. It aims to build capacity for the next generation of qualified African scientists, engineers and technologists in respective fields, to promote science, engineering, technology, and innovation and their applications to foster Africa's development. On the other hand, the African University of Science and Technology established in 2007 in Nigeria is a private Educational and Research University that aims to improve capacity in S&T in Africa through offering education and applied research in science, engineering, and technology. It aims to foster capacity building in STI and engineering by enabling African students to acquire the scientific, technological, and engineering knowledge to help in achieving Africa's transformation.

In moving forward, African countries must mobilize and widen the involvement of all public and private higher education institutions to improve Africa's capacity building in STI to achieve inclusive growth and sustainable development. These aims require sustainability of commitments to STI development both at national and continental levels.

## 2.3 Commitment to STI at regional and continental level

At the regional level, African regional institutions (e.g. AU, NEPAD) contribute to capacity building in STI in Africa; there are various initiatives undertaken to promote regional STI collaboration. For instance, an early initiative on capacity building in STI and R&D (research and development) was undertaken by the African Union Commission (AUC) which established the Department of Human Resources, Science and Technology to develop human capital, education, and S&T in Africa. Relatedly, the African Union Commission (AUC) established in 2003 a Conference of Ministers in charge of Science and Technology to develop S&T in Africa. The African Union (AU) initiated the Consolidated Plan of Action (CPA) in 2005 as an instrument for capacity building, knowledge production, and technological innovation in the African countries. The CPA generated political support which paid off in the achievement of significant success in several areas of STI development, including establishment of The Pan African University; four networks of Centres of Excellence within the African Biosciences Initiative; the Bio-Innovate and the African Biosafety Network of Expertise; the Southern Africa and West Africa Networks of Water Centres of Excellence; the virtual African Laser Centre; and the African Institutes of Mathematical Sciences (UNESCO, 2015).

Implementation of the CPA also resulted in the launch of the African Science, Technology and Innovation Indicators (ASTII) Initiative, the establishment of the African Observatory for Science, Technology and Innovation (AOSTI), and the introduction of the African Union Research Grant (AURG), administered by the AUC. A major output of the ASTII Initiative is the publication of the African Innovation Outlook Reports which are produced biennially, and which provide evidence on the state of STI in the surveyed African countries.

Based on the experiences drawn from implementing the CPA, the STISA-2024 has emerged as the blueprint for the implementation of the Agenda 2063, focusing on three interrelated conceptual pillars, namely, STI capacity building, knowledge production, and technological innovation. The STISA-2024 exhibits a stronger and sharper focus on innovation and science for the development of the CPA. It focuses on six key priority areas which include: eradication of hunger and achieving food security; prevention and control of diseases; communication (physical and intellectual mobility); protecting our space; living together – building society; and wealth creation. In achieving the objectives within these key priority areas, the STISA-2024 defines four action pillars which include: upgrading or building research infrastructure; enhancing technical and professional competences; innovation and entrepreneurship; and providing an enabling environment for STI development in Africa (see table 1). Through the STISA-2024, there is a great expectation for the establishment of an African Science, Technology and Innovation Fund (ASTIF) which is considered as vital to sustain STI programmes, such as the networks of Centres of Excellence, encouraging creative individuals and institutions to generate and apply S&T, and to promote technology-based entrepreneurship. However, funding sources and mechanisms for the ASTIF remain one of the major obstacles to the realization of this goal. The lack of dedicated internally generated funds from AU member states poses significant threats to the implementation of STISA-2024. Member States must deliver on their commitment to ramp up investment by devoting 1% of GDP to R&D to make ASTIF operational. In adopting the STISA-2024, Member States, Regional Economic Communities (RECs), and development partners have been called up to align and to use the STISA-2024 as a reference framework for the development and implementation of the national and regional strategies for STI.

**Table 1: Summary of STISA-2024 priority areas**

| S/N | Priorities | Research and/or Innovation Areas |
|---|---|---|
| **1** | Eradicate Hunger and ensure Food and Nutrition Security | - Agriculture/Agronomy in terms of cultivation technique, seeds, soil and climate<br>- Industrial chain in terms of conservation and/or transformation and distribution infrastructure and techniques |
| **2** | Prevent and Control Diseases and ensure Well-being | - Better understanding of endemic diseases - HIV/AIDS, Malaria Hemoglobinopathies<br>- Maternal and Child Health<br>- Traditional Medicine |
| **3** | Communication (Physical & Intellectual Mobility) | - Physical communication in terms of land, air, river and maritime routes equipment and infrastructure and energy<br>- Promoting local materials<br>- Intellectual communications in terms of ICT |
| **4** | Protect our Space | - Environmental Protection, including climate change studies<br>- Biodiversity and Atmospheric Physics<br>- Space technologies, maritime and sub-maritime exploration<br>- Knowledge of the water cycle and river systems as well as river basin management |
| **5** | Live Together – Build the Society | - Citizenship, History and Shared values<br>- Pan Africanism and Regional integration<br>- Governance and Democracy, City Management, Mobility<br>- Urban Hydrology and Hydraulics<br>- Urban waste management |
| **6** | Create Wealth | - Education and Human Resource Development<br>- Exploitation and management of mineral resources, forests, aquatics, marines, etc.<br>- Management of water resources |

**Source**: The African Union Commission/AUC (2014), p. 24.

At the international level, international collaborative bilateral and multilateral partnership projects and initiatives (e.g. UNESCO and EU- AU cooperation) contribute to STI capacity building in Africa in different sectors, including: public health; agriculture, food security and nutrition; human resources development and education and research; and water, and energy and environment.

## 3 Successful Country Cases of Building Capacity in Science, Technology and Innovation (STI) and Implementing STI Policies and Strategies

This section explains the successful country cases of building capacity in science, technology and innovation in Africa and provides insights into STI policy development and implementation in selected African countries, namely Ethiopia, Rwanda, Nigeria, Morocco, Zimbabwe, and Tanzania. The selection of these countries was done primarily because of their performance (highlighting successes and less convincing outcomes) as ranked by the Global Innovation Index 2015 (Cornell University, INSEAD and WIPO 2015).

*Case 1: Ethiopia*

Despite the slow start of STI policy, the Ethiopian government has given much emphasis to the development of STI in the country. The government has formulated and adopted national STI policies and strategies to spur STI development in the country. The 2006 and 2012 National STI Policies are among them. The 2012 (STI) policy was aligned to the national vision of '*alleviating poverty and the country's ambitious plan to join the middle-income countries by around 2025'* as envisioned in the Growth and Transformation Plan of Ethiopia. The implementation of STI policy has led to successful stories and experiences in health and trade sectors in Ethiopia, as depicted in boxes 1 and 2, respectively. The rationale for choosing these sectors - health and trade - is because of the importance of these sectors for sustainable economic development in Ethiopia.

The Ethiopian Health Extension Programme (HEP), which was launched in 2014, could be cited as a successful innovative idea that makes proper use of technologies and expands the national health programme to include community-based health interventions. HEP is an innovative community-based health care delivery system aimed at providing essential promotional and preventive health care services and improvements of the families' health status (box 1 and figure 3).

The Ethiopian Commodity Exchange (ECX) is a successful market model and is another success story which makes proper use of technologies. It integrated several marketing activities and facilitated the ease of trade transactions by reducing the trading chain, and has contributed to increased producers' gain out of products marketed. The ECX has benefitted especially the local farmers, besides facilitating the trading activities. The use of mobile phone and internet technologies has reduced information asymmetry and has reduced price margins due to information gaps (Box 2).

**Box 1: Success story and experience in introducing STI in the health sector in Ethiopia: The Ethiopian Health Extension Programme (HEP)**

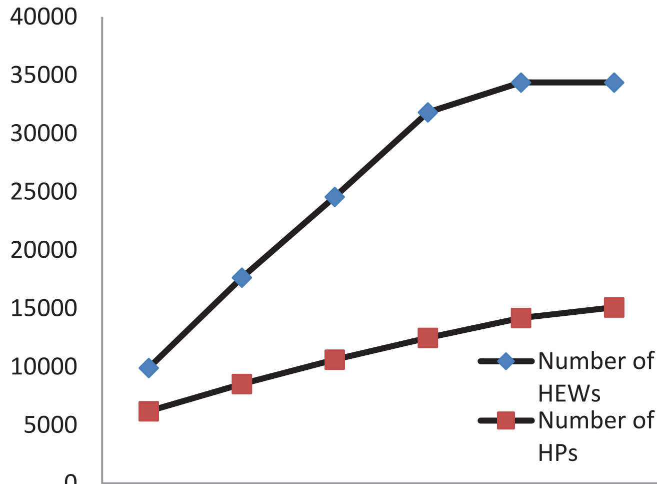
The HEP is considered as the most important institutional framework for achieving universal coverage of primary health care to the rural population in a context of limited resources. The program mobilizes Health Extension Workers (HEWs) at the village level; it promotes health at the village level by implementing clearly defined health service packages. HEP has had tangible effects on the thinking and the practices of rural people regarding disease prevention, family health, hygiene, and environmental sanitation. The HEP has been central to the community health system's strengthening, including providing standards and manuals and regular evaluations of the programme, and providing in-service training focused on identified skills gaps, and supportive supervision.

Through the HEP Ethiopia has moved onto an improved trend path for child mortality, family planning, antenatal care, and vaccination of children. HEP led to the recruitment and training of HEWs; HEP aimed to recruit, train, and deploy two female HEWs to a health post that serves a population of 3,000 to 5,000 people. One of the distinctive strategies in the implementation of HEP is the recruitment of female high school graduates from their respective villages, where possible, and from nearby villages. After recruitment from their respective villages, the female high school graduates receive one-year intensive theoretical and practical training on 16 health service packages. More than 30,000 HEWs were trained and deployed in about 15,000 villages.

The HEP lead to improved access to health services in remote areas in Ethiopia; since the beginning of the scale-up, more than 15,000 health posts have been built and more than 34,000 HEWs were deployed. The number of HEWs and health posts increased sharply over the period 2006 to 2011 (see Figure 3). A 2010 study initiated by the Ethiopian Government (Ministry of Health) indicates that about 92% of households were within an hour's (5 km) distance from a health facility. The HEP has enabled Ethiopia to increase primary health care coverage from 76.9% in 2005 to 90% in 2010. The average time taken to reach the nearest health facility has been reduced by half – from 60 minutes in 2005 to 30 minutes in 2010 – for the three largest regions (Amhara, Oromia, and Southern Nations, Nationalities, and Peoples' Region/SNNP).

**Source**: The Horn Economic and Social Policy Institute (HESPI) (2016); USAID, 2012; Centre for National Health Development in Ethiopia (CNHDE), 2011; and the ACBF's ACR 2017 for details

**Figure 3: Growth of the number of Health Extension Workers (HEWs) and Health Posts (HPs) in Ethiopia**




| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|
| Number of HEWs | 9900 | 17653 | 24571 | 31831 | 34382 | 34382 |
| Number of HPs | 6191 | 8528 | 10621 | 12488 | 14192 | 15095 |

**Source**: USAID, 2012
**Note:** Health Extension Workers (HEWs) and Health Posts (HPs)

**Box 2: Success story and experience in introducing STI in the trade sector of Ethiopia: The Ethiopian Commodity Exchange (ECX)**

Despite the challenges the ECX had faced at the early stage of implementation, particularly from traders, the ECX has been instrumental in channelling significant volumes of cereals and cash crops, especially that of coffee exports and sesame exports, to pass through the channel which was established via the ECX. It grew out of an ACBF-funded initial research done by The HESPI and was developed into a guide for the operations of the export market. The government support through the provision of laws and legislations did empower the ECX and was key to its success. Currently, the ECX stands on its own; in the initial years, it had received significant support from the Ethiopian government and from the donors. This exemplifies a successful transition from donor dependence to self-reliance.

The ECX shows a remarkable market performance in the initial years; for instance, in just three years after its establishment, the ECX has managed to exchange US$ 1 billion with zero default. The trade volume grew remarkably from 138,000 tons in 2008-9 to 508,000 tons in 2010-11. The trade value has increased by 368% in just three years, and the number of warehouses also grew from one in Addis Ababa to 55 located in 17 districts.

**Source**: The Horn Economic and Social Policy Institute (HESPI) (2016)

The major lessons learnt from the case of Ethiopia is that despite a slow start a country can make rapid improvements in subsequent years if there is policy commitment. Other lessons in the areas of STI in Ethiopia are:

- The government's commitment in establishing the relevant institutions (such as the Ministry of S&T, research institutions, universities, and Technical Vocational Education and Training/TVETs) have contributed to progress; and
- Designing relevant policies that encourage the expansion and development of STI activities, such as awards for innovation, and the 70/30 percent allocation of resources in favour of S&T in the education system, have also made a big difference in the number of S&T graduates.

*Case 2: Rwanda*

In Rwanda, STI are cross-cutting activities that involve the Ministry of Education, the Ministry of Youth and ICT, the National Commission of S&T, the Rwanda Development Board, and the National Industrial Research and Development Agency. Rwanda's Vision 2020 recognizes the crucial role of STI in transforming its socio-economic landscape from an agrarian economy into a knowledge-based one, and hence achieving socio-economic transformation (see figure 4). STI in Rwanda's Vision 2020 is seen as a strong enabler in all priority sectors, including education, ICT, health, and agriculture.

**Figure 4: The role of STI in Rwanda's Vision 2020**


**Source**: ACBF and Institute of Policy Analysis and Research in Rwanda (2016)

The innovations which were generated and the technology transfers which were promoted by the University of Rwanda have yielded tangible results, such improving the quality of Maraba coffee, promoting the biogas uptake in prisons, and the banning of plastic bags in Rwanda. These three examples clearly show how technology, applied research, and innovation could significantly contribute to socio-economic development. To support the innovative projects the Government of Rwanda, through the Ministry of Education in partnership with UNECA, has established the Rwanda Innovation Endowment Fund (RIEF) in 2012 (see box 3). The major lesson learnt from the case of Rwanda is that the establishment of RIEF, despite insufficient financing, shows some commitments by the government to fund STI. Between 2013 and 2015, the government offered US$ 100,000 for the funding of innovation projects in Rwanda. Further lessons learnt reveal that applied research and innovation conducted in collaboration with universities could significantly contribute to socio-economic development. And, a clear strategy developed by the African governments could guide the implementation of IT programs.

**Box 3: Rwanda Innovation Endowment Fund (RIEF)**

The Government of Rwanda, through the Ministry of Education, in partnership with UNECA has established RIEF to stimulate economic transformation through applied S&T and research in innovative market-oriented products and processes in priority areas of the economy. For the initial phase, the fund focused on three priority areas: agriculture, manufacturing, and ICT. For the second round of funding, energy was included as the fourth priority area. The initial phase was supported by funding from the Government of Rwanda and UNECA. For the initial phase, RIEF grant awards (with a sum of US$ 50,000 for three years) were offered to 8 innovation projects in 2013. For the second phase, RIEF grant awards (with the sum of US$ 50,000) were offered to 6 projects in 2015.

**Source**: ACBF and Institute of Policy Analysis and Research in Rwanda (2016).

*Case 3: Nigeria*

In Nigeria, some of the pertinent issues for consideration include the establishment of a National Science and Technology Fund (NSTF) as a source of funding for the implementation of the S&T policy, and the establishment of a National Agency for Science and Engineering Infrastructure (NASEI). A major new policy development was the creation of a new university[8] to focus on science and technology and the increase of the number of polytechnics. The National STI Policy (2012)

[8] This is a campus of the Nelson Mandela University of Science and Technology.

has developed new businesses geared towards advancing sustainable development in Nigeria. STI is now addressed nationally as an instrument of poverty alleviation and as a road map catalyst for sustainable development. An important message and outcome of the STI policy in Nigeria was the creation of several new institutions covering various sectors, including S&T, engineering, energy, environment, water, agriculture, and industry. These institutions work together in partnership with government institutions and the private sector to contribute to sustainable development.[9] If this change is in Nigeria really becoming reality, this model of partnership can become a lesson also for other African countries.

*Case 4: Morocco*

In Morocco, initiatives in the field of STI include a set of laws and policies in important fields. These developments include the new strategy of scientific research and the creation of the National Support Fund for Scientific Research and Technological Development. The new strategy of scientific research (2015-2030) in Morocco focuses on educational reform and supporting scientific research through a new funding system. At the level of the research funding system, so far, funding for research was provided almost entirely by the state, while inputs from the private sector are still low. With the provision of a new system of research funding, significant capacity building programmes were implemented (National Strategy for the Development of Scientific Research on the Horizon 2025). The major lesson learnt from the case of Morocco is that the provision of research funding can be helpful in facilitating STI capacity building programmes for the country, and so could be implemented also by other African countries.

*Case 5: Zimbabwe*

Zimbabwe has developed several STI initiatives, including the development of centres of learning, research and development (R&D) at numerous research institutions. In 2005, the Ministry of Science and Technology Development launched the Innovation and Commercialization Fund to promote research and innovation in the country. Zimbabwe launched the second Science and Technology Policy (2012), and its six primary goals include strengthening capacity development in STI. In the Policy 2012 the government commits to making a budgetary allocation of at least 1% of GDP for expenditures on R&D and focusing at least 60% of university education on S&T skills development.

In 2016, the Ministry of Higher and Tertiary Education, Science and Technology Development introduced the Science, Technology, Engineering and Mathematics (STEM) initiative to promote the learning of STEM disciplines. The Science, Engineering, Technology, and Innovation (SETI) System of Zimbabwe is organized as shown in figure 5. The system is characterized in four levels: the

[9] See: The African University of Science and Technology (AUST) (2016).

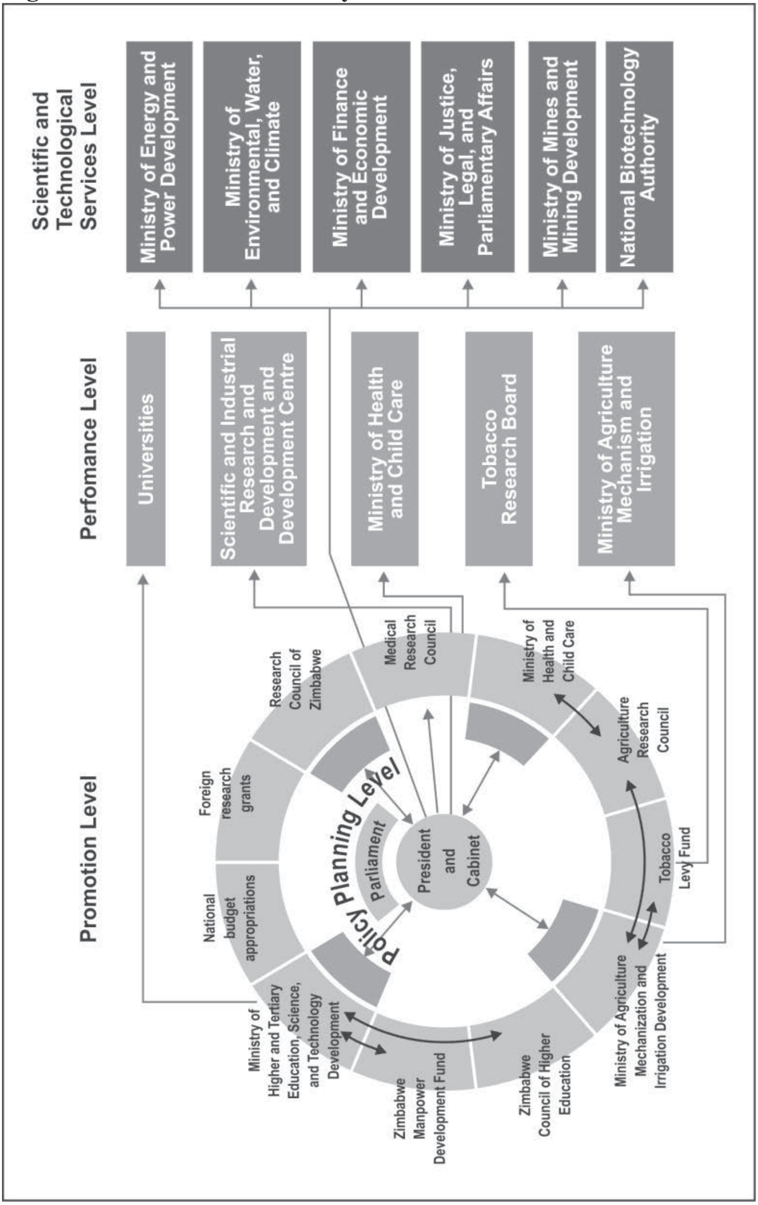
policy-planning level (policy design); the promotional level (funding – which includes STEM scholarships); the implementation level (scientific research, technological development, and productive innovation); and the scientific and technological services level (addressing the relevant national ministries and authorities).

The key lesson learnt from the case of Zimbabwe that is worthy of emulating by other African countries is the adoption of an institutional framework for the SETI System, because of its clear systematic structure, particularly at the policy-planning level (policy design). Further lessons learnt from the case of Zimbabwe is that STI development can be realised fully if an institutional framework, a supporting policy framework, and an incentives framework are put in place, and if the institutions and programmes get the requisite funding. Other lessons learnt from the case of Zimbabwe are:

- The STI sector needs to be aligned to the overarching national goals and developmental priorities.
- Given the limited fiscal space for the government to embark on investment in the STI sector, assistance from development partners and public-private partnerships become critical.
- There is a need for an enabling regulatory framework to foster public-private partnerships in higher and tertiary education institutions.
- An incentives framework is imperative for the development of STI.
- The setting up of the Innovation and Commercialisation Fund (2005), despite inadequate financing, also shows some commitments by the Government to fund STI.

Zimbabwe also presents success stories and experiences in the green fuel/energy sector and in the food/maize seed variety sector (see the boxes 4 and 5). The rationale for choosing these projects is because of the importance of these projects for enhancing green fuel/renewable energy utilisation, and for producing improved food/maize seed varieties, and hence supporting sustainable economic development in Zimbabwe.

**Figure 5: Zimbabwe's SETI System**




**Source**: ACBF and ZEPARU/Zimbabwe Economic Policy Analysis and Research Unit (2016)

**Box 4: Success story in the Green Fuel/Energy sector in Zimbabwe. Embracing Green Fuel technology: The case of the Chisumbanje Ethanol Project**

The Chisumbanje Ethanol Project, named Green Fuel, is a public-private partnership between the government of Zimbabwe (10%) and a local investor (90%). As reported by Matondi and Nhliziyo (2014), the project is a success story considered from various points of view:

- First, the plant is the biggest of its kind in Africa, putting Zimbabwe in the limelight as far as investment in green energy is concerned.
- Second, the project contributes significantly towards employment generation. The company employs about 4,500 people in the agriculture department and the mill, placing ethanol production among the largest employment creators in the country.
- Third, the investment can also be leveraged on for electricity generation. The Chisumbanje Ethanol Project is reported to be able to generate electricity amounting to 15 megawatts, which can be sufficient to power about 30,000 households.
- Fourth, there are a lot of value chain benefits that can be enjoyed from the booming ethanol project in Chisumbanje. Value chain industries that can benefit from the backward and forward linkages include fertilizer manufacturing firms, the cosmetics industry, and the explosives industry, which can leverage on harvesting some of the carbon dioxide from the plant which can be harvested.
- The Chisumbanje Ethanol Project also becomes a success story in leveraging on STI to achieve development results and to implement policy reforms on the use of renewable energies in Zimbabwe. After Green Fuel was found to be able to produce ethanol in significant quantities, the Zimbabwe Energy Regulatory Authority (ZERA), the regulatory body in the energy sector, granted Green Fuel with an ethanol blending license in August 2013. However, there are also quite critical opinions with regard of impacts on women, land and corruption. These issues are considered as a missing narrative in the debate about large-scale land acquisitions and the production of biofuels (see CAPRI 2016).

**Source**: ACBF and ZEPARU/Zimbabwe Economic Policy Analysis and Research Unit (2016), Matondi and Nhliziyo 2014, and CAPRI 2016.

**Box 5: Success story in the food/ maize seed variety sector in Zimbabwe: The Sirdamaize Project**

One of the initiatives that can be regarded as a success story is the invention of a seed variety, Sirdamaize, invented by the Scientific Industrial Research and Development Corporation of Zimbabwe (SIRDC). In 1997, SIRDC, with the support from the Biotechnology Trust Zimbabwe, the Directorate General, International Cooperation of the Netherlands, and the International Maize and Wheat Improvement Centre, began working on developing drought-tolerant maize varieties. This was a four-phase project, with the initial phase being Marker Assisted Selection (MAS) capacity building. This was followed by selection of germplasm; the development of inbred lines; and lastly the development of hybrids. MAS was a relatively new molecular biology technique at that time and was used to hasten progress on developing the varieties. The necessary tests were conducted in the laboratories at SIRDC by molecular biologists.

Using a combination of advanced molecular biology techniques and conventional breeding methods, 43 inbred lines were identified as possessing drought tolerant genes. Furthermore, upon reaching the hybrid development stage the variety SIRDAMAIZE 113 was developed and successfully registered in 2009. The path towards registration saw SIRDC involving farmers in the assessment of the variety. Farmers from Buhera, Birchenough, and Hwedza were given an opportunity to try out the new variety. The variety proved to yield well even under limiting environmental conditions. The main characteristic of SIRDAMAIZE is that it is drought-tolerant. The expected yield from the seed variety is up to 13 tonnes per hectare. However, trials done in previous years in communal areas from region two to region four had a yield of between 1.5 and nine tonnes per hectare. The variety has a low anthesis-silking interval of about -1, taking 66 days to silking and 67 to anthesis. This implies that it has an improved synchronization regarding pollination, thereby guaranteeing yield even under water-stressed conditions. The variety takes 136 days to reach maturity and has tolerance to diseases such as Maize Streak Virus, Grey Leaf Spot, Rust and Phaeospharia Leaf Spot. The ear rot and lodging percentages are 3.2% to 4.7% respectively, which is rational.

Thus, SIRDAMAIZE 113 can be classified as a recent innovation as far as giving solutions to the agriculture sector and the food security in the country which is characterized by low productivity in the face of unpredictable climate variations.

**Source**: Savadye and Shiri (2012)

*Case 6: Tanzania*

Tanzania has established the UNESCO National Commission in 1963 and has put in place various polices to foster and to support STI in the country. STI-related policies in Tanzania include the National Science and Technology Policy, the Sustainable Industrial Development Policy, the National Microfinance Policy, the ICT Policy, and the Small and Medium Sized Enterprises Policy. For instance, the National Science and Technology Policy for Tanzania, which was formulated in 1985, aims to promote S&T as a tool for economic development. The revised Policy identifies 9 sub-sectors that need priority application of S&T for national development and economic growth. These subsections are: Food and Agriculture; Industry; Energy; Natural Resources; Environmental Health; Sanitation and Population Planning; Transport and Communication; Science and Technology; and Education and Manpower. The Tanzania Commission for Science and Technology, established in 1986, is responsible to coordinate and to promote research and technology development activities in the country and to advise the Government on all matters relating to S&T, including but not limited to the formulation of S&T policy, priority setting for R&D, and allocation and utilization of resources for STI and R&D. The Tanzanian government, through the Tanzania Commission for Science and Technology, has developed the National Research Agenda for 2015-2020 to consolidate and to coordinate research activities in the National STI Ecosystem.

STI is viewed as a principle means to achieve the Tanzania National Development Vision 2025 that envisages to transforming Tanzania from a least developed country (with a low productivity-agricultural economy) to a middle-income country (with a semi-industrialised economy status) by 2025. In Tanzania, the 2009 Public Private Partnership Policy (PPPP) is beneficial to the STI because it improves the efficient delivery of goods and services by allowing both public and private sectors to collaborate in service delivery. For instance, it encourages private sector participation in the provision of secondary education and higher education through the establishment of private universities and university colleges. The involvement of the private sector and of communities in owning and managing schools and universities has allowed the rapid increase of the number of schools and universities. These schools and universities are now contributing to the STI capacity development.[10]

The successes of STI in Tanzania can be seen in both higher education and in health sectors. In higher education, the most inspiring story is the establishment of the Nelson Mandela African Institution of Science and Technology that the ACBF supports. It aims to develop the next generation of African scientists, engineers and technologists, who will drive the continent's development through the application of science, engineering and technology. Probably the greatest STI achieve-

[10] See Laltaika and Malima (2016).

ments in Tanzania have been recorded in the fields of Health and Medical researches and interventions, especially in Malaria control and prevention, Tanzania has been applauded for its achievement in the battle against Malaria (see box 6).

**Box 6: The successes in the battle against malaria in Tanzania**

- Malaria is a major public health challenge in the United Republic of Tanzania. Ninety-three percent of the mainland population and the entire population of Zanzibar are at risk of infection; *Plasmodium falciparum* accounts for 96% of the cases. Although there is a possibility of developing immunity to the parasite, this has not often occurred.
- Two separate malaria control programmes operate in the country: first, the National Malaria Control Programme which serves the Mainland; and second, the Zanzibar Malaria Control Programme which operates in Zanzibar. They contributed to reduce the malaria prevalence in the country.
- The National Malaria Control Programme's malaria prevention and treatment effort has managed to reduce the malaria prevalence in Tanzania. There is a decline in parasitaemia prevalence, in severe childhood anaemia, and in all-cause under-five child mortality. The Programme saved the lives of 63,000 children between 1999 and 2010.
- The most significant achievement was in Zanzibar where the Zanzibar Malaria Control Programme, in collaboration with the US President's Malaria Initiative, managed to reduce malaria prevalence from 40 per cent in 2005 to below one per cent in 2013 (USAID, 2016), following multiple successful interventions which include raising awareness, use of treated mosquito nets, proper diagnosis, and residual spray.
- These achievements can be attributed to activities by multiple stakeholders, including the US President's Malaria Initiative, to introduce and expand coverage of effective malaria prevention and treatment measures.

**Sources**: WHO/World Health Organization (2015) and USAID (2016)

The key messages to be learnt from the case of Tanzania are: Increasing awareness about the role of STI for sustainable development and coherent reforms at central government and sub-national level are important and pay off. A lack of commitment to increase the government budget for R&D is partly due to the lack of awareness with regard of the importance of STI among policy makers. The involvement of the private sector in the provision of education and research infrastructure needs to be encouraged. The low enrolment in STI-related programmes in higher learning institutions and the lack of intellectual property awareness in various research institutions are two of the main barriers that prevent STI development in the country.

## 4 Conclusions and Policy Recommendations

This paper examines the successful cases of building capacity in Africa's science, technology and innovation systems. Section 1 shows that the increasing recognition by African governments and policy makers of the important role of STI as a driver of economic growth and sustainable development appears from the fact that a great number of African countries has now a strategy for the promotion of STI, with capacity development as part of the strategy. Section 2 assesses the commitment to STI strategies and capacity development, and explains the key initiatives undertaken toward building capacity in science, technology and innovation for Africa's transformation, mainly the key STI initiatives in research and development and in higher education in Africa. It explains that STI Initiatives (in R&D and in higher education), which are undertaken by national, regional and international institutions, contribute to STI capacity building in Africa. At the national level, the widespread network of specialized S&T universities in many African countries emphasizes the importance of universities and higher education institutions in capacity building in S&T. The involvement of both public and private higher education institutions contributes to capacity building in STI. At the regional level, African regional institutions (e.g. AU, NEPAD) contribute to capacity building in STI in Africa; the initiatives undertaken promote regional STI collaboration. At the international level, international collaborative bilateral and multilateral partnership projects and initiatives (e.g. UNESCO and EU- AU cooperation) contribute to STI capacity building in Africa in different sectors, including public health; agriculture, food security and nutrition; human resources development; education and research; and water, energy and environment. Section 3 discusses the successful country cases of building capacity in science, technology and innovation in Africa and provides insights into STI policy development and implementation in selected African countries, namely Ethiopia, Rwanda, Nigeria, Morocco, Zimbabwe, and Tanzania. Many lessons can be learned from the case studies.

The main policy recommendations are that the African countries must mobilize political and financial support for development and implementation of coordinated sustainable STI capacity building to facilitate and accelerate Africa's transformation; to increase investment in higher education and R&D; to encourage partnership between public and private higher education and R&D institutions to promote STI capacity building at the national, regional and continental levels; to increase commitments to fund STI by setting up more innovation and research funds in all African countries; to improve human and financial resources necessary for capacity building in STI to facilitate technological innovations, transformation, inclusive and sustainable development in all African countries; to enhance regional cooperation and adopt a coherent framework of cooperation between African governments, scientists, universities, policy makers, private sector, and civil society to support capacity building in STI; to create an enabling regulatory framework and institutional environment for enhancing public–private partnerships in higher education institutions and enhancing capacity building in STI in African countries; and to encourage private institutions' initiatives to complement government STI initiatives in all African countries.

Enhancing the role of various institutions and stakeholders in all African countries, which are involved directly and indirectly in capacity building in S&T, in research and development, and in innovation, remains critical. For instance, African governments must create the relevant environment for enhancing STI development by formulating good STI policies and strategies, by creating efficient STI institutions to implement and to follow-up implementation of STI policies and strategies, by improving STI infrastructure, by supporting sustainable financing schemes for STI, and by improving investment in human resources (education, training, etc.). The private sector must support and complement the governments' efforts by providing funding, by investing in the development of critical skills (education, vocational training, etc.), by encouraging innovation in private firms, etc. Africa must continue to pursue South–South scientific co-operation by promoting policies which allow scientists and students a greater mobility across African countries and emerging countries.

The African Union (AU) must build on the progress made to develop and nurture more regional and international centres of excellence in areas that are of critical importance to Africa's STI development. Higher education and research institutions in African countries should forge strong regional networks and partnerships to develop centres of excellence that will facilitate world-class research by African scientists. These centres of excellence can help African institutions to standardize research outputs, expertise and best STI practices. To augment their investment in STI, African governments and the African Union (AU) must pursue new and innovative funding alliances involving bilateral and multilateral donors, governments, private sector, and businesses. Strategic investment in science, technology, engineering and mathematics (STEM) education is critical for Africa to achieve a "critical mass" in human resources and to promote innovation, to promote competitiveness, and to nurture the next generation of innovators, entrepreneurs and scientists. In pursuing an STI-driven development, African governments must make serious commitments to develop its institutional capacity by investing substantially in high-quality universities, state-of-the-art well-equipped and maintained laboratories, ICT infrastructures, and research funding mechanisms. Africa must intensify its efforts towards bridging the gender disparity gap by promoting women's participation and leadership in STI, by gender mainstreaming and aiming at gender equity in STI, and by developing gender-friendly policy frameworks that encourage young women and girls to pursue science and engineering programmes. While African countries endeavour to develop their STI infrastructure, an essential component of the development process is to build its domestic capacity to address the capacity gaps and to ensure sustainable development through STI on the continent. STI capacity building in African countries remains a formidable challenge. It involves the acquisition of skills, knowledge, the provision of STI infrastructure, public and private sector support through policies, and the allocation of financial resources which are needed to develop and to sustain innovation-led and knowledge-driven economies. In moving forward, African countries must mobilize and widen the involvement of all public and private higher education institutions to improve development, utilization, and retention of Africa's capacity in STI to achieve inclusive and sustainable development. Reviewing the experiences of successful African case countries of STI development will help to find better solutions also in other African countries.

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**Annex 1: Science and Technology Universities and Higher Education Institutions in Africa**

| Country | Name of universities | Year of establishment | Type of ownership |
|---|---|---|---|
| Algeria | University of Science and Technology, Houari Boumediene | 1974 | Public |
| | Oran University of Science and Technology | 1975 | |
| Angola | Universidade Técnica de Angola | | |
| Benin | University of Science and Technology of Benin | 1996 | Private |
| | Institut Supérieur des Sciences et Techniques | | Private |
| Botswana | Botswana International University of Science and Technology | 2005 | Public |
| Burkina Faso | University of Ouaga I-Pr Joseph Ki-Zerbo | 1974 | Public |
| | Polytechnic University of Bobo-Dioulasso | 1996 | Public |
| | Institute for Science | 2004 | Public |
| | Polytechnic center of Fada N'Gourma | 2009 | Public |
| | Polytechnic center of Ouahigouya | 2010 | Public |
| | Polytechnic center of Dédougou | 2012 | Public |
| | Higher Institute for Informatics | 1996 | Private |
| | St Thomas d'Aquin University | 1995 | Private |
| | Catholic University of West Africa | - | Private |
| | University Aube Nouvelle | 1989 | Private |
| | Higher school of applied sciences | - | Private |
| | Other small R&D schools (4) | | Public |
| | Other small R&D schools (10) | | Private |
| Cameroon | Bamenda University Institute of Science and Technology | | Private |
| | Bernice University of Science and Technology | | Private |
| | Catholic University Institute of Buéa-School of Engineering | 2010 | Private |
| | Catholic University Institute of Buea - School of Information Technology | | Private |

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|---|---|---|---|
| | Institute of Science Technology Cameroon, Bamenda | | Private |
| | University College of Technology Buea | | Private |
| | Institut Supérieur des Technologies et de l'Innovation | | Private |
| | The ICT University | | Private |
| | Christian University Institute - Higher Institute of Sciences, Engineering and Technology | | Private |
| Congo | University of Technology of the Congo | 2010 | Private |
| The Republic of the Congo | Higher Institute of Technology of Central Africa | 2002 | |
| Côte d'Ivoire | Institut National Polytechnique Félix Houphouët Boigny | | |
| | The University of Science and Technology of Ivory Coast | 2009 | Private |
| | Ecole Superieure Africaine des Techniques de la Communication | | |
| | The Higher Institute of Technology of Ivory Coast | 2007 | Private |
| | Institut Supérieur de Technologie Dubass | | |
| Egypt | University of Science and Technology at Zewail City | 2011 | Public |
| | Egypt-Japan University of Science and Technology | 2010 | Public |
| | Institute of Aviation Engineering and Technology | 1997 | Private |
| | Alexandria Higher Institute of Engineering and Technology | 1996 | Private |
| | Arab Academy for Science, Technology & Maritime Transport | 1972 | Private |
| | Cairo Higher Institute for Engineering, Computer Science & Management | 1995 | Private |
| | Higher Institute for Engineering and Technology in Kafr Elsheikh | 2011 | Private |
| | International Academy for Engineering and Media Sciences | 2002 | Private |

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|---|---|---|---|
| | Misr University for Science and Technology | 1996 | Private |
| | Modern University for Technology and Information | 2004 | Private |
| Eritrea | Eritrea Institute of Technology | 2003 | |
| Ethiopia | Addis Ababa Science and Technology University | | |
| | Graduate School of Telecommunications & Information Technology | | |
| | HiLCoE School of Computer Science and Technology college | | |
| | Eprom Technology College | | |
| | Kombolcha Institute of Technology | | |
| | Mekelle Institute of Technology | 2002 | |
| | Ethiopia Institute of Technology | | |
| | Adama science and technology University | | |
| | Universal Technology College | | |
| Gabon | Université des Sciences et Techniques de Masuku | | |
| Ghana | Kwame Nkrumah University of Science and Technology | 1952 | Public |
| | University of Mines and Technology | 2001 | Public |
| | Accra Institute of Technology | 2005 | Private |
| | Anglican University College of Technology | 2008 | Private |
| | Osei Tutu II Institute for Advanced ICT Studies | | |
| | Accra Polytechnic | | |
| | Ghana Telecom University College | | |
| | Kumasi Polytechnic | | |
| | Koforidua Polytechnic | | |
| | University of Energy and Natural Resources | | |
| | Takoradi Polytechnic | | |
| | Ho Polytechnic | | |
| | Cape Coast Polytechnic | | |
| | Tamale Polytechnic | | |
| | Sunyani Polytechnic | | |
| | Bolgatanga Polytechnic | | |

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|---|---|---|---|
| Côte d'Ivoire | The University of Science and Technology of Ivory Coast | 2009 | Private |
| | Ecole Superieure Africaine des Techniques de la Communication | | |
| | The Higher Institute of Technology of Ivory Coast | 2007 | Private |
| | Institut Supérieur de Technologie Dubass | | |
| Kenya | Masinde Muliro University of Science and Technology | 1972 | Public |
| | Dedan Kimathi University of Technology | 1972 | Public |
| | Jomo Kenyatta University of Agriculture and Technology | 1981 | Public |
| | Jaramogi Oginga Odinga University of Science and Technology | 2009 | Public |
| | Meru University of Science and Technology | 2008 | Public |
| | International Center of Technology (ICT-Thika) – Thika | | Private |
| | The Kenya College of Science and Technology | | Private |
| | Kenya Institute of Biomedical Sciences and Technology-Nakuru | | Private |
| Libya | College of Electronic Technology - Tripoli | | |
| | College of Electrical and Electronic Technology - Benghazi | | |
| | College of Engineering Technology - Houn | | |
| | College of Engineering Technology – Janzur | | |
| | College of Engineering Technology – Zuwarah | | |
| | College of Mechanical Engineering Technology – Benghazi | | |
| | College of Computer Technology - Zawiya | | |
| | College of Medical Technology – Derna | | |
| | College of Medical Technology – Misurata | | |

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|---|---|---|---|
| Madagascar | Institut Supérieur de Technologie d'Antananarivo | | |
| | Institut Superieur Polytechnique de Madagascar | | |
| Malawi | Malawi University of Science and Technology | 2012 | Public |
| Mali | École Nationale d'Ingénieurs Abderhame Baba Touré | | |
| Mauritania | Université des Sciences, de Technologie et de Médecine | | |
| Mauritius | University of Mauritius (Faculty of Science) | 1965 | Public |
| | University of Technology, Mauritius | 2000 | Public |
| Morocco | The Scientific Institute | 1920 | |
| | École Nationale de l'Industrie Minerale | | |
| | École Marocaine des Sciences de l'Ingenieur | | |
| | High Technology School in Morocco | | |
| | Institut de Formation en Technologie Alimentaire | | |
| | Institut Supérieur du Génie Appliqué | | |
| | École Supérieure d'Ingénierie en Sciences Appliquées | | |
| | Institut Polytechnique Privé de Casablanca | | |
| | École Polyvalente Supérieure d'Informatique et d'Electronique | | |
| | École Marocaine d'Ingénierie | | |
| | École d'Ingénierie en Génie des Systèmes Industriels Casablanca | | |
| | École Supérieure Vinci d'Informatique et des Telecoms de Rabat/Maroc | | |
| | École Polytechnique Privée d'Agadir | | |
| Namibia | Namibia University of Science and Technology | | |
| Nigeria | Our Saviour Institute of Science, Agriculture and Technology | 1989 | Private |
| | Akwa Ibom State University (formerly Akwa Ibom State University of Science and Technology) | 2010 | Public |
| | Bells University of Technology | 2004 | Private |

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|---|---|---|---|
| | Cross River University of Technology | 2002 | Public |
| | Enugu State University of Science and Technology | 1979 | Public |
| | Kano State University of Science and Technology | | |
| | Kebbi State University of Technology | | |
| | Ladoke Akintola University of Technology | 1990 | Public |
| | Modibbo Adama University of Technology Yola | | |
| | Ondo State University of Science and Technology | 2010 | Public |
| | Rivers State University of Science and Technology | 1980 | Public |
| Rwanda | Tumba College of Technology | | Private |
| Senegal | Institut de technologie alimentaire | | |
| Somali | Juba University of Science and Technology | | |
| | Modern University for Science and Technology | | |
| South Africa | Tshwane University of Technology | 2004 | Public |
| | Central University of Technology | 1981 | Public |
| | Durban University of Technology | 2002 | Public |
| | Vaal University of Technology | 2004 | Public |
| | Walter Sisulu University for Technology and Science | 2005 | Public |
| | Cape Peninsula University of Technology | 2005 | Public |
| | Mangosuthu University of Technology | 1979 | Public |
| | University of Mpumalanga | 2014 | Public |
| | The Sol Plaatje University | 2014 | Public |
| South Sudan | John Garang University of Science and Technology | 2006 | Public |
| Sudan | Sudan University of Science and Technology | 1932 | Public |
| | Bayan College for Science & Technology | 1997 | Private |
| | Garden City College For Science And Technology | | Private |
| | The Future University of Sudan | 1991 | Private |

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|---|---|---|---|
| | University of Medical Sciences and Technology | 1995 | Private |
| | University of Science and Technology – Omdurman | 1995 | Private |
| Tanzania | Nelson Mandela African Institute of Science and Technology | 2010 | Public |
| | Mbeya University of Science and Technology | 2012/13 | Public |
| | International Medical and Technological University | 1997 | Private |
| Togo | The University of Science and Technology of Togo | 2012 | Private |
| Tunisia | Higher institutes of technological studies | | |
| Uganda | Mbarara University of Science and Technology | 1989 | Public |
| Zambia | Information and Communications University | 1998 | Private |
| | Victoria Falls University of Technology Livingstone Zambia | | Private |
| Zimbabwe | Chinhoyi University of Technology | 2001 | Public |
| | Harare Institute of Technology | 1988 | Public |
| | Manicaland University of Science and Technology | | |
| | National University of Science and Technology | 1991 | Public |
| | National University of Technology | | Public |

**Sources**: Wikipedia: https://en.wikipedia.org/wiki/Category:Lists_of_universities_and_colleges_in_Africa (accessed on 8 July 2016), and Ranking Web Of Universities: http://www.webometrics.info/en (accessed on 8 July 2016)

# Unit 2: Science, Technology and Innovation (STI) Policies for Sudan's Economic Revitalization

# Science, Technology and Innovation (STI) Policies for Sudan's Economic Revitalization - An Introduction

**Samia Satti Osman Mohamed Nour[1] and Karl Wohlmuth[2]**

## 1 The Issues

### 1.1 Sudan needs coherent Structural Transformation Policies

Sudan is forced, because of political instability, social inequities and economic imbalances, to move towards structural transformation. This has many reasons. The separation of South Sudan in July 2011 has fundamentally changed the economic parameters of the country. While the Sudan was an agricultural exporter from independence to the year 1999, the oil exports since then have made Sudan becoming dependent on foreign exchange and public revenues which were derived mainly from oil. Not only the economic structure has changed with the oil exports since 1999, but also the governance frameworks were fundamentally altered. The consequences for the Sudan and its people were serious as the oil windfall incomes led to corruption, to increases in subsidies (for fuel and food), and to a neglect of regular taxation modalities and proper budgeting. The way back to an economy which is based on agriculture exports, and the development of other mining activities for export, like gold, have since 2011 not been easy routes for policymakers in Sudan. While the promotion of the agriculture sector and the re-emergence of agricultural exports is still under way, the development of other mining activities (like gold for export) is still done in an unplanned and chaotic manner without applying a suitable framework of policy interventions.

In the meantime, the agricultural export markets have changed considerably. Global agricultural value chains are now important, and for the successful working with and in such value chains it is necessary to have successful lead firms on the top, preferably leading local firms. Such a situation is in Sudan only relevant in the case of gum Arabic as Sudan has a global monopoly position (producing 75-80% of total world output).[3] But even in this case Sudan is not exploiting its role as a leader in global gum Arabic production; exports are mainly done in raw form.

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[1] Samia Satti Osman Mohamed Nour is Full Professor of Economics at the university of Khartoum, Khartoum, Sudan

[2] Karl Wohlmuth is Professor Emeritus at the University of Bremen, Bremen, Germany

[3] See on such figures for Sudan: Index Mundi, Sudan Economy Profile 2017; Web Access: http://www.indexmundi.com/sudan/economy_profile.html

Sudan has opportunities in many agricultural products, such as in cotton, groundnuts (peanuts), sorghum, millet, wheat, gum Arabic, sugarcane, cassava (manioc, tapioca), mangoes, papaya, bananas, sweet potatoes, sesame seeds; animal feed, sheep and other livestock.[4] To derive benefits from such global agricultural value chains, Sudan needs to open its economy in a transparent way and needs to promote foreign investment flowing in the country towards new sectors (manufacturing, logistics, transport, finance services, etc.). Foreign investment to the oil sector was in the past neither transparent nor was it supporting inclusive growth. Rule of law is important for foreign investors, but also for domestic investors in productive sectors, and improving the conditions for doing business in Sudan is a key issue for all investors.[5] Sudan is on rank 170 out of 190 countries, and with a score value of 44.46 it is far below the frontier of 100 (best case), and the score value is worse than the regional average of Sub Saharan Africa (with a score value of 50.43). And, Sudan is far worse in the "ease of doing business" conditions than Kenya (with a country rank of 80 and a score value of 65.15). While the overall rank of Sudan is 170, the situation of Sudan is worse in fields such as protecting minority investors (rank 186), trading across borders (rank 185), and getting credit (rank 173).

Also, STI policies are becoming more important in Sudan as a tool to support structural transformation. Processing of agricultural raw materials requires that modern technologies are used in factories and installing modern logistics facilities is part of building successful agricultural value chains. New seeds varieties and improved quality controls are requested for Sudan to be able to compete on international markets. Although Sudan is correctly perceived to be a promising potential agricultural exporter of raw products and an exporter of processed foods as well, R&D is needed along the whole value chain. Quality standards and testing facilities matter also, not only for the end products, but also for inputs and intermediate products. So, the country needs to change quickly the economic outlook from an oil economy to an agriculture-based economy, driven by STI development. Therefore, crucial policy decisions are needed to initiate a change of the economic structure, of the economic policy, and of the governance frameworks. Sudan has seen since the 1990s a period of deindustrialization, as the decline of manufacturing (as a share in GDP and in total employment) was not well managed in the period of large-scale oil exports. However, in the years since 2008 to 2016

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[4] See the following reference: http://www.indexmundi.com/sudan/gdp_composition_by_sector.html:

[5] See on Doing Business 2018 in Sudan the following source: http://www.doingbusiness.org/data/exploreeconomies/sudan

the share of manufacturing in GDP has stabilized around 10%.[6] Industry has in 2016 a share of 21.2% in GDP, which is much lower than in 2008 when the oil sector contributed considerably to the GDP[7], but the share of industry in the labour force is only 7%[8]. Sudan's industries (oil, cotton ginning, textiles, cement, edible oils, sugar, soap distilling, shoes, petroleum refining, pharmaceuticals, armaments, automobile/light truck assembly, and milling)[9] have still a basis for successful reindustrialization. Reindustrialization is necessary to broaden the production pattern of competitive manufactured goods and to expand the volume of manufactured exports, preferably of products at increasing levels of value added. Strategies of reindustrialization could be related to four areas (promoting the long-neglected sectors, like agriculture and manufacturing; supporting the integration of local manufacturers into global value chains (especially linked to agricultural and other mining value chains); supporting green industry and growth initiatives (in eco-tourism, waste management, building industry, renewable energy, etc.); and promoting regional industry development initiatives (to reach a spatial dispersion of industries, especially in the basic needs-related sectors). Although there are ideas to go in this direction, a coherent policy framework is not yet in place in Sudan.

### 1.2 The oil-based economy has fundamentally changed the economic, social and governance structures of Sudan

As the economic incentives and the business modalities have changed since the 1990s fundamentally, based on the growth of the oil-based economy, a correction of the incentives structure towards a more neutral incentives regime may not be easy to be reached. It is therefore important to look at the socio-economic characteristics of the Sudanese economy, at the technological developments in the context of globalization and digitalization, and at the current economic situation[10]. Sudan was the largest country in Africa and the Arab world until 2011, when South Sudan separated as an independent country, following an independence referendum. Sudan is now the third-largest country in Africa (after Algeria and the Democratic Republic of Congo), and it is also the third largest country in the Arab world (after Algeria and Saudi Arabia). According to the World Bank classification, Sudan is classified amongst the group of lower-medium-income economies.[11] According to the UNDP's HDI (Human Development Index)

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[6] See: AfDB et al. 2017, African Economic Outlook, Country Note Sudan, 2017, Web Access: http://www.africaneconomicoutlook.org/en/country-notes/sudan

[7] See: AfDB et al. 2017, African Economic Outlook, Country Note Sudan, 2017, Web Access: http://www.africaneconomicoutlook.org/en/country-notes/sudan

[8] See the following reference: http://www.indexmundi.com/sudan/economy_profile.html

[9] See the following reference: http://www.indexmundi.com/sudan/economy_profile.html

[10] See: Nour 2015 and AfDB et al. 2017

[11] World Bank source on Sudan: http://www.worldbank.org/en/country/sudan

classification the country belongs to the low income countries and to the low human development group.[12] Statistical data for Sudan (see CBoS/Central Bank of Sudan 2014) about the structure of Sudan's economy (measured as shares of GDP at constant prices) indicate for the year 2014 the dominance of the services sector (47.8%), while the shares of the agricultural sector (28.2%) and of the industrial sector (24.0%) are much lower (see: Central Bank of Sudan, Annual Report, 2014, p. 118).[13] As part of the industrial sector the sub-sector "Processing and Handicraft" has a share of 17.2%, while the petroleum sub-sector is left with only 3.4%. Data from the CIA World Factbook[14] give other figures for the GDP composition by sector for the year 2016; the agriculture sector has a share of 27.5%, while industry has a share of 20.7%, and the services sector has a share of 51.8% (2016 est.).[15] Most recent data from the African Economic Outlook for 2017 put the manufacturing sector at around 10%, meaning that the sector has kept largely its importance since 2008 (AfDB et al. 2017).[16] Obvious is the tremendous shift away from the petroleum sub-sector, left with only a minor position in GDP.

The situation with regard of employment is different in terms of sector shares. The structure of the Sudanese economy shows that - prior to the start of the oil exports in 1999 - the employment shares of the sectors in total employment (for 1990) and the value added as a percentage of GDP (for 2002) diverged considerably for the agricultural sector (70%, 39%), the services sector (21%, 43%), and for the industrial sector (9%, 18%) (according to: World Bank, World Development Indicators/WDI database, 2005).[17] Data for labour force shares of sectors (1998, est.) put the share for agriculture at 80%, for industry at 7%, and for the services sector at 13%.[18] More up to date labour force data by economic sectors are not available.[19]

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[12] The World Bank and the United Nations Development Programme (UNDP)/ Human Development Report Project classify the World countries differently according to income level. While UNDP classifies Sudan as a low-income country, the World Bank classifies Sudan as belonging to the group of the lower middle-income countries. See: http://hdr.undp.org/ and http://www.worldbank.org/en/country/sudan

[13] See CBoS, Annual Report 2014: https://www.cbos.gov.sd/en/content/annual-report-2014

[14] See CIA World Factbook: https://www.cia.gov/library/publications/the-world-factbook/

[15] See more recent data on the GDP composition based on the CIA World Factbook (updated July 9, 2017): http://www.indexmundi.com/sudan/gdp_composition_by_sector.html

[16] See: AfDB et al. 2017, African Economic Outlook, Country Note Sudan, 2017, Web Access: http://www.africaneconomicoutlook.org/en/country-notes/sudan

[17] See World Bank, World Development Indicators/WDI database, 2005: https://data.worldbank.org/data-catalog/world-development-indicators

[18] See: http://www.indexmundi.com/sudan/economy_profile.html

[19] See: www.ilo.org/ilostat/faces/oracle/webcenter/.../Page21.jspx

Some substantial changes have occurred in the shares over time, and the changes of the sectoral GDP, employment and labour force shares are important. The employment share of agriculture has even increased, while the employment shares of services and industry sectors have decreased. This turn towards agriculture may be the result of the declining role of the oil economy and of increasing poverty and food insecurity in the country, while the decline of the employment shares of the other sectors may be due to the structural changes in industry and services sectors.

From the observed shifts it follows that there is a great demand for SIT policies for agriculture and for manufacturing (Processing and Handicraft). The increasing role of agriculture and of manufacturing requests a quick reversal of STI policies towards increasing value added in these two sectors/subsectors. Agricultural R&D and industrial R&D for key manufacturing fields, especially food industries, give new options to become competitive at regional levels and to substitute in an effective way for imports. R&D inputs are needed for the expanding pharmaceutical industry, and for other processing sectors, like ceramics, food products, refrigerators, etc. (CBoS, Annual Report 2014, Chapter 8: Production). However, such a turn of policies from an Oil-led economy to an STI-led economy needs to meet crucial preconditions.

The structure of the Sudan economy is characterised by rent-seeking, what means that interest groups and individual persons receive "political rents" (incomes earned because of political connections, without delivering a service to the economic units for the income received). This situation may have occurred in Sudan because of the shifting from an agricultural-based economy to an oil-based (or oil-dependent) economy. There was a high dependency on oil production for exports and revenues, with oil contributing over 95 percent of exports and about 50 percent of government revenues. The consequences in terms of corruption, bribing, and misuse of public funds were serious and damaging, and increasing biases in governance frameworks have emerged. Various indexes reveal how serious the situation is. The Corruptions Perceptions Index for 2016 reveals that Sudan has rank 170 out of 176 countries, while the score value is as low as 14 out of 100 points.[20] In the Ibrahim Index of African Governance (IIAG)[21] Sudan is placed at rank 49 out of the 54 countries in Africa, and the overall governance score is 30.4 out of 100 (this is a further deterioration of -0.6 since 2006). In the IIAG, ranks and scores for the areas Safety & Rule of Law and Sustainable Economic Opportunity have deteriorated since 2006, while those for Participation & Human Rights and for Human Development have improved somewhat.[22] The heavy reliance on

[20] See: https://www.transparency.org/country/SDN

[21] See the Ibrahim Index of African Governance: http://mo.ibrahim.foundation/iiag/

[22] See: http://iiag.online/

oil revenues had tremendous consequences for the Sudanese economy as the country turned from a low income to a lower middle income country (according to the World Bank classification of countries), because of the relatively high growth rates sustained over years, but the transition to an oil economy and to an oil exporter in 1999 has brought with it uncertainty and high fluctuations in economic growth.[23] Also, the lack of transparency has created mistrust during the politically decisive period of 2005 to 2011 after the Comprehensive Peace Agreement (CPA) between the Government of Sudan and the SPLM movement, because the Government of the then Autonomous Region of South Sudan had doubts about the oil production figures which were released by the central government of Sudan as a basis for financial transfers to the South.[24] Increasing tensions between Sudan and the Autonomous Region of South Sudan led to militarization and did draw away resources from economic modernization. Also, the political developments after 2011 led to a new round of militarization and conflict, again drawing away resources from structural modernization policies,

Despite of many years of growth and high oil revenues, Sudan is still characterised by high rates of poverty, unemployment and inequalities in resources sharing. The (headcount) poverty rate is given as 46.5% (2009 est.), the unemployment rate is at 13.6% (2014 est.), the lowest 10% of the households have a share in income or consumption of only 2.7%, while the highest 10% of the households (with the highest income or consumption) have a share of 26.7% (2009 est.).[25] The unemployment rate of the youth is (for the total) at 20%, with 16% for the male youth and 32% of the female youth. The per capita GDP (in PPP dollars) is stagnating in recent years because of low real growth rates and an increasing population.[26] The public revenues were at $7.3 billion, the public expenditures at $11.3 billion (2016 est.), this implying a -4.2% of GDP public deficit (2016 est.). So, the budget deficit is at an unsustainable level, and corrective measures (on food and petrol subsidies, and on social security expenditures, like health) affect the people, while the military and security expenditures are not reduced. The current account deficit is at -$5,5 billion $ (2016 est.), while the exports are only at $3.7 billion against imports at $9.3 billion (2016 est.).[27] Despite of the huge agricultural potential the Sudan is importing foodstuffs and wheat, and many industrial goods are also imported which could be produced locally because of the relatively diversified industry base of the country. The social situation is not improving, as the current account and the budget continue to show huge deficits which are leading to

[23] See: World Bank, 2008; World Bank, 2014; World Bank, 2015

[24] See: https://www.globalwitness.org/en/archive/oil-production-figures-underpinning-sudans-peace-agreement-dont-add/

[25] See: http://www.indexmundi.com/sudan/economy_profile.html

[26] See: http://www.indexmundi.com/sudan/economy_profile.html

[27] See: : http://www.indexmundi.com/sudan/economy_profile.html

further austerity measures (but not for military and security expenditures). Therefore, the IMF demands further fiscal measures in its recent Article IV Visit to Sudan.[28] As unsustainable fiscal deficits persist, as inflation is still high, and as economic growth remains below potential, the social situation of the people is not improving. An even sharper policy of austerity measures is proposed by the IMF - more exchange rate flexibility, more reduction of remaining subsidies, a more constrained monetary policy, more fiscal discipline, etc. But there are also demands from the IMF for the expansion of social safety nets for the most vulnerable people. A change of austerity policies is proposed but would imply drastic cuts of security and military expenditures.

Following the exploitation of oil and the improvement in its economic performance based on the oil revenues, the country has turned from a low-income economy into a lower middle-income economy (according to the World Bank classification). Consequently, Sudan's real economic growth averaged about 9% during 2005-2007, putting Sudan among the fastest growing economies in Africa (World Bank, 2008, 2014, 2015). Although this process has led to high public revenues and consequently to high public expenditures, it has not affected positively the living standards of most of the people, mainly because of the inequality of incomes and consumption levels in the country.[29] Resources were allocated to defence, to security, and to projects of high public visibility. The high level of income inequality and the increasing urban-rural divide have eroded the average income gains by economic growth. In 2010, Sudan was considered as the 17th–fastest – growing economy in the world, given the rapid development of the country - largely derived from oil revenues, despite of persisting international sanctions.[30] Therefore, Sudan has missed the opportunities to switch to an STI-led development path after the Peace Agreement of 2005 and after the Separation of South Sudan in 2011. Data show that the neglect of the STI infrastructure continued, leading to unfavourable positions on science, technology and innovation indexes, ranks and scores (as given evidence in the contributions to this Unit 2).

### 1.3 Economic Mismanagement prior and after the separation of South Sudan

Although the process of separation has started already in 2005 with the Comprehensive Peace Agreement, the Autonomous Region of South Sudan and the Central Government in Khartoum did not harmoniously cooperate to prepare for the

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[28] See: https://www.imf.org/en/News/Articles/2017/09/27/pr17373-imf-staff-completes-2017-article-iv-visit-to-sudan

[29] So, the IMF has consistently requested in negotiations with the government also a poverty reduction strategy for Sudan: see IMF 2013

[30] See: http://www.sd.undp.org/content/sudan/en/home/countryinfo/

unity state after the transition period of six years or for a friendly form of separation. Instead of preparing for agreements on oil, trade, debt, assets, citizenship, migration, on internally displaced persons, and refugees dispersed in the whole of Sudan, and on mobility of labour and mobility of capital in the future, the tensions between Khartoum (Central Government) and Juba (Regional Government for the South Sudan) increased and expenditures for the military and for security escalated tremendously, especially also in South Sudan. Instead of "development" there was a rush towards an army and security build-up (because of mistrusting the intentions of the other side). Then, the secession of the South in 2011 had gravely affected the economy of Sudan as more than 80% of Sudan's oil fields existed in the southern part of the former country. This decline in oil revenues caused a major adjustment to the Sudan's fiscal situation and prompted sharp financial austerity measures. The situation was further exacerbated by the continuing tensions between Sudan and South Sudan in the contested Three Areas (Blue Nile, South Kordofan, Abyei) and their inability to reach an agreement over the transit fees for oil from South Sudan.[31] The independence of the South Sudan has had immediate negative fiscal and balance of payments implications for Sudan, because of the loss of the bulk of the oil production and oil export revenues, as about 75 percent of Sudan's oil revenues were generated from southern oil fields.[32] The civil war in South Sudan from 2013 onwards also affected the Sudan negatively because of new waves of refugees and a collapse of cross-border economic activities along the border between Sudan and South Sudan. Sudan since suffers from even higher poverty rates, higher unemployment rates, and higher youth unemployment rates, and the spatial disparities in development within Sudan have further increased, just to mention the significant regional disparities between the riverain states and the states in the West, the East and the South in Sudan. In these hinterland areas there are various political, economic and climatic factors which contribute to the growing inequalities and to the unbalanced development in Sudan.

Thus, the prevailing economic structure in Sudan hinders the allocation of resources to support the promotion of the national innovation system (NIS). The policymakers during the era of the rent-seeking economy, which was based on oil revenues, have shown no interest to invest into STI infrastructure, human resources for STI development, and into R&D facilities in public and private firms. Thus, because of the fundamental change of the situation for Sudan since the separation of the South the new economic structure in Sudan implies urgent needs for

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[31] See: http://www.sd.undp.org/content/sudan/en/home/countryinfo/

[32] See: International Monetary Fund/IMF (2013), Sudan Interim Poverty Reduction Strategy Paper IMF Country Report No. 13/318, October 2013; Web Access: http://www.imf.org/external/pubs/ft/scr/2013/cr13318.pdf.

a structural change within and between the economic sectors (agriculture, industry, and services sectors) to promote innovation, building capabilities, moving towards a knowledge economy, aiming at inclusive growth, and so towards a more sustainable type of development. This imperative for change implies the importance of implementing coherent STI policies for Sudan in view of the lack of sound and consistent STI policies in Sudan as documented in so many studies, index rankings and reports on the state of STI. However, Sudan and South Sudan have opportunities to cooperate in the future in areas such as STI development. Such a cooperation is important, especially for the border areas along the new international border between Sudan and South Sudan (see Wohlmuth 2012). Prior to the civil war, the STI cooperation between the North and the South of Sudan was highly relevant and adapted to the needs of development. The major national R&D institutions had an outreach to the South. Also, in the transition period 2005 to 2011 some Unity Projects emphasized also STI development and STI cooperation in the border regions.

### 1.4 Potentials for Cooperation in the Development of STI Infrastructure and the Building of Sub-Regional Innovation Systems

Both countries, Sudan and South Sudan, can cooperate with great mutual benefit in important areas of developing Science, Technology and Innovation (STI) infrastructure and the building of human capacities. They can also support each other in developing and interlinking their still rudimentary National and Sub-Regional Innovation Systems (NISs) and can also provide for skills in specific areas. Sudan and South Sudan can learn from other African countries how to build up STI institutions. Rwanda demonstrates how STI development can be accelerated along with steps to develop agro-industries and to convert comparative advantages of the country into competitive ones (Watkins/Verma, eds., 2008; Wohlmuth 2011). Rwanda is developing the STI infrastructure for five key sectors and is building the required human capacities. Rwanda is therefore an example for developing STI in Sudan and South Sudan (Wohlmuth 2012, 2013a, 2013b). The food processing industry and the high value-added export sector in Rwanda are the two key sectors which are supported by building up an STI infrastructure and the related human capacities. Also, Rwanda is building up the national capacities for producing appropriate technologies, looking as well at the diffusion of such technologies to the provinces. The national research and training institutes, the technology institutes, and the university research infrastructure in Rwanda are adapted to this process. The energy and drinking water infrastructure in Rwanda is examined by reviewing the needs to rehabilitate and to build the required STI infrastructure. Last, but not least, client-focused agricultural research is linked to farmers and processors by identifying and removing the deficiencies of the public agricultural research system. This is not a vision or a general plan, but the main elements of the STI strategy are already implemented in Rwanda, based on concrete action plans (Watkins/Verma 2008). Thereby, the National Innovation System (NIS) of Rwanda is strengthened although it is still rudimentary. STI infrastructure and the NIS are important pillars for pursuing pro-active agro-industrial development strategies at three levels: at subsector level, at value chain level and at the level of export capacity enhancement (Wohlmuth 2013b).

Sudan and South Sudan have the potential to bundle their capacities and the available infrastructure in such a constructive way, although this potential was neglected during the decades of civil war and as well after the Comprehensive Peace Agreement (CPA). There was a doubling of agricultural research and development investments in Sudan in the period 2001-2008, but the total agricultural R&D investments (measured as a percentage of agricultural GDP) are among the lowest in Sub Saharan Africa (SSA). As the number of full-time researchers in agricultural R&D has increased to more than 1,000, there is a potential to be used by both countries now. Sudan is equipped with various respected agricultural research agencies/institutes, like the Agricultural Research Corporation (ARC), but they need to be reorganized and linked better to agro-industries. Sudan can thus supply R&D solutions to the border-states of the two Sudans (see Stads/ El-Siddig 2010 on these data). As ARC has built some few capacities in Southern, Western and Eastern regions, it would be important for South Sudan not to break the links to ARC, as the accumulated know-how of this institution in different agro-climatic regions is important for South Sudan's agricultural and agro-industrial development strategy. Also, the Animal Resources Research Corporation (ARRC) had some base in South Sudan, and the knowledge of the whole institution should be used by extending links.

As South Sudan is now orienting agricultural R&D towards its six ecological zones, the inputs from such institutions in the North (Sudan) are highly relevant. Although South Sudan cooperates with institutions of other neighbour countries in agricultural R&D like Uganda, Kenya, and as well with the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), a balanced approach is recommended. A R&D plan for the agro-sector is elaborated in South Sudan, but it needs to be extended also to agro-industries and full agro-industrial value chains. The same applies to Sudan. The Hydrology Research Station (HRS) and the National Centre for Research (NCR) in Sudan also have accumulated vast knowledge which is also relevant for South Sudan. Also, universities in Sudan like the University of Khartoum and the Gezira University have a lot to offer in this respect if basic agricultural R&D is revitalized there, and they could supply knowledge also to established and upcoming university institutions in Southern Sudan. The regional research centres in the states of the two countries need urgent rehabilitation and quality improvement so that they can support local agro-industrial development. Such competencies play a role as assessed in growth diagnostics frameworks for states and can be used for establishing Local Innovation Systems (LISs). Although there are some few examples of good cooperation between the private sector and the public research system, especially in the Sudanese sugar industry, but also in food industry, much more of such cooperation is needed in both countries.

Co-operation between the Agricultural Research Corporation (ARC) of Sudan and the Southern Sudan Agricultural Research and Technology Organization (SSARTO) along the lines of agro-industrial development programmes would be very helpful and should be extended to the private sector (see on these institutions Stads/El-Siddig 2010, p. 4). Most important however, beside of cross-country co-operation in research and development, is innovation. It depends on linking the farmers, the agro-processors and overall agribusiness to agricultural research and development, public regulatory authorities, intellectual property organizations, innovation finance organizations, and technical and commercial services companies. By such linkages National Innovation Systems (NISs) and Agricultural Innovation Systems (AISs) are strengthened. Only few companies in Sudan, as an example the Kenana Sugar Company, are linked directly to such innovation systems; this is brought out in this Unit quite clearly. In South Sudan such linkages need to be created in the next years to promote agriculture and agribusiness. North-South and region-wide links are important for both countries. Innovation is always working cross-border if the environment for the firms and the farms is enabling. The conflicts since 2013 in South Sudan have however impeded such cross-border contacts at the level of STI.

Although the STI indicators in general show for Sudan a poor performance, the lack of coordination between research and the productive sector is a major factor which is impeding innovation in the economy (Nour 2010, 2012). Direct links to firms and farms are generally weak. There are so many complementarities for Sudan and South Sudan which could lead to mutually beneficial cooperation, as both countries need to redirect development strategies to productive sectors (agriculture, industry, trade logistics, transport, finance, energy, telecommunications, other services, and water), and more general to cross-border infrastructure development, environmental protection and climate change adaptation. Although more funding and better policies are surely needed, most important is the intensive co-operation of R&D institutions with productive sectors and knowhow partners in the wider region. Pooling funds and resources and sharing tasks between R&D centres in South Sudan and Sudan could be beneficial especially for the ten border states (five in Sudan[33] and five in South Sudan[34]). The number of states at the international border between Sudan and South Sudan has increased, making cross-border cooperation not easier.

A priority change is needed for both countries towards researching more on rain-fed crops and on traditional and new export crops. Regrettably, Sudan's agricultural research and development system has neglected traditional sector rain-fed crops compared to irrigated sector crops; this has also repercussions on potential transfers of knowledge to South Sudan. The conflicts in Sudan, the conflicts between Sudan and South Sudan, and the conflicts in South Sudan since 2011 have also disrupted the trade routes between the two countries. Both countries could benefit from an institutional upgrading and interlinking strategy for the STI infrastructure, as it was done in Rwanda by focussing on the crops which are important for local consumption and export. Cross-border knowledge transfers would be feasible and important for both countries, especially for regions having the same agro-ecological zones in both countries what is the case in the border-states. A border states development programme would be supportive for development in both countries, and STI infrastructure would be a core element of it.

## 1.5 The importance of coherent STI policies for structural transformation in Sudan

Coherent STI policies are important for Sudan to manage the transition to a new economy which is based on increasing value added in the agriculture sector, higher levels of processing agricultural products, use of STI for structural change between and within economic sectors, transition to a knowledge-based and innovation-led economy, revitalizing the manufacturing production, upgrading exports towards higher value-added products, orienting the economic policy towards inclusive growth regarding environmental objectives, social protection objectives, and balancing spatial disparities objectives. Concerning the transition to a knowledge economy, Nour (2013: p. 179) indicates that in Sudan the implementation of comprehensive strategies in the field of S&T was not fully carried out, mainly due to the inadequate base of financial and human resources. Also, the lack of adequate STI data had a role in leading to poor policies (see Nour 2010, 2012, CBS). Moreover, the results presented by UNESCO (UNESCO 2015/2016) and by Nour (Nour

[33] Sudan had after the separation of South Sudan 15 states, but three more were created in Darfur (two additional states in 2012) and in Kordofan (one additional state in 2013), bringing the number of states to 18.

[34] There were 10 states in South Sudan, but the government has increased the number of new states (32 states since 14th of January 2017, the number of states was increased from 28 states which were there since 2015 instead of the former 10 states which were there at independence in 2011); see on the most recent increase to 32 states: https://paanluelwel.com/2017/01/22/the-32-federal-states-of-the-republic-of-south-sudan/.

2013) indicate that, unfortunately, Sudan does not yet dispose of the human and financial resources which are necessary to promote science and technology effectively. Also, for building up human and financial resources the "critical mass" of researchers and of STI funding is not reached yet; building the "critical mass" in Sudan would lead to cumulative advantages in the direction of a knowledge economy.

Sudan would be in a better position if it had encouraged more private sector involvement and regional co-operation, if it had restructured its essentially agriculture-based economic system which was neglected in the oil era, and if it had pooled its resources, which were abundant in the years of increasing oil exports, to develop its S&T capacity (Nour, 2012). As indicated by the UNESCO Science Report 2015 (UNESCO 2015/2016, Zou'bi, Moneef R. et al. 2015/2016), in 2013 the Ministry of Science and Communication in Khartoum has embarked on a revision of its Science and Technology Policy (of 2003) with the technical assistance of UNESCO. The outcomes were major recommendations, including those advocating the re-establishment of a Higher Council for Science and Technology, to be headed by the First Deputy President of the Republic, which would co-ordinate and oversee relevant institutions and research centres attached to various ministries, with the Ministry of Science and Communications acting as a rapporteur of the council. In addition to the establishment of an Innovation Fund to finance government research, with a focus on employing the proceeds of Awqaf and Zakat for this purpose, this measure should be combined with the adoption of legislation for increasing financial allocations to scientific research and trade-related actions, such as creating exemptions from some or all the customs duties on imported goods and equipment that support research. All these measures should enable Gross Expenditures on Research and Development (GERD) to rise to 1% of GDP by 2021; and the establishment of an Observatory of STI Indicators, with the technical support of UNESCO, would give the policymakers a sound tool for decisions. Moreover, coherent STI policies are so important for Sudan because the country has a quite diversified institutional framework for research and development (R&D). The following research centres, among others, fall under the umbrella of the Ministry of Science and Communication: Agricultural Research Corporation (ARC)[35]; Animal Resources Research Corporation (ARRC)[36]; National Centre for Research (NCR)[37]; Industrial Research and Consultancy Centre

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[35] See: https://www.researchgate.net/institution/Agricultural_Research_Corporation_ARC for the various departments, the publications, the top cooperation partners, and the staff, and: http://www.agriskmanagementforum.org/org/agricultural-research-corporation-sudan

[36] See: http://www.gfar.net/organizations/animal-resources-research-corporation-khartoum

[37] See about the agro-related departments and publications: https://www.researchgate.net/institution/National_Centre_for_Research_Sudan

(IRCC)[38]; Sudan Atomic Energy Commission (SAEC)[39]; Sudanese Standards and Metrology Organization (SSMO)[40]; Sudan Meteorological Authority (SMA)[41]; Central Laboratory[42]; and the Economic and Social Research Bureau (ESRB). But there are other R&D institutions attached to other ministries and authorities as well, so that a Higher Council for Science and Technology makes sense as an instrument to coordinate such agencies.

All these institutions contribute to the work along the research priorities of Sudan and are part of a diversified STI infrastructure. Most of these institutions also have some link to agriculture development what makes them potentially important partners for the new policy direction of revitalizing agriculture production and exports. Despite of achievements and long experiences, the research infrastructure is not related to agricultural practice and to policy directives. Because of the underfunding, the understaffing and the lack of priorities, the output of the research infrastructure is unsatisfactory. The research capacity is not linked to the main pillars of the innovation system, and this is the case since decades. Agro-related research is deeply embedded since the years after 1900. Agricultural Research has in Sudan a long history, dating back to the beginning of the last century.[43] The earliest experimental farms were started at Shendi in 1902 and at El Kamlin in 1903. The purpose was to explore the possibilities of growing irrigated cotton in the northern Sudan. Shortly afterwards, more experimental farms were started at Rumbek, Tonj and Wau, primarily to test cotton under rain-fed conditions in the southern Sudan. This shows that South Sudan was early integrated into the overall experimentation work under rainfed conditions. Organized scientific research in Sudan was started in 1903 with the establishment of the Wellcome Tropical Research Laboratories (WTRL), named after the drug entrepreneur Henry Solomon Wellcome. They were part of the Department of Education, but their activities included chemical and entomological research related to agriculture. A year later, the Department of Agriculture established the Shambat Research Farm near Khartoum to conduct botanical and agronomic research in close cooperation with the WTRL. Based on the Gezira Research Farm, which was established in 1918 in Wad Medani, the Agricultural Research Corporation (ARC) developed in various steps. It is important to study the long history of research institutions, especially in the cases of agricultural R&D. This is a necessary step for

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[38] See on the role for the food industries: https://www.researchgate.net/institution/Industrial_Research_and_Consultancy_Centre
[39] See: https://www.researchgate.net/institution/Sudan_Atomic_Energy_Commission/departments
[40] See: https://www.iso.org/member/2078.html
[41] See: www.wmo.int/pages/prog/wcp/wcdmp/documents/Sudan.pdf
[42] See: http://centrallab.gov.sd/
[43] See the synopsis: http://www.aginfra.eu/node/456

reforming sectoral, regional and national innovation systems. Also, the other institutions mentioned above have a long tradition and a successful research & development record. It is therefore not too difficult to make the R&D system in Sudan working again towards revitalization of Sudan's economic base.

## 1.6 New perspectives towards structural transformation via STI development

It is obvious that the reform of the STI framework in Sudan is important for structural change and that the reform needs new perspectives. The strategic problems confronting economic development in Sudan request a strong coordination of STI institutions and functions to bundle together the various resources which are available in higher education, science and technology, and information and communication technology institutions. As Sudan's economy is characterised by a relatively low GDP per capita and by a presence of high rates of poverty, unemployment, and youth unemployment, and high inequalities in income, assets, land and in resources-sharing, only the perspective of inclusive growth will be the base for an adequate framework for Sudan. Meaningful is only a concept of inclusive growth which encompasses economic, social, political and spatial inclusion. Following the loss of the greatest part of its oil revenues in 2011, structural changes in the economy and the improvement in the economic performance necessitate a planned long-term transition process which is agriculture-based and innovation-led, and which focusses strongly on the development of human resources and capabilities (covering human capabilities, institutional capabilities, innovation capabilities, technological capabilities, and IT capabilities).

Sudan has turned from a low-income economy to a lower medium income economy, according to the World Bank classification, but to maintain this income position the transition to an innovation-led economy needs to become a successful process. The secession of the South Sudan in 2011 had seriously and critically affected the Sudanese economy (UNDP, 2014), particularly because of the loss of the greater part of Sudan's oil production, of its public revenues and of its export revenues, and this loss can be compensated only by a sound combination of agriculture-based, diversification-focussed, and innovation-led development policies. The importance of coherent STI policies for such a complex restructuring process in Sudan is great, and therefore the strengthening of the national innovation system (NIS) will be a high priority in Sudan. Based on a rebuilt NIS it will be possible to transform the prevailing economic structure in Sudan, which needs structural changes between and within the key economic sectors (agriculture, industrial, and services sectors). Manufacturing has a key role to play as it allows to overcome the deindustrialization process from which Sudan suffers since the 1990s. The manufacturing base of the country is still strong, although spatially concentrated, and allows for a rapid process of reindustrialization to take place. Such structural changes will allow it to promote innovation, to create a knowledge economy, and to aim at inclusive growth and sustainable development in Sudan. This implies that the importance of implementing coherent STI policies is vital for Sudan in the next years and decades, although a well-balanced framework is requested along an agenda for action that comprises short-term to medium-term to long-term agendas for action. Some proposals were already made for such a drastic change of policies, structures and institutions in Sudan (see World Bank 2015, World Bank 2014, UNCTAD 2015, AfDB et al., African Economic Outlook, Country Note Sudan, 2017, Wohlmuth 2016, Wohlmuth 2013a, Wohlmuth 2012, Murtada Mustafa 2017). Key strategies are based on diversifying the economy, on developing human resources and entrepreneurship, on building a viable national innovation system, on revising trade and foreign investment policies, on laying the foundations for economic cooperation between Sudan and South Sudan, on creating a functioning fiscal federalism and an adequate governance structure, and on reforming effectively the investment policy process.

## 2 The Contributions

Four essays cover important issues of Sudan's STI system. The first essay is about the structure and dynamics of the national innovation system (NIS) of Sudan. The second essay is on the working of the agricultural R&D system in Sudan. The third essay is on the role of innovative industrial firms in Sudan. The fourth essay is on the role of foreign investment as a source of knowledge transfers to Sudan. So, the Unit 2 of volume 20 covers the major issues of Sudan's STI system and key sector-specific factors and policies. Major reform proposals and action plans are discussed.

In the first essay to this Unit 2 **Samia Satti Osman Mohamed Nour** contributes a study on **The National Innovation System in Sudan – Is it enhancing national competitiveness and contributing to a higher business performance?** The study uses both, descriptive and comparative approaches, to assess the components of the overall system and to make comparisons with data from comparator countries in Africa, in Sub Saharan Africa, and in other developing areas. The author uses a definition of the national innovation system (NIS) which is used in the literature to examine the characteristics, the causes, and the implications of underdeveloped national innovation systems. This is done by integrating analyses of higher education institutions, science and technology institutions, and information and communication technology institutions. The purpose of the analysis is to present with the case of Sudan a new case study of African countries. This is important as detailed analyses of NISs for Least Developed and Low-Income Countries in Africa are rare. Although Sudan was upgraded (by the World Bank classification of countries according to the income status) to a Lower Middle-Income Country because of its oil exports, incomes and revenues, the basic structure of the Sudanese innovation system is weak and corresponds more to the characteristics of a Low-Income Country.

This essay examines three hypotheses: firstly, that the national innovation system (NIS) of Sudan is hampered by several determining factors and that it is therefore characterized by serious weaknesses compared with other countries in Africa and the developing world; secondly, that the innovation performance in Sudan has deteriorated during the period of 2011-2015, the period after the separation of South Sudan; and thirdly, that the weaknesses of the national innovation system of Sudan have serious implications on the functioning of the economy of Sudan and its firms. This essay is useful also from a policy perspective since it provides useful insights for stimulating new policies for developing and upgrading the national innovation system (NIS) so that it can contribute to inclusive growth in Sudan. The study also recommends the implementation of coherent and sound STI policies, as well as improving the policy environment so that the economic structure of Sudan can support innovation. All this requests that the allocation of financial and human resources to the subsectors of the NIS is improved, that the incentives to encourage the public and private sectors to contribute to R&D activities are increased, and that the key elements and pillars of the NIS are bound together - by strengthening the linkages between the sectors and between the stakeholders belonging to the national innovation system (NIS) of Sudan and by designing and implementing STI policies which cover the whole "research & development to production and to usage" value chain.

The essay also discusses the important policy issue that the National Innovation System (NIS) of Sudan is working with an overwhelming contribution from the public sector, while the private sector is only a minor contributor to the system. The researches for the study find support for the first hypothesis that the national innovation system (NIS) is hampered by several factors and is characterized by serious weaknesses in Sudan when compared with the NISs of other African and developing countries. It was found out that Sudan has lagged far behind other African and developing countries in terms of S&T input indicators, higher education indicators, and information and communication technology (ICT) indicators. Also, the three subsystems of the NIS (higher education institutions, science and technology institutions, and information and communication technology institutions) need more integration among itself and with the domestic and foreign firms in Sudan and with other government institutions. The results of the researches also support the second hypothesis that the innovation performance in Sudan has deteriorated during the period 2011-2015. It was found out that there was a deterioration in terms of the rank and the score value in terms of the overall Global Innovation Index (GII), the GII input sub-index, the GII output sub-index, and the innovation efficiency ratio (IER) in Sudan during the period 2011-2015. There are various causes of this deterioration, but austerity policies, neglect of institutions, diversion of funds to other policy areas, brain drain, and gaps in STI policies should be mentioned as important factors. The results of the researches also support the third hypothesis that the weaknesses of the national innovation system (NIS) have serious implications for the conduct of the economy and for the development of the firms in Sudan. These serious implications appear in terms of unfavourable S&T output indicators (such as an insignificant number of patents and low shares of high technology exports), declining international competitiveness, lack of further integration into the global and regional economy, low ranks and score values for the knowledge economy index (KEI)[44], insignificant shares of medium and high technology exports, low investment into technology infrastructure, low ranks and score values of the technology achievement index (TAI)[45], and a weak capacity to absorb, to transfer and to create knowledge in Sudan.

The serious implications of the rudimentary national innovation system (NIS) of Sudan also appear in terms of the weak linkages of the R&D system with enterprises. The linkages between external knowledge sources and enterprises are insignificant, and the lack of internal R&D departments adds to this deficiency. It is well observed that internal R&D departments are valuable to absorb knowledge from external sources and to create the basis for newly applied research results, technology developments, and product and process innovations. The findings in this study are useful from a policy perspective since it provides useful insights for stimulating new policies for enhancing the national innovation system (NIS) by linking the enterprises with the R&D system, the financing mechanisms for R&D and innovations, the higher education and vocational training institutions, the patent offices and regulating agencies, and with other pillars of the national innovation system (NIS). In this context the results of the study are helpful for stimulating through policy measures the innovative activity of firms and inclusive growth at the national level. Based on these insights, it is recommended to implement a national innovation system (NIS) that has strong linkages between the major pillars and is based on coherent and sound STI policies. Of great importance is a reform programme that incorporates the three subsystems of the NIS - Higher Education institutions, S&T institutions, and ICT institutions. The three key capabilities of modern production systems (technological capability, IT capability, and innovation capability) can be strengthened on this basis. Coherent

[44] See on the KEI: https://knoema.de/WBKEI2013/knowledge-economy-index-world-bank-2012

[45] See on the TAI: http://hdr.undp.org/en/content/measuring-technology-achievement-nations-and-capacity-participate-network-age

STI policies are so important for Sudan as they allow it to shift from the still prevailing rent-seeking economic structure to a science, technology, and innovation (STI)-based and knowledge-based economy, thereby enhancing national competitiveness, contributing to a higher business performance, reducing poverty and inequality, and achieving inclusive growth and sustainable development.

An Agenda for Action is presented to create a viable National Innovation System (NIS) for Sudan based on an Action Programme that is implemented via short-term, medium-term and long-term actions over 13 years for the period 2018-2031. Priority action should be on measures to improve public spending on R&D as a percentage of the GDP, to promote human capital accumulation in the R&D sector, to promote ICT hardware, software and training development, and to promote the STI infrastructure at all levels of action. The short-term agenda should cover one year (over the period 2018-2019) and should put priority to improve public spending on R&D/GDP to 0.50%, to promote human capital in R&D, to promote ICT, and to promote STI infrastructure. Medium term actions are intended for two years (over the period 2019-2021) and should put priority to improve public spending on R&D/GDP to 1%, and further measures to promote human capital in R&D, to promote ICT, and to promote STI infrastructure. Long term actions are intended for ten years (over the period 2021-2031) and should put priority to improve public spending on R&D/GDP to 1.50%, and further measures to promote human capital in R&D, to promote ICT, and to promote STI infrastructure. In addition, the Government of Sudan needs to establish a Science Observatory, and an Innovation Fund that should be supported by stakeholders on a trilateral basis with support from the government (public sector), the private sector, and the civil society; also, external sources of funding will play a role. All stakeholders, such as the government, public and private institutions, and the scientific community, should contribute to support sustainable funding for the promotion of the national innovation system (NIS) and the STI infrastructure in Sudan. Moreover, Sudan needs to implement a sound, sustainable and coherent STI strategy, to improve investment in higher education and vocational training, to reduce brain drain and to move to brain gain, to involve scientists and entrepreneurs from the diaspora, to improve international co-operation on R&D, to improve the transfer of new technologies, to encourage the private sector to contribute to the R&D effort, and to motivate scientists to engage in public-private partnership projects for the promotion of the national innovation system (NIS) and the STI infrastructure in Sudan. Social, economic, environmental and political reforms and STI policy reforms should be complementing each other in Sudan, and this can be achieved by making them consistent with each other.

It is recommended in the essay that it would be most suitable for STI in Sudan to focus on Agro-Based Industries (ABIs), particularly because Sudan has comparative advantages in agriculture and in agricultural products, which could be turned into competitive advantages. Despite of the huge agricultural potential the

Sudan has, the country is importing foodstuffs and wheat as well as many processed food products. Sudan would gain additional competitive advantages - with positive impacts on broad and inclusive industrialization - by focussing on Agro-Based Industries (ABIs) in its STI endeavours. Agro-Based Industries (ABIs) are those industries that are based on agricultural raw materials to be processed in food industries or industries which depend on agricultural products as raw materials but are directed to other industries, such as textile, cosmetic and pharmacy products. Also, backward and forward linkages of the agriculture sector have a huge potential for inclusive growth and employment creation. For all these agro-related value chains many new STI inputs are requested, in production, in logistics, in marketing, in supplying modern inputs, in linking production to world markets via globally accepted standards of quality, etc. Most important, along the whole agricultural value chain, R&D (research and development) inputs are needed to increase productivity.

Agro-Based Industries (ABIs), such as cotton, jute, silk and woollen textiles, sugarcane and vegetable oil, need high quality raw products and inputs to gain and to maintain local and international competitiveness. As an example, cotton textile industries use cotton as raw material and then they process them to make yarn, fabric and dresses. Although Sudan has in its history shown a great capability in this industry, the advantage of having an integrated production chain was lost. Some special production niches could however be revived, although this may be in the context of a fragmented value chain (see on such new opportunities and their imitations: Jodie Keane and Roland Baimbill-Johnson, eds., 2017). In addition to agriculture-based industries, it is recommended to focus STI in Sudan more on manufacturing industries which are based on the rich, accessible and diversified mining resources. Sudan has a comparative advantage in mining, extractive industries and natural resources, such as metals, gold, and oil. The value chains based on these mining sectors are however not organized yet. Again, it is necessary to turn the comparative advantages into competitive advantages of firms. Sudan could gain additional competitive advantages - with positive impacts on its industrialization process - by focusing on specific extractive and manufacturing industries. Furthermore, it is recommended to focus STI more on green, environment-friendly, and sustainable renewable energy technologies, like solar energy, particularly because Sudan has the comparative advantages of the availability of Sun as a source of renewable energy. Sudan could also in this field turn its comparative advantages into competitive advantages - with positive impacts on industrialization - by focusing on solar energy-related STI areas.

In the second essay to this Unit 2, the two authors **Migdam E. Abdelgani and Nazar M. Hassan** present a study with the title **The Impact of Agricultural Research on Agriculture Yield in Sudan.** As agriculture is a key economic sector in Sudan, and as again the importance of this sector is on the increase in Sudan since 2011, the importance of agricultural research is now greater than ever in the past. There is a huge potential to increase the yields of various crops in Sudan, and the yield increases are so important as it is necessary to see arable land more and more as a scarce resource. The increasing importance of agriculture as an economic sector is caused by the loss of the oil fields which are mainly located in South Sudan. Export diversification was always important, but now this objective has a tremendous impact on the future of Sudan. However, also the issues of providing for food security in all of Sudan and achieving structural change through productivity increases matter for the Sudan. Achieving food security for the growing population of Sudan is a complex task because of the violent conflicts in some regions, and because of the conflicts about land rights and land use in rain-fed agriculture areas. The competition between crop production and livestock production is prevalent in many areas, and so the theme of using agricultural research as a tool for agricultural yield increases has got an even greater significance. Research institutions and policymakers need to respond to these requirements. The two authors assess the possibilities, challenges and opportunities to use agricultural R&D in a pro-active manner for broad-based productivity increases. The focus is on broad-based and sustainable yield increases, so that agricultural R&D can deliver long-term successes. Productivity increases based on yield increases should also be adapted to expected climate changes which may occur in some areas of Sudan; drought-resilient crop varieties using less water, energy and chemicals for production are sought after.

This essay uses descriptive and comparative analytical approaches to investigate the correlation between the scientific and developmental work (that is done in Sudan in the different agricultural research centres inside and outside the universities) and the productivity of the Sudanese agricultural sector (as assessed for the different crops). If such a correlation already exists, the country can strengthen the linkages between the research and the production system. If these linkages are not there, the country has the task to create such a correlation. Frequent droughts and other environmental events, coupled with government neglect of the agricultural sector for decades while focusing on oil production, have led the agricultural sector to contribute directly to an unprecedented level of poverty and food insecurity in Sudan. While various new and improved technologies have been released by ARC (Agricultural Research Corporation) and other research centres, only very few scientific research results of the different agricultural research centres had been put into practice to improve the agricultural yield of the sector. But with a quite low "knowledge economy index" (KEI) as found for Sudan, agricultural research cannot solely be responsible for its lack of contribution to the productivity increase of the agricultural sector, as many other impediments are stifling innovation and the entrepreneurial agricultural culture in Sudan. Such impediments are the lack of adequate innovation policies, the lack of adequate technology transfer mechanisms, the underdeveloped processing capacities, the lack of integrated agricultural value chains, the lack of adequate higher education and vocational training systems, the gaps in internal R&D in enterprises, cooperatives and farming units, and the serious underfunding of human resources and R&D.

The findings of the authors imply that the agricultural research system of Sudan is not really adapted to the needs of the key agricultural sector which has become even more important since 2011 because of the need to go for inclusive growth, food security, environmental protection, social safety nets, and rural employment. The prevailing agricultural R&D system of Sudan is neither set to serve the priorities of the agricultural sector/system in terms of optimal resources management, nor do their activities address the sector's priorities to improve on its yield and productivity. For the agriculture sector in general, the frequent occurrences of drought and the low productivity of crop and livestock production are directly related to poor policies (national, sub-regional, and sectoral) and mismanagement, the gaps of the governance system (in vertical and horizontal terms, and in all spheres from political to social and to economic and to corporate ones), the deficiencies of the land tenure system, and the environmental and climatic changes associated with the deterioration of biodiversity. Most important is the analysis of mobilization tools like the National Crop Campaigns (NCCs), as practised for rice in Egypt. Sudan can learn from the experiences of Egypt with such campaigns. The experiences of Egypt show that such campaigns can impact positively on production volume and on the yield of crops, if they are sustained over the years, and if such campaigns overcome the usual way of targeting small pilot projects in the agricultural sector instead of large-scale projects as it used to be the case in the past. So, Sudan can learn from the way the NCCs have been worked out in Egypt to correlate research and production systems.

The authors start with an Introduction to the theme, emphasizing the role of agriculture and of R&D in the sector, highlighting trends and levels of R&D spending and the work of the R&D institutions. It is argued in a main section that the fragmentation of the STI capacity and the imbalances in support infrastructure and quality management hinder a better use of R&D in the agriculture sector. The focus is in detail on the various agricultural research institutions operating at universities or independently from them; their work is not coordinated with the agricultural production system despite of the long history of some of the (public) institutions. Emphasized is the fact that the private sector is still of minor importance in promoting R&D and in linking with the production system. The neglect of private research efforts is a serious deficiency, but the authors relate it to the lack of cooperative business clusters in agriculture. This is the case for the rainfed subsistence agriculture but also for the rainfed mechanized farming sector. So, the authors propose a new institutional arrangement – the Agro-politan Cooperative Business Cluster (ACBC) model. The ACBC model is introduced, resemblng to some extent the cooperative agriculture business ventures which have a tradition in Sudan but were neglected by policymakers. Cooperatives in Sudan's agriculture were not unsuccessful, but did not get political, legal and financial support. Despite of some importance, these ventures were not attracted by high public visibiltiy. In a further key section the 2012 national rice campaign of Egypt is analysed, and the relevance for improving the rice production system in Sudan is brought in. The campaign recommendations show that the Sudan can definitely learn from the case of Egypt, especially in the sphere of transferring research results to large-scale field testing. Especially, the large-scale volume of the programme in Egypt, applying new research results to large rice production areas, is of importance and of interest to the Sudan. However, such campaigns can also be used for production and productivity icnreases of other crops in Sudan.

In the third essay to this Unit 2 of volume 20 **Samia Satti Osman Mohamed Nour** presents an analysis with the title **Innovation in Industrial Firms in Sudan**. This essay has a focus on the industrial sector of Sudan as two international firms (using their own description of manufacturing activities) and two large-sized and two medium-sized manufacturing firms (using primary data from a Firms Survey) are considered. This is the first analysis on specific manufacturing firms in Sudan done with the purpose to investigate the propensity to innovate. Although these firms have all their base in Khartoum, the capital city, the results of the investigation have far-reaching implications. It is important to find out if firms in countries like Sudan with a weak national innovation system (NIS) have the ability and the propensity to innovate in terms of products and processes, and it is also important to learn if such firms have internal R&D facilities and research staff or if they rely only on external knowledge. As specific sectors are concerned (food industries, chemical industry, textile industry, and metal works), the respective innovation systems at the sector level are also relevant. Sector-specific innovation systems are researched beside of the national innovation systems to understand the typical characteristics of industrial sectors in terms of innovation conditions (if product innovations or process innovations matter more, what type of proprietary knowledge is important, what the role of R&D is if the concentration of market power is considered, and to what extent foreign capital is involved in the sector).

This essay examines the existence of innovation strategies and the implementation of innovations in industrial firms in Sudan with the intention also to use the study and the research results as a new case of innovative activity in Africa. Sudan is an important case to study, as the country needs to reindustrialize now, using the still relevant manufacturing base, after the loss of most of the oil reserves to South Sudan. A major source of foreign exchange and of public revenues has gone, and the revitalized sectors agriculture and industry emerge as new potential sources of revenues. Although Sudan has a long history of industrialization, the manufacturing sector has suffered from policy neglect in the period of oil discoveries, oil production, and oil exports. The author uses descriptive, comparative and analytical approaches, using the framework of sectoral innovation systems that is often used in the international literature to assess the type and the intensity of innovations in a specific industrial sector. In the essay use is made of primary data which are based on a Firms Survey (March 2017) that had been collected from two large size firms and two medium size firms working in the manufacturing industries in Sudan. This Firms Survey was a follow-up to an earlier Firms Survey with a larger sample of firms.

The essay investigates the size and the intensity of innovations (product and process innovation), assesses the innovation capacity, evaluates the innovation and R&D strategies and the human resources (training) strategies, and investigates the main factors hindering innovations and those contributing towards the promotion of innovations in the selected firms. The results corroborate the first hypothesis concerning the existence of innovations in industrial firms in Sudan. The findings support the second hypothesis that the degree, the size, and the intensity of innovations are determined by the firm size. The results also confirm the third hypothesis regarding the limited size and intensity of innovations (product and process innovation), as well as the limited innovation capacity, and the limited role of innovation and R&D strategies and human resources (training) strategies. The findings as well support the fourth hypothesis that the inadequate availability of human resources and the inadequate availability of financial resources are the major constraints for innovations and therefore for the development of local technologies and for the local adaptation of foreign imported technologies in the industrial manufacturing firms in Sudan. It is also observed that there is a quite limited cooperation between private firms, industry associations, universities, research institutes, government authorities and the firms of the public sector for promoting innovation, R&D, and human resources development (training). Based on these results it is recommended to strengthen the efforts for the provision of adequate human and financial resources as the main factors contributing towards the promotion of innovations and towards a greater role of the innovative capacity in industrial firms in Sudan.

After an Introduction to explain the logic of the argument and the perspectives of the analysis the author assesses the relevance of the literature on the sectoral innovation systems by reviewing the rich international literature and then condensing the approaches towards the ones being relevant for this essay. It is shown that most of the studies on innovations in African industries discuss the issues at the level of the national innovation systems (NISs), so that this contribution is one of the few studies relating innovation activity in African firms to specific sectors of industry. Then, in a further section the characteristics of the sectoral innovation systems are related to large size industry firms in Sudan. This is done in the form of a Self-Assessment by the two companies Kenana Sugar Company (KSC) and DAL (Daoud Abdel Latif) Group of Industries, two large size food manufacturing industrial firms in Sudan.

These two firms are characterized by large size business ventures and by long-standing establishments which operate across many business units and sectors and produce diversified products with well recognized trademarks in the domestic market of Sudan, but they have also export activity and international business operations. They are characterized by the adoption of explicit policies to enhance Training and Skills Development (TSD) and Research & Development (R&D). They are also characterized by an increasing awareness about their commitment to contribute to economic and social development, to human resources development, and to education, environment, and sustainable development. In the self-assessment various issues are brought out in details: the size of business operations, the long-term experiences of the firms, the range of diversified products, and the well-recognized trademarks in Sudan. Also, the contribution to economic and social development and to sustainability is presented, and the ways of enhancing human development, education, and human resources development are highlighted. Major issues covered are enhancing environment and sustainable development through operations of the firms and enhancing Research and Development (R&D) in these firms.

Quite different are the experiences of the industrial firms which are reviewed in the next section of the essay. Covered are two large-size industrial firms (one belonging to the food industry and the other to the chemical industry) and two medium-size industrial firms (one belonging to the metal industry and one to the textile industry), which were included in the Firms Survey of 2017 (and as well in an earlier Firms Survey done by the author). Compared with the two firms for which self-assessments were made, these four firms gave information based on standardized questionnaires. The questions on innovative activity were specific and were addressed to firms in various industrial sectors. The results show that the size of the firm matters, that sector conditions matter, that the attitudes of the management matter, and that policy support matters and can be helpful to induce innovative activity. These results also give some credibility to industrial policy actions in Sudan. Industrial policy can induce innovative activity if the real obstacles to innovation are identified and if the policy interventions are direct and effective in overcoming these observed bottlenecks. However, a full-scale survey would be needed to study the innovative activity of enterprises also in other industrial sectors, but also in intermediate size cities, in other states than only in Khartoum State, and in remote areas. Also, innovative activity of enterprises in rural areas and in informal sectors needs to be researched deeply.

In conclusion, Sudan has innovative firms in the manufacturing sector, but more research is needed to identify them, and to make their experiences usable for other firms being on the move towards higher levels of innovative activity. Also, the other hypotheses leading the research for this essay were supported by facts. The size of firms matters for innovation, the innovative firms have only a quite limited innovation capacity, and the innovative firms suffer from financial and human constraints which impede further waves of innovations. All these results may contribute to an Agenda for Action towards higher levels of innovations in the industry sector.

In the fourth essay to this Unit 2 **Mohammed Elhaj Mustafa Ali** presents an analysis **on Knowledge Spillovers from Foreign Direct Investment to Domestic Firms in Sudan.** This study aims basically to examine the impact of FDI knowledge spillover effects on domestic firms in Sudan. Complying with previous literature, the study investigates the role that could be played by these types of effects in facilitating growth in Sudanese domestic firms via its contribution to labour productivity. Using time series data covering the period from 1980 to 2014, the results of the research indicate that there is a positive relationship between FDI knowledge spillovers and labour productivity in Sudan. Interestingly, this positive relationship has been observed not only in the long run but also in the short run confirming that FDI knowledge spillovers exercise an influence in escalating labour productivity and, consistently, in boosting growth in domestic firms. In addition, the investigation proves that the rest of the variables which are incorporated in the analysis is associated with the correct signs, being generally significant, and being robust to the model specification. Based on these findings, the study recommends policymakers to initiate effective policies to encourage FDI inflows into Sudan and, concurrently, to exploit the full advantages of the potential benefits arising from its knowledge spillovers. The results suggest that, given that the enabling environment is created and given that foreign investors are interested in knowledge transfers to the industrial sector of Sudan, foreign investment in Sudan may have the potential to contribute to industrial diversification via knowledge transfers to domestic firms and workers.

The essay raises important issues for policymakers in Sudan. Too many investment codes and regulations were not applied seriously by politicians and civil service agents, and one investment code replaced the other. But foreign investment is forthcoming only if the policy framework is coherent, if the civil service adheres to it, and if the conditions under which foreign enterprises do their businesses are transparent. But neither rule of law nor other doing business conditions are granted and transparent as the poor ease of doing business index for Sudan consistently observes. Also, all the other relevant indexes show that Sudan is not a good place for foreign investors. The Corruption Perceptions Index (CPI), the Ibrahim Index of African Governance (IIAG), and the Knowledge Economy Index (KEI) reveal that there are limits of doing business in Sudan. The oil sector was an exception in terms of foreign investment, as foreign investors from China, India, Malaysia and other countries did negotiate with the government of Sudan and with local state-owned oil companies about access to the oil fields and about broad investment and business packages. These packages included production of oil, marketing and distribution of oil, exploration of new oil fields, infrastructure deals, services and maintenance deals, agreements on foreign labour, on local industries, on technology transfers, and on training programmes, etc. But, the oil sector-related foreign investments did induce directly and indirectly also investments in other sectors (industry, services and agriculture). The spending power from the oil revenues attracted others to come in. Normally, in the case of manufacturing the situation is different. Foreign investors look mainly at already established domestic markets in developing countries, and they favour industrial areas where the country might have a comparative advantage, such as Sudan in agro-processing, in the food industry, in processing other minerals, and in selected other fields where Sudan may be an interesting partner. In the case of Sudan, the oil-related investments and the revenues from the export of oil since 1999 have created specific markets (mostly in services, such as real estate, finance, retail business, and trade) which were fuelled by an increasing spending power. But, as the author documents, the country has attracted significant foreign investors also in other sectors, in manufacturing, in other services sub-sectors, and in agriculture. These oil-sector expansion-related and growth-induced foreign investments are important under the heading of employment and training. These investments can now be the base of a reindustrialization strategy in Sudan, after the loss of the major oil fields to the South Sudan.

The author starts after the Introduction with a section on a Literature Review, with a deep investigation of the literature dealing with knowledge transfers to domestic firms associated with foreign investment in developing countries. This is done to assess the potential effects of foreign investment on the absorption of knowledge by domestic firms. The literature is broad, and to some extent the empirical studies show contradictory results in regard of knowledge spillovers by foreign investors to domestic firms. So, it can be concluded that there may be a role of foreign direct investments (FDI) in knowledge spillovers to local firms and in boosting growth of local firms via its contribution to labour productivity. There is a potential, but the conditions must be appropriate for knowledge transfers. So, the literature submits that FDI knowledge spillovers are not assured; rather they are governed by some important conditional factors. These factors, as discussed by the author in his essay, include the host country's absorptive capacity, the type of FDI hosted, the extent of the technological gap between foreign and domestic firms, the type of the sectors in which affiliates of multinational corporations (MNCs) are transplanted, and the geographical proximity of foreign investments to local firms. Hence, solving the puzzle about the occurrence and the effectiveness of knowledge spillovers becomes dependent on the presence (absence) of these conditions. Yet, these conditions are differing across regions, countries, localities, and even firms. In other words, these conditions are determining the magnitude of knowledge spillovers being disseminated to Sudanese domestic firms through labour productivity (as a major transmission channel to the growth of the domestic firms and the growth of the economy). Thus, an advanced econometric technique, represented by the Autoregressive-Distributed Lag (ARDL) approach, is instigated to determine whether FDI's knowledge spillovers lead to the growth of domestic firms via their contributions to labour productivity.

After the literature review the author analyses in a descriptive overview the performance of foreign investment in Sudan. It is interesting to see how broad the interest of foreign investors outside the oil sector is, especially from Arab investors who have substantial foreign investment positions in Sudan. The author looks at FDI stock (FDIS), gross capital formation (GKF), gross fixed capital formation (GFKF), and private gross fixed capital formation (PGFKF) as percentages of Sudan's GDP. The data show that from 1995 onwards Sudan became an important location for foreign investment, although in the early years the flows were limited to the oil sector and oil-related investments. Prominent examples for the role of FDI-related knowledge spillovers in promoting Sudanese domestic firms can be observed in all the three sectors which are dominating the economy, namely industry, services, and agriculture. For example, in the industrial sector the influence of the knowledge spillovers can best be traced in the cement industry. The cement industry is an interesting case; foreign investments in the sector have obvious knowledge spillovers to domestic cement firms. Also, in the services sector, such as in the hotels branch, foreign investment is important and knowledge spillovers may have a role. Agriculture is also of interest to foreign investors, but this sector shows a tremendous gap with regard of transparency on the underlying land deals. It is not possible to say anything about knowledge spillovers related to this sector.

Next in the performance analysis is a review of the absorptive capacity for FDI in Sudan. R&D, vocational training and education systems of the country do not facilitate the absorption of foreign technologies by domestic firms. These firms cannot fully use the knowledge diffused by foreign firms because of the constraints on the learning process. This is a problem, as many of the foreign investors outside the oil sector could be useful as sources of knowledge to domestic firms; this is so as these foreign investors have a relatively high capacity for employment creation. Although many of these foreign investors are driven by the oil sector expansion, the relatively great number of employees in these firms makes a diffusion of knowledge possible, and positive effects of increasing labour mobility are becoming a reality. Also, it was found that the source countries of FDI in Sudan have implications for employment generation and for knowledge spillovers; also, this issue is of relevance for policymakers in Sudan. A continuous review of the role of non-oil investments in Sudan is of great importance, because of the great employment creation potential which is also a channel for the transmission of knowledge spillovers.

The empirical and econometric analyses in the essay support the results from the literature survey and from the descriptive studies. In a section on the research methodology the author outlines the model specification. In further sections the empirical results and the implications of the empirical results are presented. Six policy implications and various policy recommendations give guidelines for policymakers to follow up. Key issues are how to support the domestic firms in the absorption of technologies by specific measures, how to locate FDI projects in proximity to domestic firms, how to educate and to train their workers, how to build up the infrastructure to induce foreign and domestic investment, and how to link businesses and technical colleges.

## 3 The Strategy

### 3.1 Strengthening the National Innovation System of Sudan for Redirecting Economic Policies

Sudan needs to strengthen its national innovation system (NIS) which is still in a very rudimentary state. This is a difficult task, as first it is necessary to define the innovation system for the purposes of deep policy and institutional reform. The term "national innovation system" is often used in the sense of the three core subsystems (higher education institutions, science & technology institutions, and ICT institutions). These three subsystems are considered in Sudan as the basic elements of the national innovation system. However, reforms of these subsystems were always done in an unrelated and uncoordinated way. There were reforms of the higher education institutions, by supporting private universities and by establishing regional universities. There were reforms of the science & technology institutions by changing the surveillance and monitoring through ministries and councils. And with the digitalization the ICT institutions were established and later reformed, by changing the regulatory institutions, by privatizing the telecommunication operators, and by supporting other service providers which are part of the IT sector. But the reforms at the level of the subsystems were never synchronized. This would need a coordination at the highest government policy levels and would request a common understanding of the functioning of these three subsystems.

These three subsystems need also to be linked with other pillars of the national innovation system, like the innovation finance institutions, the vocational and technical training institutions, the regulatory and policymaking government bodies, and patent and standards offices. Most important are the links of the three subsystems with the enterprises, as the enterprises are the real innovators in the economy. They organize innovations (product and process innovations, technical and non-technical innovations, radical and incremental innovations, organizational innovations, management innovations, etc.). There is a correlation between national R&D funding and staffing and the innovative capacity of enterprises. In this regard the low levels of funding and staffing of R&D in Sudan affect all enterprises in their innovative capacity. Only few enterprises in the country have their own R&D staff and their internal R&D units, although many more enterprises need such internal R&D mechanisms and have also the size to go in this direction.

The greatest obstacle to STI development in Sudan is the lack of any systematic linkages between the enterprises and the other important pillars of the NIS, like the research & development institutions, the regulatory agencies, the innovation finance institutions, the policymaking institutions, etc. To bring these pillars into systematic contact, it is necessary to introduce incentive mechanisms. Such incentive mechanisms can have different forms. Enterprises and R&D units can cooperate based on matching grants to start joint research and development projects. Higher education institutions (private and public ones) can cooperate with enterprises (private and public ones) through the hiring of students and graduates for joint study and research projects at enterprises, and with feedback on academic programmes. Banks and other financial institutions, also microfinance and crowdfunding platforms, can open wings to finance innovation projects and start-up ventures. Vocational training institutions can cooperate with technical colleges and enterprises towards further training programmes.

Most important, the economic policy institutions, the enterprises and the higher education institutions need to consider in their plans and programmes the new priorities at the sector level. As agriculture and agribusiness are now again becoming important economic sectors, new development strategies for the agriculture sector and for the STI sector are imperative. Strategies for the agriculture sector and related research & development programmes need to be co-ordinated. Also, the statistical apparatus of the country needs to work on STI indicators which reflect the new economic priorities. STI data for the agriculture sector and related value chains matter in this context. International and regional cooperation on STI policies is another important area of action. National innovation systems (NISs) cannot be separated for a national economy; they need to be open for technology and information flows and for cooperation with STI actors in other regions to learn from their experiences and their approaches. The economic revitalization in Sudan is now a process which can support the strengthening of the national innovation system (NIS). However, these NIS-focussed reforms need to be coordinated with political, social, macroeconomic, governance, corporate, and institutional reforms.

## 3.2 Improving the Agricultural R&D System of Sudan along the Major Value Chains

The revitalization of the agriculture sector in Sudan has important implications for the STI policy. As the sector is composed of irrigated and rain-fed sub-sectors (the rain-fed subsector is also divided into a traditional and a semi-mechanized part), but also the livestock, forestry and fisheries sub-sectors play a role. Both, the crops sector and the livestock sector are important for the livelihoods of the people, for resource mobilization and for the export business. The available data for the years 2010 to 2014 show how dependent the cultivated area and the production level are on weather conditions, but also on policies, the security situation, and on STI inputs (CBoS, 2014, Chapter 8[46]). STI inputs allow it at all production stages to compensate for deficiencies in production conditions. However, it is not always easy to determine which influences matter most in a certain period. The annual variations in the production of key crops are huge, as can be seen for varieties of gum Arabic. The case of gum Arabic production fluctuations shows that policy environments and the emphasis on quality increases matter a lot, but also security concerns and political instability. While a favourable policy environment for gum Arabic can lead to sustainable production increases, a deteriorating security situation reduces production (see CBoS, 2014, chapter 8, p. 133). Cotton production and productivity are on the increase since 2010, and the use of modern technologies plays a role for this change. The staple crops in Sudan are mainly sorghum (Dura), wheat and millet. The data show decreases of the cultivated area and of the productivity (as measured by production over the harvested area). The main oil seeds are groundnuts, sesame and sunflower. For these important food crops a reduction of the cultivated area and of the productivity (except for sunflower) are seen. Despite of so many public messages, the data do not reveal so far a change in the production field towards a revitalization of agriculture as a new lead sector in Sudan after the event of 2011.

Sudan is well positioned to achieve self-sufficiency in red meat, fish, poultry, and realizes self-sufficiency in animal products; Sudan is producing a surplus in live stocks, meat products, leather and fish, and is exporting such products to satisfy the growing world demand. But in 2014, the livestock and poultry products witnessed quite uneven increases (CBoS, chapter 8, 2014). The production of eggs registered the highest rate of increase, compared with the other products. STI inputs are important, as examples show, to cope with adverse weather conditions, to increase productivity, to compensate for labour shortages through mechanization and planning, and to care for storage, transport and processing. Therefore, a coherent development strategy for these subsectors is requested, but this is not

[46] The Annual Report for 2014 of the Central Bank of Sudan is the last one which is available on the website (1/2018).

enough. All the decades since independence of Sudan in 1956 the government has worked on plans and programmes for these sub-sectors and on policies to mobilize the resources of the sector for the build-up of the industry. Also, the value chains in the context of these subsectors matter. Value chains care for the whole production and marketing from the raw product to the processing and distribution stages. Integrated value chains allow for adding value at all the relevant stages.

Such value chains are in the case of Sudan at different levels of development and integration. Some value chains are globalized, as in the case of gum Arabic, as Sudan has a near-monopoly position on the world market. Other value chains, such as in the cases of cotton, sesame, livestock etc., are advanced but need strengthening and integration. Unfortunately, the value chains for the various agricultural export products are not coordinated with national policies (on agriculture, processing, trade, logistics, infrastructure, education and training, macroeconomic policy, etc.). Macroeconomic imbalances impact negatively on the working of the value chains, and the loss of the oil revenues has led to new imbalances (in the form of budget and current account deficits). Removing the old and new imbalances is a prerequisite for functioning value chains. But the gap with regard of lead firms affects the integration of the various stages of the value chains and impacts negatively on the innovative activity at all stages of the value chain. The gum Arabic value chain is an example where a lead firm in Sudan potentially controls the market at the global level, as Sudan is a key producer. But the Sudan exports the product mostly in raw form and so cannot reap the benefits of its near-monopoly position. To benefit from the higher prices of products after processing the raw gum, lead firms need to improve on the capabilities to transform the raw product. This requests that crucial capabilities (technological, innovation, ICT, logistics, R&D, human capital, and management capabilities) are developed for the specific value chain. In many other cases of Sudan's agricultural value chains there is no presence of strong lead firms to carry forward the integration of the value chain. So, the country is dependent on foreign lead firms to link the local producers to the global markets. It is obvious that STI policies matter for all the value chains and for all the stages from raw product and processing to distribution and final consumption.

However, the most important constraint to an economic revitalization is the agricultural R&D as it currently works; it is not focussed on the specific crop, on the specific value chain, on the agro-climatic zone, and on large-scale testing of R&D results. The agricultural R&D system is limited to pilot field testing of research results instead of applying the research results in large-area field tests. Sudan has a great history of agricultural R&D, but the system is not complete because it is not covering all the major agricultural sub-sectors and the related value chains. The irrigated subsector has dominated R&D for long time, while the rain-fed sectors were neglected, although they are so important for food security, for balancing crop and livestock production, and for environmental protection. Agricultural

R&D needs a focus on all the subsectors, but also a focus on the related domestic and global value chains. How limited the focus of the agricultural R&D institutions is can be seen when looking at the R&D expenditures per crop and region. Sudan has a long history of agricultural R&D, as it started around 1900, but from the beginning the Gezira cotton sector dominated the research activity. Although there was also an early research focus on rain-fed crops in Southern Sudan, the research output was not readily used for yield and production increases through large-scale field testing and extension services. Sudan is an example of a country where excellent agricultural R&D was done early in research institutions and on test farms, but Sudan is also an example of a country which never has applied the research results on a broad front.

It is necessary to reorganize the public agricultural R&D system around the Agricultural Research Corporation (ARC) and the other specialized public research institutes; but also, the researches at university level need to be included in such a research cluster. The researches at university level go beyond the central level, as some universities were established in the provinces; and so, the researches done there are nearer to the farm regions. Regional universities have some advantages with regard of applied research; they can do field testing of research results near the fields and farms in the region. However, the Sudan has never worked on a long-term research plan to support systematically via STI inputs the development of food and export crops. Underfunding and understaffing of R&D and of extension work have limited the exploitation of opportunities in agriculture; underreporting on the real situation of agriculture has hampered the development of the sector. The indicators on inputs and outputs of agricultural research are therefore not up to date and do not facilitate the work of the extension service. Beside of R&D, the innovation processes in farms and cooperatives are not supported, and information on innovation inputs (such as new equipment and new seed varieties) and innovation outputs (better product qualities and new export niches) is not available. It is therefore also difficult to say anything about the efficiency of innovation processes.

However, Sudan can learn from other countries in terms of large-scale field testing. National Crops Campaigns (NCCs) are a method to introduce researches based on large-scale field tests. Sudan can learn from Egypt and from other countries (Vietnam) how to use research results in large-scale field testing of new rice varieties. Experiences in these countries reveal strong yield and production increases if the support for large-scale field testing is maintained for some years. Farmers, extension workers, sector officers, and the research staff can be involved through joint training programmes. Obviously, a detailed documentation about the developments is needed in the context of large-scale field testing to find out the strong and the weak points. A revival of cooperatives in Sudan can be a helpful step to broaden the impact of the NCCs. Cooperatives in agriculture had a role in the history of Sudan, but never they were supported effectively by the central government. Any revival of cooperatives will have to start at the level of states and their regional universities, but central support will remain an important factor for successful field testing interventions.

Institutional reforms at the level of R&D institutions are needed. An optimal allocation of R&D funds between sub-sectors, crops, public and private stakeholders, along the stages of the specific value chains, and at the level of agro-climate zones, regions and areas is needed to bring forward the sector. Also, within institutions, such as the ARC, institutional reforms are necessary to link the respective institution with other key stakeholders. The question is if such institutions, like the ARC, can take on a new role towards supporting the revival of the agricultural sector. Such an institution needs adequate funding and independence from the political level, and it needs also continuous advice from the farmers and from extension workers, but also from international development and research partners. A new emphasis in this direction may help to bring such institutions back to the centre of an STI-focussed agricultural development strategy.

### 3.3 Reindustrializing the Sudan through Innovative Industrial Firms

Sudan is on the way of reindustrializing the country. During the era of oil exploration, oil production and oil exports the agriculture and the manufacturing sectors were neglected by the policymakers. Now the time has come to reindustrialize the country through exploiting the potentials of the non-oil sectors such as agriculture and industry, through developing new value chains and by strengthening traditional value chains, through green growth initiatives in urban and rural areas, and through the support of industries in the periphery beyond the state of Khartoum. These four strategies at reindustrialization can be combined to generate employment, to develop the hinterland regions, to increase the resource efficiency, and to generate foreign exchange by exports. The base for all this is to have a look at the industries that are working smoothly. Sudan has a small number of diversified, innovative and internationally active conglomerates, especially in the food sector, like the Kenana Group and the DAL Group. These are the firms which are considered as highly innovative. Sudan has also many firms in various manufacturing sub-sectors (metal works, chemical industry, food industry, pharmaceutical industry, cement industry, etc.) with a potential to grow, to internationalize and to innovate. The base of such firms is rooted in local raw materials, local technical expertise, local financial sources and finance from the Arab region, and local and regional markets.

The industrial sector in Sudan comprises various subsectors (petroleum, mining, quarrying, processing industries, hand crafts, electricity and water). The contribution of the industrial sector to the GDP has increased from 21.6% in 2013 to 24% in 2014 (CBoS, 2014, chapter 8), and the manufacturing sector has now a great role in this increase, while the share of petroleum has decreased since 2011 sharply. The key industrial sub-sectors need a Reconstruction and Innovation Support Programme (RISP). This is especially the case for the petroleum subsector, the sugar industry, the pharmaceutical industry, the cement industry, and other processing industries (like the food industry, and the ceramics and the paints sectors). Also the electricity and water subsector of industry need a reconstruction programme. While oil production has decreased sharply since 2011, the production of oil derivatives has declined somewhat, but some categories remained important, especially the production of jet fuel, butane gas, benzene, and heavy gasoline. Around twenty companies are mining gold in Sudan, but there are also other mining products of importance (like chrome and salt). However, there is a lack of transparency in these mining activities. To make the sector relevant for employment and revenues, innovative strategies are requested.

The share of the manufacturing sector is dominating now the overall industry sector with around 17%. The sugar industry is of importance but suffered from the low professional and technical standards of the workers and the low and not competitive wages. The cement industry is an example of a flourishing industry sector, leading to production levels of self-sufficiency in Sudan. The production capacity is on the average still at a moderate level, but some factories are above average in performance. This points to innovative strategies in some firms. Problems are caused by a lack of spare parts (as sanctions hindered importation), electricity power outages, and increasing prices of furnace and fuel. Some factories have coped better with these problems by innovative strategies; management and innovation capacity are making the difference. The pharmaceutical industry is also expanding, by producing tablets, capsules and suspensions (powder and liquids); the production of dialysis fluids was launched in 2014 and is evidence of a considerable innovation potential in this manufacturing sub-sector. Other processing industries show increases for ceramics, paints, wheat flour, and biscuits, but decreases for edible oil and soft drinks. Also, the electricity and water sub-sector of industry and the various services sub-sectors are important for the performance of the manufacturing sector and its innovative capacity. Advances, such as in the telecommunication branch, are helpful, but other services subsectors are hindering development of the manufacturing sector, such as health and education, roads and bridges, finance and banking, and other services. There is no coherent innovation strategy in Sudan covering all these economic sectors, as the NIS is still quite rudimentary.

The Firms Survey 2017 on industrial firms in Sudan shows that there is also an innovative capacity in Sudan's industrial firms which can be strengthened by policy measures. The results support the first hypothesis concerning the existence of innovations in industrial firms in Sudan. Despite of the rudimentary national innovation system, product and process innovations take place in industrial firms, although at a limited scale. The findings support the second hypothesis that the degree, the size, and the intensity of innovations are determined by the firm size. Large industrial firms have aa greater potential for innovations and can also use external knowledge more intensively for innovations than smaller firms. The results also confirm the third hypothesis regarding the limited size and intensity of innovations (product and process innovation), as well as the limited innovation capacity, and the limited role of innovation and R&D strategies and human resources (training) strategies. A strengthened National Innovation System (NIS) and a coherent Industrial Policy (IP) can support the innovative capacity in these firms. The findings as well support the fourth hypothesis that the inadequate availability of human resources and the inadequate availability of financial resources are the major constraints for innovations and therefore for the development of local technologies and for the local adaptation of foreign imported technologies in the industrial manufacturing firms in Sudan. The combination of inadequate human and financial resources points to major constraints on the innovation process, which can only be overcome by policy action on national and sectoral innovation systems and by developing coherent industrial policies at the national and the sector levels.

Sudan needs a "transformative industrial policy" to develop the manufacturing sector based on an innovation-led strategy. The "transformative industrial policy" (see UNECA 2016) is an attempt to revitalize the concept of industrial policy for low income countries. Although there are respectable arguments to justify the use of industrial policy instruments, implementation has always been a major problem, especially so in Africa. A developmental state (when existing) can use the major arguments (to justify industrial policy) for successful policy action, if the administrative capacity is there to handle such policies and tools. Evidence shows (UNECA 2016) that also African low-income countries, such as Ethiopia and Rwanda, can benefit from reasonably effective industrial policy action. In such countries the practised industrial policy is transformative, as structural change is promoted within the manufacturing sector and between the key economic sectors. Sudan can learn also from the current industrial policies of advanced countries and from the early policies of these countries. Sudan as well as other African countries can also learn from the currently practised "smart" industrial policies and from industrial policies via integrating local producers into global and regional value chains. "Smart" policies refer to the potential of established industrial sectors, to the already accumulated technical and organizational capabilities, and to the new long-term industrial policy objectives and targets which are relevant for the country. Green industries are an example of "smart industrialization", as they are saving resources and energy, protecting the environment, leading to new value chains, and creating employment; in many cases they are also skill-intensive and R&D-intensive. Processing of certain gum Arabic varieties is an interesting example for a "smart" industrialization in Sudan, as such products have a high value added and are relevant as inputs for various industries (such as chemical, cosmetic, and food industries). However, a "smart" industrial policy can be successful only if STI inputs are provided systematically and if private businesses have incentives to support further processing. Despite of the fact that global trade rules constrain the "policy space" for industrial policies, such "smart" strategies are relevant for countries like the Sudan, as the country is strengthening its STI base and reindustrializing the economy.

## 3.4 Maximizing the Knowledge Transfers from Affiliates of Foreign Investors in Sudan

STI policies need to look carefully at the potential of foreign direct investment (FDI) for knowledge transfers. But, too often this potential is not addressed in STI policymaking efforts. This is also the case in Sudan. Sudan has a history of attracting foreign investment form the Arab region, while the oil industry has attracted foreign investment form China, India, Malaysia, and other countries. Despite of the early interest of the Sudan in attracting foreign investment, going back to the "breadbasket strategy" (a programme of supplying the Arab world with food from Sudan) in the 1970s, the investment laws of the country remained in all the decades rudimentary and were never fully implemented. The Sudan tried to attract Arab region investors based on its abundant agricultural and livestock resources to invest in large-scale agro-industrial projects to supply domestic and export markets with food products (with sugar, cereals, meat, etc.). Despite of these abundant resources has the country never developed a solid framework for foreign investment in the sense of coherent laws, regulations, practices and policies to maximise the overall benefits from foreign investment. Foreign investment can deliver various benefits, such as providing capital, generating employment, leading to know how transfers in the fields of management, marketing, organization, skills and technology development, involving local producers into global and regional value chains, transforming local producers to become exporters, etc. However, to generate these effects it is necessary to have an investment policy framework that is binding on the foreign investors but also on the bureaucracy of the country to avoid arbitrary decisions on both sides. Effective investment policy frameworks constrain the actions of private investors and of public administrations.

Recent strategy papers highlight the opportunities and the challenges of such a policy framework for foreign investors (see UNCTAD 2015). As Sudan is handicapped by internal conflicts and political instabilities, investors will only invest on a long-term basis in safe areas (probably around the capital city of Khartoum State). This concentration of investment activity in the Three Towns of Khartoum (Khartoum, Khartoum North and Omdurman) has advantages, as also numerous local investors are very active in the area, especially in the manufacturing sector. Agglomeration advantages matter in such dense urban areas, and knowledge transfers depend on such agglomerations. However, the other states in Sudan where agro-industrial and mining resources are plenty may get disadvantaged, especially so if infrastructure is not developed to connect these remote areas. Foreign investment needs to be mobilized also to such areas, but to reach such a goal it may be necessary to have a package of incentives as these areas are not normally sought after by the foreign investors. To justify such incentive packages, the benefits and costs of such measures need to be assessed, and they should conform to regular investment laws. Foreign investment is therefore needed to create regional development centres/poles in other states. In contrast to other African countries, Sudan has not succeeded in spatially distributing its industries (except the first development planning periods after independence).

Sudan has published over time many development planning documents and various revisions of investment laws, what is important, but the development plans and the investment laws were not coordinated. The result was that the policies for attracting foreign investors to new industries were never based on coherent strategies. While Sudan has improved its investment policy framework and has opened its outlook to regional and global investors, the reforms of the investment policy framework and of the investment legislation were limited to basic concepts. The secondary legislation, in areas of competition and market development, environment and climate change, taxation and fiscal federalism, etc., was not profoundly enacted. All these important aspects of legislation were not made consistent with the primary legislation on foreign investment. And, implementation problems were never solved because of the weak institutional capacity in most of the policy areas and the uncoordinated work of administrations at different government levels.

Policy gaps are still there in important areas. Establishing an affiliate in Sudan remains a difficult task, as different offices need to be consulted and as all steps towards establishing a firm are heavily taxed; access to land is largely unregulated and made difficult because of conflicting law systems and regulations; and finding out the relevant tax regime which is applied to a specific foreign investment is a problem for the investor but also for the offices being responsible for collecting public revenues. Arbitrariness of decisions on access to land, on establishing an affiliate, and in regard of the applicable tax regime involves huge costs to investors. While the most recent legislative framework on foreign investment foresees institutions such as an anti-monopoly council and an anti-corruption commission, not much was done to put these legislated priorities into reality. This means that the arbitrariness of decisions on foreign investment is not overcome and avoided.

The development of "free production zones" for foreign investors (to facilitate imports of inputs and the processing for exports) is another point to be discussed in Sudan[47], and the country can learn from the "transformative industrial policy"

[47] The country has taken some early steps, since 1994, to establish free zones (the Suakin Free Zone near Port Sudan and the Aljaily Free Zone near Khartoum), but the activity

of Ethiopia and from some industrial policy initiatives in Rwanda. Also, the issue of local skills availability is highly relevant for foreign investors and for domestic firms, as knowledge transfers can take place only if qualified local staff are able to communicate, to channel and to apply the new information transferred from foreign investors. In Sudan, the skill levels of employees in most firms and production sectors are not appropriate, and further education and training programmes are weak or totally absent. Successful steps to integrate local producers into regional and global value chains depend on the upgrading of local skills. As reported above, the national innovation system (NIS) of Sudan, composed of higher education institutions, science & technology institutions, and ICT institutions, can only become a productive force for enterprises if the basic education and vocational training system is becoming adequately organized. Foreign and domestic enterprises therefore depend on such basic education and training systems as a precondition of a functioning national innovation system (NIS).

A public-private policy dialogue is requested to bring domestic and foreign investors into a policy dialogue with key public offices and institutions at the different government levels. Such a dialogue was proposed for Sudan over years by many investment promotion experts but is not working so far. Such a policy dialogue could aid in developing strategies to maximize knowledge transfers through packages of reform measures for doing business in Sudan. The ease of doing business indicators could be discussed in such dialogue for a on an annual basis when the new data on the ease of doing business are coming out (from the World Bank and the International Finance Corporation)[48]. So far, only the overall rank of the country is used as a yardstick for policymakers and business people, but it is important to have a policy dialogue on the detailed ranks and scores for all the ten key areas of doing business, as they reflect the phases and stages of the development of the firm. Also, other ranks and scores are of interest to be discussed in a policy dialogue forum.

Investment agencies need to separate the regulation and the promotion function, so that conflicts between regulatory and promotion functions are avoided. Attracting foreign investors is a task for regulators so that the establishment is done according to the laws of the host country, but it is also a task for investment promotors to search for foreign investors who are in line with development objectives and development plans. A problem in Sudan is the fact that the regulatory and the promotion functions are not separated by the responsible institutions. Offices being responsible for regulation are also promoting foreign investment, so that the control function according to the laws is not really exercised when foreign

there was insignificant. Web Access: http://www.sudaninvest.org/English/Sudan-Invest-FreeZone.htm

[48] See on the 2018 data: http://www.doingbusiness.org/data/exploreeconomies/sudan

investment promotion is done by the same people. A strict separation of these two functions is therefore needed. In the case of Sudan, various offices have overlapping functions on regulation and promotion of foreign investment. A fully independent investment promotion agency (IPA) is proposed to channel investment to Sudan based on the agreed upon development objectives. Knowledge spillovers can be targeted by the IPA, by selecting and favouring certain firms by looking at the technological level and the employment projections for the affiliate in Sudan. Regulating agencies need to care for an adherence of the investor to laws and regulations (on land, labour, taxation, competition, etc.). It was proposed (UNCTAD, 2015) that the functions of the new IPA should be developed in two stages, first, image building, investor targeting and facilitation; and second, investment aftercare, policy advocacy and business linkages. It was also emphasized that sufficient human and financial resources, capacity-building and training of the staff are requirements for the success of the proposed strategy. It was also recommended that the National Investment Authority (NIA) and the Investment Promotion Agency (IPA) should be placed under the supervision of the High Council for Investment (HCI). Separation of functions and supervision of institutions could be combined in a most favourable way. However, also other options could be foreseen, such as to establish within the National Investment Authority (NIA) two separated departments for regulation and promotion functions.

While the potential for knowledge transfers through FDI is great, also in Sudan, the reality shows that the potentials are not exploited at all. A new strategy for revitalizing foreign investment should be based on a national reindustrialization programme for the manufacturing sector. Such a new strategy to attract foreign investment and a new programme to reindustrialize the manufacturing sector need to be based on three significant fitness tests (Mustafa Ali, 2017): First, market fitness conditions signal the existence of the factors that make the country's economy fit for marketability conditions as anticipated by foreign businesses. Second, the social fitness conditions comprise a combination of social factors that work together in assisting the country to be more welcoming for FDI investors than other countries. Third, the risk-free environment fitness conditions are related to the factors resulting from the possibility of unpredictable changes in the business environment and estimate the probability that these changes can influence the operations of foreign investors.

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# The National Innovation System in Sudan – Is it enhancing national competitiveness and contributing to a higher business performance?

**Samia Satti Osman Mohamed Nour**[1]

## 1 Introduction

The central theme of this paper focuses on enhancing the national innovation system (NIS) in Sudan as a new case study of African countries. The core themes discussed in this paper examine the characteristics of the national innovation system, the change in innovation performance during the period 2011-2015, the causes and consequences or implications of the poor state of the national innovation system, and the policy options to improve the national innovation system in Sudan. The paper addresses the following questions: First, what are the major characteristics and constraints of the national innovation system in Sudan? Second, how important is the development of innovation performance in Sudan during the period 2011-2015? Third, what are the major implications for restructuring the national innovation system and for related policy reforms?

We examine three hypotheses: The first hypothesis is that the national innovation system is hampered by several factors and is characterized by serious weaknesses in Sudan, compared with other African and other countries. This hypothesis implies that Sudan has manifestly lagged far behind other African and other countries in terms of S&T input indicators and information and communication technology (ICT) indicators. We examine the second hypothesis that the innovation performance in Sudan has deteriorated during the period 2011-2015. This hypothesis implies that the deterioration in terms of rank and score value in terms of the Global Innovation Index (GII), the GII input sub-index, the GII output sub-index, and the innovation efficiency ratio in Sudan during the period 2011-2015 needs to be investigated in detail (see on the GII the annual report by Cornell University et al.). Examined is also the third hypothesis that the poor state of the national innovation system in Sudan has serious implications for the economy and its competitiveness. The serious implications are apparent in terms of poor Science and Technology (S&T) output indicators, lack of competitiveness, lack of integration in the global economy, an unsatisfactory knowledge economy index,

[1]Samia Satti Osman Mohamed Nour is Professor of Economics at the University of Khartoum, Khartoum, Sudan; E-mail: samia_satti@hotmail.com; samiasatti@yahoo.com

a low share of high technology exports, inadequate technology infrastructure, a low technology achievement index, and a low level of capacity to create knowledge in Sudan. Most serious implications also appear in terms of weak linkages of STI activities with enterprises.

This paper uses the conceptual framework of the "national innovation systems" and the results of the "Global Innovation Index", and used are both, descriptive and comparative approaches to provide an empirical investigation of the causes and consequences of the poor national innovation system and of the poor innovation performance, innovation efficiency, and innovation quality in Sudan. The definition of the national innovation system approach is used as found in the literature; the national innovation system is defined by subsystems, including education and higher education institutions, S&T institutions, and information and communication technology (ICT) institutions. Also, other indicators are used, such as competitiveness indicators, ratios of high-technology exports, and the knowledge economy index. The GII reports (2011-2015), issued by INSEAD et al., are a very important source of the analysis, since it provides a comprehensive set of information about several relevant indicators, including the overall GII index, the GII innovation input index, the GII innovation output index, the innovation efficiency ratio, the innovation quality assessment, and the GII pillars. It is of interest to use the GII conceptual framework and the NIS framework to examine the changes in innovation performance in Sudan, because the GII conceptual framework illustrates the performance in terms of a rank and a score value (comprising the Global Innovation Index, the GII input sub-index, the GII output sub-index, the innovation efficiency ratio, and the GII pillars) during the period 2011-2015.

Different from previous studies in the Sudanese literature which focus on the analysis of science and technology indicators, innovation policy, intellectual property rights (IPRs), and the interaction between technological change and skill development in Sudan (Nour 2005, 2012, 2013a, 2013b, 2013c, 2014 2015), this study focuses on the national innovation system and the change in innovation performance in Sudan. The analysis adds new aspects to the existing few studies in the Sudanese literature, and the few studies in the African literature, on the innovation system in the African countries (see, as an example, Muchie, Gammeltoft, and Lundvall, 2003). Particularly, the analysis provides a more comprehensive and more recent analysis of the national innovation system in Sudan; so, the study presents a new case study of a NIS in African countries. A gap is filled in the Sudanese and the African literature by providing an empirical investigation of the characteristics, the causes and consequences, as well as the policy implications of the poor national innovation system in Sudan. The national innovation system (NIS) of Sudan is compared to the ones of other African countries (mainly Sudan is compared with other North African countries and with South Africa), and an analysis and an explanation are given with regard of the change in innovation performance in Sudan during the period 2011-2015. The paper is useful from a policy perspective since it provides useful insights for stimulating the design and implementation of new policies for enhancing the national innovation system, and hence of inclusive growth in Sudan and Africa.

The paper is organized as follows: Section 1 presents an introduction and briefly shows the aims, the methodology, and the structure of the study. Section 2 presents the conceptual framework and the literature review; this section examines the conceptual framework of the “national innovation system" and the instrument of the “Global Innovation Index (GII)", concepts and tools as discussed in the international literature. Section 3 provides background information about the general socio-economic characteristics and the prevailing economic structure in Sudan; this will help to understand the correspondence of the economic system and the innovation system. Section 4 examines the characteristics of the national innovation system by discussing the three core subsystems. In section 5 the change in the innovation performance of Sudan during the period 2011-2015 is analysed by using findings of the Global Innovation Index (GII). Section 6 explains the causes and the consequences and the policy implications of the inadequate national innovation system in Sudan as compared to other countries in Africa and in the world. Finally, the section 7 provides the conclusions and the policy recommendations.

## 2 Conceptual framework and literature review: The National Innovation System (NIS) and the Global Innovation Index (GII)

Before examining the characteristics and implications of the national innovation system in Sudan, it is convenient to show briefly the definition of the concepts and to review the literature on national innovation systems and on the Global Innovation Index (GII). This section therefore focuses on a brief definition of the concepts and reviews the literature on National Innovation Systems and the Global Innovation Index.

The concept of an “innovation system” has been widely used in the international literature to reflect the interrelationship between technical and institutional change. The importance of the innovation system approaches is so great as they put special emphasis on institutions, as they highlight the vital role of institutions in influencing innovation (Lundvall, 1992), as they emphasize the importance of the interaction between the various institutions contributing to the creation, the store, and the transfer of knowledge, skills, and new technologies (Metcalfe, 1995), and as they help policy makers to develop instruments for enhancing innovative performance in the knowledge-based economies (OECD, 1997a). Several studies examine different approaches of innovation systems from the national, sectoral, local, and regional perspectives. There is considerable debate in the literature about focusing the analysis of the innovation systems at national rather than other scales. "The rationale that the national innovation system approach has taken on increased analytical importance in the technology field is due to three factors: the recognition of the economic importance of knowledge; the increasing use of systems approaches; and the growing number of institutions involved in knowledge generation" (OECD, 1997a, p. 11). The national level is most useful due to its concern with the flow of knowledge and its impact on economic growth and building knowledge-based economies; it improves the understanding of the causes of gaps in economic development and helps in bridging the development and the technological gap between developed and developing regions (see Feinson, 2003). Considerable debate in the literature is on the relevance of the innovation system to the developing countries to accelerate their catching-up processes. Strengthening institutions provides opportunities to enhance innovation policies, and therefore, may stimulate economic growth and sustainable development in developed and developing regions.

The pioneering contribution by Lundvall (1992) provides a clear and comprehensive definition of the concept of a national innovation system. Lundvall's (1992) definition includes "all parts and aspects of the economic structure and the institutional set-up affecting learning as well as searching and exploring the production system; the marketing system and the system of finance present themselves as subsystems in which learning take place. A definition of the system of innovation must be kept open and flexible regarding which subsystems should be included and which processes should be studied. Determining in detail which subsystems and social institutions should be included, or excluded, in the analysis of the system is a task involving historical analysis as well as theoretical considerations…." (Lundvall, 1992, pp. 12-13). Lundvall (1992) attempted a theoretical approach to link the national innovation system approach to innovation theory (Lundvall, 1992: p. 1). A next contribution edited by Nelson (1993) provides an empirical analysis of the national innovation system approach. Freeman and Soete (1997) argue that "the many national interactions (whether public or private) between various institutions dealing with science and technology as well as with higher education, innovation and technology diffusion in the much broader sense, have become known as 'national systems of innovation'. A clear understanding of such national systemic interactions provides an essential bridge when moving from the micro- to the macro- economics of innovation. It is also essential for comprehending fully the growth dynamics of science and technology and the particularly striking way in which such growth dynamics appears to differ across countries" (Freeman and Soete, 1997: p. 291).

All the definitions of the innovation system approaches are consistent in highlighting the vital role of institutions in influencing innovation. Lundvall (1992) argues that " the 'structure of production' and the 'institutional set-up' are the two most important dimensions, which 'jointly define a system of innovation… the institutional set-up … is the second important dimension of the system of innovation'" (Lundvall, 1992: p. 9, p. 10). Nelson (ed., 1993) mentions organizations supporting R&D, while Nelson and Rosenberg (1993) stress 'the institutions and mechanisms supporting technological innovation' (Nelson and Rosenberg, 1993: p. 1). Moreover, the OECD (1999) provides a definition of the concept of the National Innovation System (NIS) "according to Metcalfe (1995)". National innovation systems are defined as the "… set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provide the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts which define new technologies" (Metcalfe, 1995). Furthermore "the innovative performance of an economy depends not only on how the individual institutions (e.g. firms, research institutes, universities) perform in isolation", but also on "how they interact with each other as elements of a collective system of knowledge creation and use, and on their interplay with social institutions (such as values, norms, legal frameworks)" (Smith, 1996, OECD, 1999: p. 24).

According to the OECD (1999) the market and non-market institutions in a country that influence the direction and speed of innovation and technology diffusion can be said to constitute to a national innovation system. The OECD (1999) stresses the analysis and the policy implications of the systemic approach based on the notion of the national innovation system (NIS). Such an analysis implies that the NIS is a tool for policy analysis; it helps to define the tasks of governments in promoting innovation-led growth, by emphasizing that governments have a responsibility for improving the institutional framework for knowledge exchange among firms and between market and non-market organizations (OECD, 1999: pp. 21-23).

There is a considerable debate in the literature about focusing the analysis of the innovation system at national rather than other scales. As there are remarkable differences in the institutional set-up, the investment in R&D, and the economic and innovation performance, there will be notable differences between the national innovation systems of the various countries. National innovation systems secure the importance of political and policy aspects of process innovations, as most public policies influencing the innovation system and/or the overall economy are still designed and implemented at the national level (Edquist, 1997: p. 12). Moreover, the OECD (1999) indicates that "innovation systems also exist at other levels, e.g. there are world-wide, regional or local networks of firms and clusters of industries. While these systems may or may not be confined within a country's borders, but national characteristics and frameworks always play a role in shaping them. This also holds true in regard of the internationalization of innovative activities, which to a large extent reflects foreign investors' perceptions of the relative strength of national innovation systems. Major advantage of the concept of a NIS is that it provides a tool for analysing country specificities in the innovative process in a globalized economy, as well as a guide for policy formulation. It highlights interactions and interfaces between various actors and the workings of the whole system, rather than the performance of its individual components" (Lundvall, 1992; OECD, 1999: p. 23).

Much of the literature is addressing the national approach, while several studies also examine different approaches of the systems of innovation from the sectoral, local and regional perspectives. Feinson (2003) finds that the concept of the National Innovation System (NIS) has been gaining intellectual and practical coherence over decades, enjoying initial strong adoption by the OECD and developed countries, and more recently becoming the focus of increased attention to address some of the more profound catching-up issues for developing nations. As the divide(s) between the developed and developing world(s) becomes increasingly stark, economists and policymakers view the NIS as having a great potential, both as a source of understanding of the roots and the primary causes of the gulf in economic development, as well as a powerful conceptual framework that can produce policies and institutions capable of bridging that gulf. Lundvall and colleagues speculate that the NIS thinking gained ground because "mainstream macroeconomic theory and policy have failed to deliver an understanding and control of the factors behind international competitiveness and economic development" (Lundvall, 2003, p. 214; Feinson, 2003: p. 14).

According to the OECD (1997), the rationale that the national innovation system approach has taken on increased analytical importance in the technology field is due to three factors: 1. the recognition of the economic importance of knowledge; 2. the increasing use of systems approaches; and 3. the growing number of institutions involved in knowledge generation (OECD, 1997, p. 11). There are marked differences in the relative roles and weights of the different institutions in the national innovation systems, which partly accounts for the focus on the country level (OECD, 1997, p. 12). Concerning policy relevance, for policy makers an understanding of the national innovation system can help identify leverage points for enhancing innovative performance and overall competitiveness (OECD 1997: p. 13).

Opinions in the literature emphasize important aspects: Edquist (2011) focuses upon the design of innovation policy through diagnostic analysis and provides a framework for identification of systemic problems (or failures) in innovation systems. It is argued that "activities" in innovation systems are the determinants of the development and diffusion of innovations. Examples are R&D processes, the provision of organizations and institutions, the financing of innovations, the incubation activities, etc. These activities are partly performed by private organizations and partly by public organizations, the latter performing tasks that constitute innovation policy. Yoon and Hyun (2009) examine the relevance and the usefulness of the concept of national innovation systems. They provide an analytical and theoretical discussion of the national innovation systems perspective, the relationship between technological development and economic progress over the past several decades, and the driving forces behind innovations. They study an economic actor's desire to gain and sustain competitive advantages and analyse the institutional elements which shape the behaviours and interactions of economic actors in terms of innovative performance. Golichenko (2016) demonstrates the role of neoclassical economic theory as well as evolutionary, institutional, and neo-Schumpeterian approaches to the formation of the NIS. He identifies problems that must be addressed by the new concept, describes the main characteristics of the approaches and fosters the analysis of the NIS, by explaining the advantages and disadvantages of these approaches. He proposes an alternative approach for developing a NIS theory based on structural-objective and functional approaches to the analysis of the national innovation system. Fagerberg and Srholec (2008) focus on the role of capabilities in economic development. Using factor analysis on data for 25 indicators and 115 countries between 1992 and 2004, they identify four different types of "capabilities": the development of the "innovation system", the quality of "governance", the character of the "political system", and the degree of "openness" of the economy. Innovation systems and governance are shown to be of greatest importance for economic development.

Many new studies in the literature examine several aspects related to the national innovation system. For instance, Knell (2015) examines the interaction between the national innovation systems and the Global Innovation Networks (GINs). Within this context, Chaminade, Zabala and Treccani (2010) examine the Swedish national innovation system and its relevance for the emergence of global innovation networks and explore the links between the NIS in Sweden and the participation of Swedish firms and Swedish universities in global innovation networks. They find that the Swedish innovation system is highly internationalized in terms of global research collaboration, global generation of innovation, and global sourcing of knowhow. Firms as well as universities are very active internationally in terms of their research and innovation activities. As it is the case for many small countries, the Swedish economy has a strong international orientation, and this is also reflected in the national innovation system; the national innovation system is dominated by internationally oriented industrial firms and universities.

The Global Innovation Index (GII) conceptual framework is focused both on improving ways to measure innovation and understanding it, and on identifying targeted policies and good practices. The GII helps to create an environment in which innovation factors are continually evaluated. Four measures are calculated: the overall GII, the Input and Output Sub-Indices, and the Innovation Efficiency Ratio. The overall GII score is the simple average of the Input and Output Sub-Index scores. The Innovation Input Sub-Index is comprised of five input pillars that capture elements of the national economy which enable innovative activities:

(1) Institutions, (2) Human capital and research, (3) Infrastructure, (4) Market sophistication, and (5) Business sophistication. The Innovation Output Sub-Index provides information about output that is the result of innovative activities within the economy. There are two output pillars: (6) Knowledge and technology outputs, and (7) Creative outputs. The Innovation Efficiency Ratio is the ratio of the Output Sub-Index score over the Input Sub-Index score. It shows how much innovation output a given country is getting for its innovation inputs. Each pillar is divided into three sub-pillars and each sub-pillar is composed of individual indicators, for a total of 79 indicators. The variables included in the GII provide the best and most current assessment of global innovation (Cornell University et al., The Global Innovation Index Report 2015: pp. 9-10).[2]

[2] The Global Innovation Index (GII) is relevant for the case of Sudan since it explains the innovation performance, the resources (input), the outcome (output), and the efficiency of innovation in Sudan compared to other world countries. The Global Innovation Index (GII), issued by INSEAD since 2007, aims to determine and to find metrics and approaches to better capture the richness of innovation in society and to go beyond such traditional measures of innovation as the number of PhDs, the number of research articles produced, the research centres created, the patents issued, and the research and development (R&D) expenditures. The GII Report (2011) includes 125 countries; the overall GII scores provide a composite picture of the state of each country's innovation performance. According to the conceptual framework used in the GII Report (2011), the GII relies on two sub-indices, the innovation input sub-index and the innovation output sub-index, each built around pillars. The GII has five input pillars that define aspects of the environment conducive to innovation within an economy and capture elements of the national economy that enable innovative activities: (1) institutions, (2) human capital and research, (3) infrastructure, (4) market sophistication, and (5) business sophistication. Two output pillars that capture actual evidence of innovation output are: (6) scientific output, and (7) creative output. Each pillar is divided into sub-pillars and each sub-pillar is composed of individual indicators. Sub-pillar scores are calculated as the weighted average of individual indicators; pillar scores are calculated as the simple average of the sub-pillar scores. Four measures are then calculated: the innovation input sub-index is the simple average of the first five pillar scores. The innovation output sub-index is the simple average of the last two pillar scores. The overall GII is the simple average of the input and output sub-indices. The Innovation Efficiency Index is the ratio of the output sub-index over the input sub-index. See on this methodology: The Global Innovation Index Report (2011: pages 3, 8-9). The GII profile provides only normalized scores in the [0, 100] range, to facilitate the replicability of results and to provide a sense of the scores with greater leverage for each country – see the Global Innovation Index Report (2011: page 119).

## 3 General socio-economic characteristics of Sudan

This section shows the general socio-economic characteristics of Sudan, since the national innovation system is linked to both, the resources directly devoted to innovation development, and to the whole economic structure that supports innovation. Table 1 illustrates the substantial gap between Sudan, Africa, and the world regions in terms of standards of economic development, as measured by GDP per capita and the human development index (HDI). In general, Sudan is characterized by low standards of economic development, together with high population numbers and growth rates[3]. According to the World Bank classification of economies, Sudan is classified among the lower medium-income economies. According to the classification of the UNDP's HDI, the human development index for Sudan is classified among the world low-human development index group and is, on average, lower than the average for the world countries. Furthermore, average life expectancy, mean years of schooling, expected years of schooling, literacy rate, and gross enrolment ratios in primary, secondary and tertiary education for Sudan fall behind the standard rates of the world regions, advanced Asian countries, North Africa, and South Africa (see table 1).

Sudan was the largest country in Africa and the Arab world until 2011, when South Sudan separated as an independent country, following an independence referendum. Sudan is now the third-largest country in Africa (after Algeria and the Democratic Republic of Congo), and as well the third largest country in the Arab world (after Algeria and Saudi Arabia). Data from Sudan's Central Bureau of Statistics and the Central Bank of Sudan (2013) about the structure of Sudan's economy indicate the dominance of the services sector (49%, 46.7%) and of the agricultural sector (30.6%, 30.6%), while there is a low share of the industrial sector (20.4%, 21.1%) in GDP in the years 2012 and 2013 respectively (see the Central Bank of Sudan, 2013, p. 120). The manufacturing sector is even smaller, but comprises not only food industries and metal industries but also oil refining activities.

[3] See: http://www.worldometers.info/world-population/sudan-population/

**Table 1**: **General socio-economic characteristics of Sudan compared to Africa, and other world regions (2015)**

| | Population | Gross national income p.c. | Human Development Index | | Life expectancy at birth | Expected years of schooling | Mean years of schooling |
|---|---|---|---|---|---|---|---|
| | **Total millions** | **2011 PPP $** | **Value** | **Rank** | **years** | **years** | **years** |
| **Sudan** | **40.2** | **3,846** | **0.490** | **165** | **63.7** | **7.2** | **3.5** |
| North and South Africa | | | | | | | |
| Algeria | 39.7 | 13,533 | 0.745 | 83 | 75.0 | 14.4 | 7.8 |
| Egypt | 91.5 | 10,064 | 0.691 | 111 | 71.3 | 13.1 | 7.1 |
| Libya | 6.3 | 14,303 | 0.716 | 102 | 71.8 | 13.4 | 7.3 |
| Morocco | 34.4 | 7,195 | 0.647 | 123 | 74.3 | 12.1 | 5.0 |
| Tunisia | 11.3 | 10,249 | 0.725 | 97 | 75.0 | 14.6 | 7.1 |
| North Africa | | | | | | | |
| South Africa | 54.5 | 12,087 | 0.666 | 119 | 57.7 | 13.0 | 10.3 |
| Advanced Asian countries | | | | | | | |
| China | 1,376.0 | 13,345 | 0.738 | 90 | 76.0 | 13.5 | 7.6 c |
| Korea | 50.3 | 34,541 | 0.901 | 18 | 82.1 | 16.6 | 12.2 |
| India | 1,311.1 | 5,663 | 0.624 | 131 | 68.3 | 11.7 | 6.3 c |
| Malaysia | 30.3 | 24,62 | 0.789 | 59 | 74.9 | 13.1 | 10.1 |
| Singapore | 5.6 | 78,162 | 0.925 | 5 | 83.2 | 15.4 d | 11.6 |
| Human Development Index Groups | | | | | | | |
| Very high human development (VHHD) | 1,350.1 | 39,605 | 0.892 | | 79.4 | 16.4 | 12.2 |
| High human development (HHD) | 2,379.4 | 13,844 | 0.746 | | 75.5 | 13.8 | 8.1 |
| Medium human development (MHD) | 2,622.3 | 6,281 | 0.631 | | 68.6 | 11.5 | 6.6 |
| Low human development (LHD) | 929.2 | 2,649 | 0.497 | | 59.3 | 9.3 | 4.6 |
| Regions | | | | | | | |
| Arab States | 387.6 | 14,958 | 0.687 | | 70.8 | 11.7 | 6.8 |
| East Asia and the Pacific | 2,041.6 | 12,125 | 0.720 | | 74.2 | 13.0 | 7.7 |
| Europe and Central Asia | 239.4 | 12,862 | 0.756 | | 72.6 | 13.9 | 10.3 |
| Latin America and the Caribbean | 629.0 | 14,028 | 0.751 | | 75.2 | 14.1 | 8.3 |
| South Asia | 1,823.0 | 5,799 | 0.621 | | 68.7 | 11.3 | 6.2 |
| Sub-Saharan Africa | 949.5 | 3,383 | 0.523 | | 58.9 | 9.7 | 5.4 |
| Developing countries | 6,071.2 | 9,257 | 0.668 | | 70.0 | 11.8 | 7.2 |
| Least developed countries | 954.4 | 2,385 | 0.508 | | 63.6 | 9.4 | 4.4 |
| OECD | 1,276.4 | 37,916 | 0.887 | | 80.3 | 15.9 | 11.9 |
| World | 7,349.5 | 14,447 | 0.717 | | 71.6 | 12.3 | 8.3 |

**Source:** UNDP (2016), PPP – purchasing power parity. pp. 198-201, 222-225. United Nations Development Programme (UNDP) "Human Development Report (2016), "Human Development for Everyone", UNDP: New York, USA. pp. 198-201, pp. 222-225. **Note**: VHHD refers to very high human development, HHD refers to high human development, MDH refers to medium human development, and LHD refers to low human development.

The Sudanese economy is regarded as a rent-seeking economy (as economic privileges of interest groups and corporations are maintained and extended by political connections) and is classified as a primary exports economy, that suffers from uncertainty about world demand and prices and experiences high fluctuations in economic growth, Sudan's economy has been characterised by low GDP per capita income, the presence of high rates of poverty, high rates of unemployment, and severe inequalities in resources-sharing. The independence of South Sudan has had immediate negative fiscal and balance of payments implications for Sudan. Because of the loss of the bulk of the oil production and the export revenues, Sudan has lost about 75 percent of its oil revenues.[4] Thus, the prevailing economic structure in Sudan hinders the allocation of sufficient resources to support the promotion of the national innovation system in Sudan. As diversification of production is very limited, the national innovation system (NIS) has an important role to play for the future development course of Sudan.

## 4 Characteristics of the national systems of innovation in Sudan

This section examines the first research question and hypothesis that the national innovation system is characterized by serious weaknesses in Sudan. It identifies two obvious characteristics of the national innovation system of Sudan, namely the prevalence of serious weaknesses and the tendency to fall continuously behind the world level. Investigated is the first research question and hypothesis by using relevant secondary data which are obtained from different sources and by using the definition of the national innovation system that was used in previous studies (see: Nour, 2014; Nour 2016), based on the state of the subsystems of education and higher education institutions, S&T and R&D institutions, and ICT and networking institutions.

### 4.1 The Subsystem of Education and Higher Education Institutions

Sudan shows considerable weaknesses concerning the subsystem of education and higher education institutions. For instance, over the period 2005-2015 the adult illiteracy rate in Sudan (24.1%) is below the rate of Sub-Saharan Africa (35.7%) and the least developed countries (36.7%), but is above the World level (15.7%), the rate of developing countries (16.7%), the rate of North Africa (19.88%), and the rate of South Africa (5.7%). The illiteracy rate constitutes nearly a quarter

[4] See International Monetary Fund/IMF (2013), "Sudan Interim Poverty Reduction Strategy Paper", IMF Country Report No. 13/318, October 2013; Web Access: http://www.imf.org/external/pubs/ft/scr/2013/cr13318.pdf, accessed on September 04, 2014, p. 6.

(25%) in Sudan (24.1%) and this rate is comparable to two of the North African countries (Egypt with 24.8%, and Morocco with 27.6%), but the rate of Sudan is far above the World level (15.7%) and as well above the rate of other African countries (South Africa with 5.7%, Libya with 9%, Algeria with 19.8%, and Tunisia with 18.2%). The high level of illiteracy has implications for the quality of the labour force and for labour productivity.

Over the period 2005-2015 the percentage of population with at least some secondary education in Sudan is less than a quarter (15.2%), and the gross enrolment ratios in secondary (41%) and tertiary (17%) education in Sudan fall far behind the ratios in advanced Asian countries (Korea, Singapore, Malaysia, China, and India), at the World level, in North Africa, in South Africa, in Africa, in the Arab states, and are below all other World regions, even the developing countries, Sub-Saharan Africa, and the least developed countries (as can be observed from table 2). The percentage of population with at least some secondary education in South Africa, the World, in Developing countries, in North Africa and the Arab States is nearly five times, nearly four times, and nearly three times above the level of Sudan, respectively. The percentage of gross enrolment in secondary education in South Africa, in the World, in Developing countries, in North Africa and the Arab States is nearly three times and nearly two times above the level of Sudan, respectively. The percentage of gross enrolment in tertiary education in the Developing countries is above the level of Sudan, and in the World, in Arab States and in North Africa the percentage is nearly two times above the level of Sudan. Also, these facts mean that the quality of the labour force is negatively affected by these gaps.

In 2015, the mean years of schooling (3.5) and the expected years of schooling (7.2) in Sudan fall far behind the mean years in advanced Asian countries (Korea, Singapore, Malaysia, China, and India), and the World level, North Africa, South Africa, Africa, the Arab states, and the mean years of Sudan are below the ones of all other world regions, even the developing countries, Sub-Saharan Africa, and the least developed countries (see table 2). The mean years of schooling in South Africa, in the World and in Developing countries, in North Africa and the Arab States are nearly three times and nearly two times above the level of Sudan, respectively. The expected years of schooling in South Africa, the World, the Developing countries, North Africa and the Arab States are nearly two times above the level of Sudan. The impact of the years of schooling on the labour productivity is a proven association, and so the education system is showing serious weaknesses as a part of the national innovation system (NIS).

**Table 2: Literacy and Education in Sudan compared to selected African countries and World regions (2005-2015)**

| | Literacy rates | | | Gross enrolment ratio | | Government expenditure on education | | |
|---|---|---|---|---|---|---|---|---|
| | Adult Literacy rates | Adult illiteracy rates | Population with at least some secondary education | Secondary | Tertiary | % of GDP | Expected years of schooling | Mean years of schooling |
| | % aged 15 and above | % aged 15 and above | % aged 25 and above | % of secondary school–age population | % of tertiary school–age population | | years | years |
| | 2005-2015 | 2005-2015 | 2005-2015 | 2010-2015 | 2010-2015 | 2010-2014 | 2015 | 2015 |
| **Sudan** | **75.9** | **24.1** | **16.3** | **43** | **17** | | **7.2** | **3.5** |
| North and South Africa | | | | | | | | |
| Algeria | 80.2 | 19.8 | 34.9 | 100 | 35 | | 14.4 | 7.8 |
| Egypt | 75.2 | 24.8 | 61.4 | 86 | 32 | | 13.1 | 7.1 |
| Libya | 91.0 | 9 | 55.1 | | | | 13.4 | 7.3 |
| Morocco | 72.4 | 27.6 | 29.4 | 69 | 25 | | 12.1 | 5.0 |
| Tunisia | 81.8 | 18.2 | 43.9 | 88 | 35 | 6.2 | 14.6 | 7.1 |
| North Africa | | 19.88 | | | | | | |
| South Africa | 94.3 | 5.7 | 74.9 | 94 | 20 | 6.1 | 13.0 | 10.3 |
| Advanced Asian countries | | | | | | | | |
| China | 96.4 | 3.4 | 75.0 | 94 | 39 | | 13.5 | 7.6 |
| Korea | 100 | 0 | 91.4 | 98 | 95 | 4.6 | 16.6 | 12.2 |
| India | 72.1 | 27.9 | 48.7 | 69 | 24 | 3.8 | 11.7 | 6.3 |
| Malaysia | 94.6 | 5.4 | 77.1 | 79 | 30 | 6.1 | 13.1 | 10.1 |
| Singapore | 96.8 | 3.2 | 78.6 | | | 2.9 | 15.4 d | 11.6 |
| Human Development Index Groups | | | | | | | | |
| Very high human development | 100 | 0 | 88.8 | 106 | 75 | 5.1 | 16.4 | 12.2 |
| High human development | 95.3 | 4.7 | 70.6 | 95 | 43 | | 13.8 | 8.1 |
| Medium human development | 76.4 | 23.6 | 49.1 | 68 | 23 | 3.9 | 11.5 | 6.6 |
| Low human development | 60.9 | 39.1 | 20.3 | 40 | 8 | 3.8 | 9.3 | 4.6 |

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| | Literacy rates | | | Gross enrolment ratio | | Government expenditure on education | | |
|---|---|---|---|---|---|---|---|---|
| | Adult Literacy rates | Adult illiteracy rates | Population with at least some secondary education | Secondary | Tertiary | % of GDP | Expected years of schooling | Mean years of schooling |
| | % aged 15 and above | % aged 15 and above | % aged 25 and above | % of secondary school–age population | % of tertiary school–age population | | years | years |
| | **2005-2015** | **2005-2015** | **2005-2015** | **2010-2015** | **2010-2015** | **2010-2014** | **2015** | **2015** |
| **Sudan** | **75.9** | **24.1** | **16.3** | **43** | **17** | | **7.2** | **3.5** |
| Regions | | | | | | | | |
| Arab States | 80.7 | 19.3 | 47.0 | 76 | 30 | | 11.7 | 6.8 |
| East Asia and the Pacific | 95.7 | 4.3 | 68.9 | 88 | 37 | | 13.0 | 7.7 |
| Europe and Central Asia | 98.1 | 1.9 | 81.7 | 98 | 55 | | 13.9 | 10.3 |
| Latin America and the Caribbean | 93.2 | 6.8 | 58.1 | 95 | 44 | 5.4 | 14.1 | 8.3 |
| South Asia | 70.3 | 29.7 | 47.9 | 65 | 23 | 3.4 | 11.3 | 6.2 |
| Sub-Saharan Africa | 64.3 | 35.7 | 29.6 | 43 | 8 | 4.8 | 9.7 | 5.4 |
| Developing countries | 83.3 | 16.7 | 57.7 | 71 | 29 | | 11.8 | 7.2 |
| Least developed countries | 63.3 | 36.7 | 25.7 | 44 | 9 | 3.3 | 9.4 | 4.4 |
| OECD | 100 | 0 | 85.5 | 104 | 70 | 5.1 | 15.9 | 11.9 |
| World | 84.3 | 15.7 | 64.9 | 76 | 35 | 5.0 | 12.3 | 8.3 |

**Source:** UNDP (2016), PPP – purchasing power parity. pp. 230-233. United Nations Development Programme (UNDP), "Human Development Report (2016), "Human Development for Everyone", UNDP: New York, USA. pp. 230-233

Over the period (2005 - 2014), the percentage of expenditure on education (defined as % of GDP) in Sudan (2.2%) falls far behind the rate of advanced Asian countries (Korea, Singapore, Malaysia, China, and India), the World level, North Africa, South Africa, Africa, the Arab states, and is below the rate of all other world regions, even the developing countries, Sub-Saharan Africa, and the least developed countries (see table 2). The percentage of expenditure on education (defined as % of GDP) in South Africa, in the World, the Developing countries, North Africa and the Arab States is nearly three times and nearly two times above the level of Sudan, respectively.

Moreover, Sudan has lags manifestly far behind North African countries and advanced Asian countries (Korea, Singapore, Malaysia and China) in terms of major skills indicators defined by the percentage share of gross enrolment ratio in tertiary education, the share of tertiary students in science, mathematics, and engineering, the Harbison-Myers Index, the Technical Enrolment Index, and the Engineering Enrolment Index.[5] In 1995, the skill indices measured by the Harbison-Myers Index, the Technical Enrolment Index, and the Engineering Enrolment Index in North Africa were nearly four times, nearly seven times, and nearly five times above the level of the indices in Sudan, respectively.

The message is that the first subsystem of the NIS, the education sector in Sudan, shows serious weaknesses to be tackled in the coming years by committed reforms as a prerequisite for a pro-developmental NIS of Sudan.

### 4.2 The Subsystem of S&T and R&D Institutions

The institutions of S&T, mainly the R&D institutions, show remarkable serious weaknesses in the African countries (see: UNESCO, 2015; UNESCO 2010). The S&T input indicator as measured by the spending on R&D as a percentage of GDP for all African countries is lagging far behind the one of the advanced Asian countries and other world regions (see table 3). The S&T indicators, first, measured by expenditure on R&D, defined as % of GDP, is extremely low (at 0.3%), second, the number of FTE researchers, measured per million people, is as well low (19 FTE researchers per million), third, the share of graduate students in science, engineering and agriculture is low (only 18.7%), and fourth, the number of patents granted to residents and non-residents per million people in Sudan (only 11 patents granted), are all below the international standard and below the levels of Europe and Central Asia, the advanced Asian countries (Korea, Singapore, Malaysia, China, and India), the World level, North Africa, South Africa, and below all world regions, including East Asia and the Pacific, Europe and Central Asia, Latin America and the Caribbean, North America, South Asia, and the OECD countries (see table 3).

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[5] The Harbison-Myers Index is the sum of secondary enrolment and tertiary enrolment times 5, both expressed as % of the age group. The Technical Enrolment Index is comprising tertiary total enrolment (times 1000) plus tertiary enrolment in technical subjects (times 5000), both as % of the population. The Engineering Enrolment Index is the same as the previous index, but with tertiary enrolments in engineering instead of enrolment in technical subjects (Lall, 1999).

**Table 3: S&T, Research and Development (R&D), and Innovation in Sudan and selected African countries compared to World regions (2002-2014)**

| Country | Research and Development (R&D) | | | Innovation |
|---|---|---|---|---|
| | Expenditure [a] | Researchers [a] | Graduates in science engineering, and agriculture [b] | Patents granted to residents and non-residents [b] |
| | % of GDP | per million people | % of total | per million people |
| | 2010–2013 | 2002–2013 | 2010–2013 | 2005–2014 |
| **Sudan** | **0.3** | **19** | **18.7** | **11** |
| African countries | | | | |
| Algeria | 0.07 | 168 | 24.4 | 813 |
| Egypt | 0.68 | 581 | 14.1 | 2136 |
| Libya | | 172 | | 35 |
| Morocco | 0.71 | 864 | 36.3 | 1097 |
| Tunisia | 0.66 | 1,394 | 44.7 | 542 |
| North Africa | | | | 4623 |
| South Africa | 0.73 | 405 | 25.4 | 7552 |
| Other countries | | | | |
| China | 2.01 | 1,089 | | 928177 |
| Korea | 4.15 | 6,457 | | 210292 |
| India | 0.82 | 157 | | 42854 |
| Malaysia | 1.09 | 1,794 | | 7620 |
| Singapore | 2 | 6,665 | | 10312 |
| World Regions | | | | |
| Arab States | | | | 6905 |
| East Asia and the Pacific | 2.55 | 1,432 | | 1553260 |
| Europe and Central Asia | 1.86 | 2,792 | | 197676 |
| Latin America and the Caribbean | 0.76 | 524 | | 61192 |
| North America | 2.69 | 3,944 | | 614283 |
| South Asia | 0.61 | 156 | | 44069 |
| OECD | 2.47 | 3,332 | | 1356075 |
| World | 2.17 | 1,268 | | 2506409 |

**Sources:** (a) The World Bank, The World Development Indicators Database (2014), accessed on January 06, 2015, (b) UNDP-HDR (2013), Human Development Report (2013), "The Rise of the South, Human progress in a Diverse World", pp. 186-189.

During the period 2010-2013, the percentage of expenditure on R&D (defined as % of GDP) in Sudan fell far behind advanced Asian countries (Korea, Singapore, Malaysia, China, and India), the World level, North Africa, South Africa, and all other world regions (see table 3). During the period 2010-2013, the percentage of expenditure on R&D (defined as % of GDP) in the World and in South Africa and in North Africa is nearly seven times and nearly two times above the level of Sudan, respectively. R&D spending in North African countries (Morocco with 0.71%, Egypt with 0.68%, and Tunisia with 0.66%) is equivalent to being more than two times the level of Sudan (with only 0.3%). Hence, Sudan is still far from fulfilling the commitment to implement the United Nations international standard criteria of spending 1% of its GDP on R&D. Furthermore, compared to the advanced Asian countries like Korea, Singapore, Malaysia, and China, North African countries and South Africa, Sudan suffers from an insufficient number of FTE researchers (see table 3).

During the period 2002-2013, the number of FTE researchers (per million people) in the World is nearly 67 times above the level of Sudan, in South Africa it is nearly 21 times above the level of Sudan, and in North Africa it is nearly 33 times above the level of Sudan. Moreover, the share of graduate students in science, engineering and agriculture in North African countries is nearly two times the share prevalent in Sudan. These findings imply poor and insufficient financial and human resources devoted to R&D and to S&T activities in Sudan when compared to North African countries and South Africa, advanced Asian countries and world regions (see table 3). During the period 2005-2014 the number of patents granted to residents and non-residents (per million people) in South Africa is nearly 687 times above the level of Sudan, and for North Africa it is nearly 420 times above the level of Sudan (see table 3).

The role of the various institutions and the sectors constituting the system of R&D, and hence the innovation capacity of a country, vary across the world countries. For instance, the role of public research institutes may be important for R&D in one country, while the role of higher education institutions may perform a great role for research in another country. For instance, the only available data for 2005 for Sudan imply that the distribution of the gross expenditures on research and development (GERD) by sector of performance reveal that research activities are mostly concentrated in the government sector (39.2%), followed by business enterprises (33.7%), and the higher education sector (27.1%). Similarly, in Tunisia the research activities are mostly concentrated in the government sector (80%), followed by the business enterprise sector (20%). In South Africa, research activities are mostly concentrated in the business enterprise sector (44.3%), followed by the higher education sector (30.7%), the government sector (22.9%), and the private non-profit sector (2.1%), respectively. In Morocco, research activities are mostly concentrated in the higher education sector (47%), followed by the business enterprise sector (29.9%) and the government sector (23.1%), respectively. In Egypt, research activities are mostly concentrated in the higher education sector (55.5%), followed by the government sector (45.5%).

The distribution of GERD by sector of performance implies the minor contribution of the business enterprise sector in Sudan and North Africa. By contrast, the distribution of GERD by sector of performance reveals the major contribution of the business enterprise sector to R&D in advanced Asian countries (China with 76.6%, Korea with 78.5%, Malaysia with 64.4%, and Singapore with 59.4%). This is a significant difference between Asian and some African countries (see table 4).

Furthermore, the distribution of human resources defined by the number of full-time equivalent (FTE) researchers by sectors of employment implies that in Sudan and Tunisia, the employment of FTE is concentrated in the higher education sector (78%, 87.1%), followed by the government sector (20%, 8.5%), and the business enterprise sector (2%, 4.3%), respectively. The employment of FTE researchers is entirely concentrated in the government sector in Libya (100%), while in both, Algeria and Egypt, the employment of FTE researchers is mostly concentrated in the government sector (86.9%, 54.3%), followed by the higher education sector (13.1%, 45.7%), respectively. In Morocco and in South Africa, the employment of FTE researchers is mostly concentrated in the higher education sector (87.2%, 64.3%), followed by the business enterprise sector (9.3%, 21.3%), the government sector (3.5%, 13%), and the non-profit sector (0% 1.4%), respectively. The distribution of employment of FTE researchers implies the minor contribution of the business enterprise sector in Sudan and North Africa. By contrast, the distribution of employment of FTE researchers implies the major contribution of the business enterprise sector in advanced Asian countries (Korea with 78.7%, China with 62.2%, and Singapore with 50.9%), respectively (see the table 4).

Different from advanced East Asian countries, such as China, Korea, Malaysia, and Singapore, the business enterprise sector provides a small contribution to R&D in Sudan and North African countries. For instance, the contribution of the business enterprise sector in terms of GERD by sector of performance in Sudan and North Africa is only minor with 20% - 33.7%, compared to the major contribution in South Africa (44.3%), Korea (78.5%), China (76.6%), Singapore (59.4%), India (38.7%), and Malaysia (64.4%). Also, the contribution of the business enterprise sector in terms of FTE researchers by sector of employment in Sudan and North Africa is small with 2% - 9.3%, compared to the major contribution in South Africa (21.3%), Korea (78.7%), China (62.2%), Singapore (50.9%), India (35.5%), and Malaysia (10.8%), respectively (see table 4).

Therefore, these findings support the first hypothesis which implies that the shares of both government/public and universities sectors are large, while the contribution of the business enterprise sector and of the private sector in R&D activities in Sudan is large (see table 4).

**Table 4: Distribution of GERD, FTE Researchers, and the Sources of Funds by Sector of Performance in Sudan and in selected African and advanced Asian countries (2005-2013) (%)**

| Country | Year | Business enterprise | Govern-ment | Higher ed-ucation | Private non-profit | Not speci-fied |
|---|---|---|---|---|---|---|
| **(a) R&D GERD by sector of performance (%)** | | | | | | |
| **Sudan** | **2005** | **33.7** | **39.2** | **27.1** | **…** | **…** |
| African countries | | | | | | |
| Morocco | 2010 | 29.9 | 23.1 | 47 | … | 0 |
| Tunisia | 2008 | 20 | 80 | | | |
| South Africa | 2012 | 44.3 | 22.9 | 30.7 | 2.1 | |
| Egypt | 2013 | | 44.5 | 55.5 | | |
| China | 2013 | 76.6 | 16.2 | 7.2 | | |
| India | 2010 | 38.7 | 45.6 | 11.5 | 4.2 | 0 |
| Korea | 2013 | 78.5 | 10.9 | 9.2 | 1.3 | |
| Malaysia | 2012 | 64.4 | 6.9 | 28.7 | 0 | 0 |
| Singapore | 2013 | 59.4 | 11.3 | 29.2 | | |
| **(b) Researchers by sector of employment in full-time equivalents (FTER) (%)** | | | | | | |
| **Sudan** | **2005** | **2** | **20** | **78** | | **…** |
| Algeria | 2005 | … | 13.1 | 86.9 | … | 0 |
| Egypt | 2013 | | 45.7 | 54.3 | … | 0 |
| Libya | 2009 | … | 100 | … | … | … |
| Morocco | 2012 | 9.3 | 3.5 | 87.2 | … | … |
| Tunisia | 2008 | 4.3 | 8.5 | 87.1 | … | 0 |
| South Africa | 2012 | 21.3 | 13 | 64.3 | 1.4 | |
| China | 2013 | 62.2 | 19.5 | 18.4 | | |
| India | 2011 | 35.5 | 60.5 | 4.1 | 0 | 0 |
| Korea | 2013 | 78.7 | 7.2 | 13 | 1 | |
| Malaysia | 2012 | 10.8 | 6.8 | 82.5 | | |
| Singapore | 2013 | 50.9 | 5.1 | 44 | | |

**Source:** UIS-UNESCO (2015), Country Profile - UIS-UNESCO (2015), Access on February 08, 2015: http://www.uis.unesco.org/DataCentre/Pages/country-profile.aspx?code=ARE&regioncode=40525

## 4. 3 The Subsystem of ICT and the Networking Institutions

The ICT institutions show remarkable improvement and an increasing trend but still suffer from great weaknesses in Sudan, compared to the World level, North Africa, South Africa, Africa, the Arab States, the advanced Asian countries, and other world regions. For instance, in 2015 the performance concerning ICT indicators as measured by fixed-telephone subscriptions (per 100 inhabitants), mobile-cellular telephone subscriptions (per 100 inhabitants), fixed (wired) broadband subscriptions (per 100 inhabitants), percentage of individuals using the Internet, and the proportion of households with Internet access at home and with a computer falls for Sudan far behind the advanced Asian countries (Korea, Singapore, Malaysia, China, and India), the World level, North Africa, South Africa, Africa, the Arab States, and other world regions (see table 5). When measuring the diffusion of ICT by the percentage of population using the Internet, telephone and mobile, it was found that the access of Sudan's population (per 100 inhabitants) Internet, telephone and mobile was only at rates of 26.61%, 0.30%, and 70.53%, respectively (see table 5). This implies an inadequate diffusion of ICT, which is for Sudan obviously falling far behind the comparable percentages for the advanced Asian countries and the developing countries. In 2015, the percentage of fixed telephone subscriptions (per 100 inhabitants) in Sudan is lagging far behind the World level. In 2015, the fixed-telephone subscriptions per 100 inhabitants in developed countries, developing countries, the World, the Arab States, Africa, North Africa, and South Africa were nearly 128 times, nearly 31 times, nearly 48 times, nearly 26 times, nearly 4 times, nearly 27 times, and nearly 26 times above the level of Sudan, respectively. The percentage of mobile-cellular telephone subscriptions (per 100 inhabitants) in Sudan is also lagging far behind the World level. In 2015, the mobile-cellular telephone subscriptions per 100 inhabitants in developed countries, the Arab States, North Africa, and South Africa were nearly two times above the level of Sudan. In 2015, mobile-cellular telephone subscriptions per 100 inhabitants in Sudan were however near to the level in developing countries, the World, and Africa. The percentage of fixed (wired)-broadband subscriptions (per 100 inhabitants) in Sudan is lagging far behind the World level. In 2015, fixed (wired)-broadband subscriptions per 100 inhabitants in developed countries, developing countries, the World, the Arab States, Africa, North Africa, and South Africa were nearly 420 times, nearly 106 times, nearly 160 times, nearly 60 times, nearly 7 times, nearly 54 times, and nearly 75 times above the level of Sudan, respectively.

The percentage of individuals using the Internet in Sudan is lagging far behind the World level. In 2015, the percentage of individuals using the Internet in developed countries, in the World, and in South Africa is nearly 3 times, nearly 2 times and nearly 2 times above the level of Sudan, respectively. In 2015, the percentage of individuals using the Internet in Sudan is near to the level in developing countries, the Arab States, Africa, and North Africa. The proportion of households with Internet access at home in Sudan is below the World level. In 2015, the proportion of households with Internet access at home in Sudan is above the level of Africa and is near to the level in developing countries, the Arab States, North Africa, and South Africa. In 2015, the proportion of households with Internet access at home in Developed countries and in the World, is nearly 3 times and nearly 2 times above the level of Sudan, respectively. The proportion of households with a computer in Sudan is near to Africa, but below the World level. In 2015, the proportion of households with a computer in developed countries, developing countries, and in the World, the Arab States, North Africa, and South Africa is nearly 6 times, nearly 2 times, and nearly 3 times above the level of Sudan, respectively.

Therefore, the results in this section support the first hypothesis that the national innovation system is characterized by serious weaknesses in Sudan, compared with other countries in the world, namely the World level, North Africa, South Africa, Africa, the Arab States, the advanced Asian countries and other world regions. This hypothesis implies that Sudan has manifestly lagged far behind other African and world countries in terms of S&T input indicators and information and communications technology (ICT) indicators (see table 5). This is not surprising since Sudan has not offered adequate human and financial resources for Education, S&T, ICT, and for the build-up of efficient national innovation systems.

## 5 The Global Innovation Index (GII) and the change in innovation performance of Sudan (2011-2015)

Based on the above results concerning the inadequate innovation system and the causes of the failures of this system in Sudan, it is useful to examine the status and the change in innovation performance in Sudan over the period 2011-2015. This section first illustrates the innovation profile of the Sudanese economy in 2015, discusses the GII and its sub-indices for Sudan as compared to North Africa and South Africa, and then examines the change in innovation performance in Sudan in the period 2011-2015. In our view, it is appropriate to use the Global Innovation Index (GII) reports (2011-2015) issued annually by Cornell University/INSEAD/WIPO to assess the innovation index, to investigate the change in the innovation performance indicators, and to examine the weaknesses in terms of the GII pillars and the innovation performance indicators. This refers to the GII input, the GII output, and the GII efficiency ratio when applied to Sudan.

**Table 5: ICT Indicators in Sudan compared to selected African and World Countries and Regions (2015)**

| | Fixed-telephone subscriptions per 100 inhabitants | Mobile-cellular telephone subscriptions per 100 inhabitants | Fixed (wired)-broadband subscriptions per 100 inhabitants | Percentage of Individuals using the Internet | Proportion of households with | |
|---|---|---|---|---|---|---|
| **Country/Year** | **2015** | **2015** | **2015** | **2015** | **Internet access at home** | **Computer** |
| **Sudan** | **0.30** | **70.53** | **0.07** | **26.61** | **29.3** | **14.0** |
| African countries | | | | | | |
| Libya | 10.00 | 157.00 | 0.97 | 19.02 | | |
| Algeria | 8.04 | 113.03 | 5.57 | 38.20 | 31.9 | 37.0 |
| Tunisia | 8.40 | 129.93 | 4.34 | 48.52 | 17.1 | 33.2 |
| Egypt | 7.36 | 110.99 | 4.52 | 35.90 | 39.2 | 47.3 |
| Morocco | 6.55 | 126.87 | 3.38 | 57.08 | 66.5 | 54.8 |
| North Africa | 8.07 | 127.56 | 3.76 | 39.74 | 38.68 | 43.08 |
| South Africa | 7.72 | 159.27 | 5.25 | 51.92 | 20.8 | 44.2 |
| Other countries | | | | | | |
| China | 16.48 | 93.16 | 18.56 | 50.30 | 41.8 | 45.5 |
| Korea | 58.06 | 118.46 | 40.25 | 89.90 | 98.8 | 77.1 |
| India | 1.99 | 78.84 | 1.34 | 26.00 | 3.1 | 9.5 |
| Malaysia | 14.34 | 143.91 | 8.95 | 71.06 | 70.1 | 67.6 |
| Singapore | 35.98 | 146.14 | 26.45 | 82.10 | 87.2 | 85.7 |
| World Regions | | | | | | |
| Developed | 38.5 | 125.7 | 29.4 | 78.1 | 81.3 | 81.0 |
| Developing | 9.3 | 93.0 | 7.4 | 36.7 | 37.6 | 33.1 |
| World | 14.3 | 98.6 | 11.2 | 43.8 | 49.0 | 45.6 |
| Africa | 1.1 | 76.2 | 0.5 | 22.5 | 13.6 | 9.7 |
| Arab States | 7.8 | 110.5 | 4.2 | 39.0 | 43.1 | 41.9 |
| Asia and Pacific | 11.0 | 93.0 | 8.9 | 38.2 | 42.7 | 36.0 |
| Europe | 37.5 | 119.8 | 29.2 | 76.3 | 81.3 | 79.8 |
| The Americas | 25.0 | 111.8 | 18.4 | 62.2 | 61.4 | 65.4 |

**Source:** International Telecommunication Union (ITU) (2016), "World Telecommunication (ITU)/ ICT Indicators database", Web Access: http://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx (Accessed 24 August 2016).

Using the Global Innovation Index (GII) reports and the Global Innovation Index (GII) conceptual framework is very useful because it illustrates the innovation performance in terms of a rank and the score value of the Global Innovation Index (GII), the innovation input sub-index, the innovation output sub-index, the innovation efficiency ratio, the innovation quality, and the GII pillars in the period 2011-2015. In addition, looking at the changes of the Global Innovation Index (GII) for Sudan and its sub-indicators can be very useful to highlight the main reasons behind hampering the potential role of STI in Sudan (see figures 1-5 and table 6).[6] The Global Innovation Index (GII) profile for Sudan implies serious weaknesses in terms of the overall GII, the input sub-index, the output sub-index, the innovation efficiency ratio, and various GII pillars in 2015. According to the GII 2015 (see: Cornell et al. 2015), Sudan with a population of 38.8 million people and a GDP per capita of PPP$ 2,673.2 ranks as number 141 in the Global Innovation Index (GII), as number 141 in the innovation input sub-index, as number 140 in the innovation output sub-index, and as the number 136 in the innovation efficiency ratio, among the 141 world countries which are included in the index in 2015. Therefore, Sudan occupies the last position.

The poor innovation performance of Sudan is related to both, the weak innovation input and the weak innovation output sub-indices for 2015 (see figures 1-5 and tables 6-7). Mainly, the weak position in terms of the global innovation index relates to the five innovation input enabler pillars, including: institutions, human capital, infrastructure, market sophistication, and business sophistication; the weak position with regard of innovation output sub-indices relates to the two output pillars, namely scientific output and creative output pillars. The weak innovation efficiency index is then a result of these sub-indices and pillars. Of the general ranking of the whole sample of 141 economies included in the calculations of the GII 2015 report, Sudan exhibits the fourth weakest position in terms of the institutions pillar (138), especially because of its weak position at the bottom place in terms of political environment (141), and the third weakest position in terms of political stability (139), having a bottom place in terms of government effectiveness (141). Sudan also occupies the eleventh weakest position in terms of regulatory environment (130), especially because of the weak position in terms of rule

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[6] According to the United Nations definition, the North Africa region includes Algeria, Egypt, Libya, Morocco, Sudan, and Tunisia. The Maghreb countries include Algeria, Morocco, Tunisia, and Libya. According to the World Bank classification of world countries, the term Middle East & North Africa (MENA) includes: Algeria, Bahrain, Djibouti, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Malta, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, United Arab Emirates, West Bank and Gaza, and Yemen. Northern Africa and Western Asia (NAWE) regions comprise 19 countries: Algeria, Bahrain, Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Morocco, Mauritania, Oman, Palestine, Qatar, Saudi Arabia, The Sudan, The Syrian Arab Republic, Tunisia, The United Arab Emirates, and Yemen.

of law (137), the weak position in terms of regulatory quality (136), and the very weak positions in terms of the business environment (118) and the time needed to start a business (112). Sudan is also ranked at a weak position in terms of human capital and research (121), because of its rank at the fifth weakest position in terms of education (137), especially in terms of tertiary education (86) and in terms of research and development (R&D) (90). Sudan has a weak position in terms of education expenditure as a % of GNI (124), in terms of school life expectancy (130), in terms of tertiary gross enrolment (%) (95), and in terms of graduates in science and engineering (%) (76).

Sudan also shows the tenth weakest performance in terms of infrastructure (132), particularly because of its weak position in terms of information and communications technology (ICT) (110), government online services (109), E-participation (108), ICT access (108), and ICT use (99). Sudan also shows the fourth weakest position in terms of general infrastructure (138), particularly electricity output (115) and gross capital formation as a % of GDP (113). Sudan shows the second weakest position in terms of market sophistication (140), particularly due to its fourth weakest position in terms of credit (138), particularly its sixth weakest position in terms of domestic credit to the private sector as % of GDP (136), and the weak position in terms of ease of getting credit (129), and in terms of investment (88), particularly due to its seventh weakest position in terms of indicators related to the strength and the ease of investor protection (135). And, Sudan occupies the third weakest position in terms of trade and competition (139), particularly because of its eighth weakest position in terms of applied tariff rates (134). Sudan shows the second weakest position in terms of business sophistication (140), particularly due to its second weakest position in terms of knowledge workers (140) and the weak position in terms of knowledge absorption (120). Sudan exhibits a weak position particularly in terms of royalty and license fee payments as % of total trade (126) and with regard of communication, computer and information services imports as % of total trade (116). Sudan shows a weak position in terms of knowledge and technology outputs (122), because of its tenth weakest position in terms of knowledge creation (132), particularly due to its weak position in terms of scientific and technical articles (127), citable documents h index of scientific research impact (109), and the PCT/Patent Cooperation Treaty resident patent applications (88). And, Sudan occupies the eighth weakest position in terms of knowledge diffusion (134), particularly because of its weak positions in terms of high-tech exports (less re-exports) as % of total trade (117) and the communication, computer and information services exports as % of total trade (108). In terms of knowledge impact (62), Sudan exhibits a weak position particularly in terms of ISO 9001 quality certificates (120). Sudan exhibits the third weakest position in terms of creative outputs (139), mainly due to its fourth weakest position in terms of creative intangibles (138) and a weak position in regard of creative goods and services (127), particularly because of its weak position in terms of creative goods and services exports (103). All these results from the Global Innovation Index 2015 reveal that Sudan has disadvantages at a broad front, meaning that the whole innovation system needs to be rebuilt and recreated. This implies that there is a weak position in terms of nearly all GII indicators, so that the relationship between innovation and development in Sudan is loose (see tables 6-7).

The Global Innovation Index (GII) for Sudan implies a seriously weak performance (in terms of the GII, the innovation input and output indices, and the efficiency ratio) compared to all countries included in the index. By regional ranking, Sudan falls behind North Africa and South Africa in terms of the global innovation index, the innovation input and innovation output sub-indices, in terms of the GII five input enabler pillars (institutions, human capital and research, infrastructure, market sophistication, and business sophistication), and in terms of the GII two output pillars (knowledge and technology outputs and creative outputs) (see tables 6a, 6b, 6c). By income group, as a lower-middle income country, Sudan is ranked far below its peers of the lower-middle income countries and below low-income countries (see tables 6-7 and figure 5).[7] In terms of GII and innovation input and output indices Sudan maintained its position and ranked at the bottom place (34) among the 34 countries included in the lower-middle income group of countries (World Bank classification) in 2015 compared to the rank of 33 in 2014 and the rank of 35 in 2013. By regional classification, in terms of both the GII and the innovation input index Sudan maintained its position at the bottom place in the Sub-Saharan Africa region and is ranked at the bottom place (32) in 2015 and at the rank of 33 in 2014 in the Sub-Saharan Africa region, while in terms of the innovation output index Sudan is ranked at the second bottom place (31) among the 32 countries in Sub-Saharan Africa region. Among the lower-middle income group Sudan comes in the fifth weakest position in terms of the innovation efficiency rank (136), just above five low income and lower-middle income countries, because of its weak position ranked at the bottom place in terms of the innovation input rank (141) and its weak position ranked as the second weakest country in terms of the innovation output rank (140), so being just above Togo (141) (see the Cornell University et al., Global Innovation Index, 2015).

[7] See the Cornell University et al., Global Innovation Index (GII) Reports (2015, 2014 and 2013). Note: Sudan was not included in the GII Report 2016.

**Table 6a: The Global Innovation Index (GII), the Input Sub-index, the Output Sub-index, and the Efficiency Ratio for Sudan compared to North and South Africa, Advanced Asia, and World's regions (2015)**

| Country | Global Innovation Index (GII) | Input Sub-index | Output Sub-index | Efficiency |
|---|---|---|---|---|
| Sudan | 15 | 21.9 | 8 | 0.4 |
| North and South Africa | | | | |
| Algeria | 24.4 | 32.1 | 16.7 | 0.5 |
| Egypt | 28.9 | 34.4 | 23.4 | 0.7 |
| Morocco | 33.2 | 40.5 | 25.8 | 0.6 |
| Tunisia | 33.5 | 39.1 | 27.9 | 0.7 |
| North Africa | 30 | 36.53 | 23.45 | 0.63 |
| South Africa | 37.4 | 45.2 | 29.7 | 0.7 |
| Advanced Asia | | | | |
| China | 47.5 | 48.4 | 46.6 | 1 |
| Korea, Republic of | 56.3 | 62.4 | 50.1 | 0.8 |
| India | 31.7 | 35.5 | 28 | 0.8 |
| Malaysia | 46 | 52.8 | 39.2 | 0.7 |
| Singapore | 59.4 | 72.1 | 46.6 | 0.6 |
| World Regions by Income level | | | | |
| Low income | 25.35 | 31.55 | 19.14 | 0.61 |
| Lower-middle income | 29.1 | 34.68 | 23.51 | 0.68 |
| Upper-middle income | 34.58 | 41.4 | 27.77 | 0.67 |
| High income | 49.63 | 56.18 | 43.07 | 0.76 |
| World Regions | | | | |
| Central and Southern Asia | 27.03 | 34.09 | 19.97 | 0.59 |
| Sub-Saharan Africa | 27.05 | 33.16 | 20.94 | 0.64 |
| Latin America and the Caribbean | 32.49 | 39.04 | 25.94 | 0.66 |
| Northern Africa and Western Asia | 35.26 | 42.31 | 28.21 | 0.67 |
| South East Asia and Oceania | 42.68 | 49.68 | 35.69 | 0.72 |
| Europe | 47.99 | 53.48 | 42.5 | 0.79 |
| Northern America | 57.91 | 66.18 | 49.65 | 0.75 |

**Source:** The Cornell University et al., The Global Innovation Index Report (2015).

**Table 6b: The Global Innovation Index (GII) and the Input Pillars for Sudan compared to North and South Africa, Advanced Asia, and World's regions (2015)**

| Country | Global Innovation Index (GII) | GII Input Pillars | | | | | |
|---|---|---|---|---|---|---|---|
| | | Institutions | Human capital and research | Infrastructure | Market sophis-tication | Business so-phistication | Input Sub-in-dex |
| Sudan | 15 | 32.5 | 15.1 | 19.7 | 28.6 | 13.7 | 21.9 |
| North and South Africa | | | | | | | |
| Algeria | 24.4 | 45.1 | 26.2 | 31.4 | 36.8 | 20.9 | 32.1 |
| Egypt | 28.9 | 39.5 | 27.9 | 37.2 | 35.9 | 31.6 | 34.4 |
| Morocco | 33.2 | 57.6 | 32.6 | 45.9 | 45.1 | 21.5 | 40.5 |
| Tunisia | 33.5 | 59.5 | 36.7 | 38.4 | 35 | 25.9 | 39.1 |
| North Africa | 30 | 50.43 | 30.85 | 38.23 | 38.20 | 24.98 | 36.53 |
| South Africa | 37.4 | 71.6 | 27.4 | 33.9 | 59.1 | 34 | 45.2 |
| Advanced Asia | | | | | | | |
| China | 47.5 | 54 | 43.1 | 50.5 | 49.2 | 44.9 | 48.4 |
| Korea, Republic of | 56.3 | 76.1 | 64.8 | 62.4 | 63.3 | 45.2 | 62.4 |
| India | 31.7 | 50 | 20 | 34.6 | 46.5 | 26.4 | 35.5 |
| Malaysia | 46 | 71.7 | 39.9 | 46.7 | 58 | 47.6 | 52.8 |
| Singapore | 59.4 | 95.4 | 60.9 | 69.5 | 71.6 | 63.1 | 72.1 |
| World Regions by Income level | | | | | | | |
| Low income | 25.35 | 46.76 | 15.88 | 22.49 | 42.14 | 30.48 | 31.55 |
| Lower-middle income | 29.1 | 49.9 | 20.6 | 30.04 | 43.53 | 29.34 | 34.68 |
| Upper-middle income | 34.58 | 58.9 | 29.85 | 38.75 | 46.17 | 33.31 | 41.4 |
| High income | 49.63 | 79.98 | 46.35 | 53.51 | 56.81 | 44.27 | 56.18 |
| World Regions | | | | | | | |
| Central and Southern Asia | 27.03 | 47.67 | 22.41 | 31.77 | 43 | 25.6 | 34.09 |
| Sub-Saharan Africa | 27.05 | 51.66 | 16.89 | 25.6 | 41.37 | 30.29 | 33.16 |
| Latin America and the Caribbean | 32.49 | 54.87 | 25.29 | 35.37 | 44.29 | 35.37 | 39.04 |
| Northern Africa and Western Asia | 35.26 | 61.05 | 32.08 | 41.74 | 46.24 | 30.44 | 42.31 |
| South East Asia and Oceania | 42.68 | 65.87 | 38.43 | 46.25 | 56.16 | 41.7 | 49.68 |
| Europe | 47.99 | 76.37 | 44.15 | 49.61 | 54.95 | 42.29 | 53.48 |
| Northern America | 57.91 | 49.65 | 89.73 | 51.5 | 59.87 | 77.48 | 66.18 |

**Source:** The Cornell University et al., The Global Innovation Index Report (2015).

**Table 6c: The Global Innovation Index (GII) and the Output Pillars for Sudan compared to North and South Africa, Advanced Asia, and World's regions (2015)**

| Country | Global Innovation Index (GII) | GII Output Pillars | | |
|---|---|---|---|---|
| | | Knowledge and technology outputs | Creative outputs | Output Sub-index |
| Sudan | 15 | 14.7 | 1.3 | 8 |
| North and South Africa | | | | |
| Algeria | 24.4 | 17.8 | 15.6 | 16.7 |
| Egypt | 28.9 | 21.7 | 25.1 | 23.4 |
| Morocco | 33.2 | 25.2 | 26.5 | 25.8 |
| Tunisia | 33.5 | 23.3 | 32.4 | 27.9 |
| North Africa | 30 | 22.00 | 24.90 | 23.45 |
| South Africa | 37.4 | 28.3 | 31.1 | 29.7 |
| Advanced Asia | | | | |
| China | 47.5 | 58 | 35.1 | 46.6 |
| Korea, Republic of | 56.3 | 56.7 | 43.6 | 50.1 |
| India | 31.7 | 30.1 | 25.9 | 28 |
| Malaysia | 46 | 36.2 | 42.1 | 39.2 |
| Singapore | 59.4 | 51.5 | 41.7 | 46.6 |
| World Regions by Income level | | | | |
| Low income | 25.35 | 18.86 | 19.43 | 19.14 |
| Lower-middle income | 29.1 | 21.41 | 25.61 | 23.51 |
| Upper-middle income | 34.58 | 25.1 | 30.44 | 27.77 |
| High income | 49.63 | 39.64 | 46.5 | 43.07 |
| World Regions | | | | |
| Central and Southern Asia | 27.03 | 20.12 | 19.82 | 19.97 |
| Sub-Saharan Africa | 27.05 | 19.34 | 22.53 | 20.94 |
| Latin America and the Caribbean | 32.49 | 21.01 | 30.86 | 25.94 |
| Northern Africa and Western Asia | 35.26 | 24.83 | 31.59 | 28.21 |
| South East Asia and Oceania | 42.68 | 35.53 | 35.84 | 35.69 |
| Europe | 47.99 | 39.44 | 45.56 | 42.5 |
| Northern America | 57.91 | 49.94 | 49.36 | 49.65 |

**Source:** The Cornell University et al., The Global Innovation Index Report (2015).

The GII Reports (Cornell University et al. 2011-2015) explain the change in innovation performance in Sudan during the period 2011-2015 (see table 7). For instance, the GII Report 2015 indicates that innovation performance in Sudan in terms of global ranking and score value has deteriorated in 2015 and 2014 compared to 2013, 2012 and 2011. For instance, in terms of the GII global ranking Sudan maintained its position at the bottom place among the world countries and is ranked 141 globally out of 141 world countries in 2015 compared to rank 143 out of 143 world countries in 2014 and a rank 141 out of 142 world countries in 2013. Particularly, Sudan occupies the bottom place in the overall GII 2015 rankings (141), maintaining the bottom place rankings of 2014 (143) and 2012 (141) because of its weak position in both the innovation input and innovation output sub-indices (141 and 140) of the general ranking of the whole sample of 141 economies included in the calculation of the GII (2015).

Sudan's rank deteriorated to the bottom place in the global rankings in 2015 and 2014 compared to the second bottom place in 2013 and 2011. In terms of the innovation input sub-index Sudan's rank deteriorated to the bottom place in the global rankings in 2015 and 2012, compared to the second bottom place in 2011 and 2014 and the seventh bottom place in 2013. Sudan has maintained its position at the bottom place among the world countries and is ranked 141 globally out of 141 world countries in 2015 compared to rank 142 out of 143 world countries in 2014, compared to rank 136 out of 142 world countries in 2013, and compared to rank 141 out of 141 world countries in 2012, while it is ranked 124 out of 125 world countries in 2011. In terms of the innovation output sub-index Sudan's rank deteriorated to the second bottom place in the global rankings in 2015, compared to the third bottom place in 2011 and the bottom place in 2014, 2013 and 2012. Sudan is ranked 140 globally out of 141 world countries in 2015, compared to rank 143 out of 143 world countries in 2014, compared to rank 142 out of 142 world countries in 2013, compared to rank 141 out of 141 world countries in 2012, while it is ranked 122 out of 125 world countries in 2011.

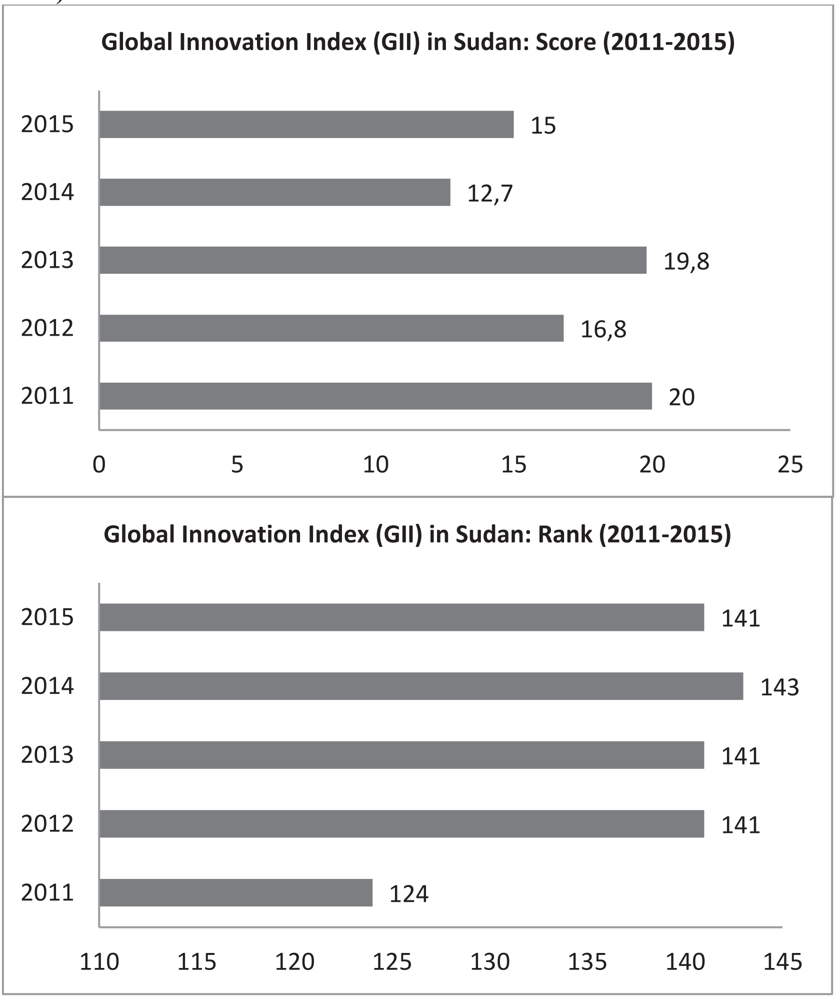
In terms of the innovation efficiency ratio Sudan's rank deteriorated to the sixth bottom place in the global rankings in 2015 compared to nineteenth bottom place in 2011, compared to the bottom place in 2012 and 2014, and compared with the fifth bottom place in 2013. Sudan is ranked 136 globally out of 141 world countries in 2015, compared to rank 143 out of 143 world countries in 2014, compared to rank 138 out of 142 world countries in 2013, compared to rank 141 out of 141 world countries in 2012, while it is ranked 107 out of 125 world countries in 2011. Therefore, these findings support the second hypothesis that the innovation performance in Sudan has deteriorated further in terms of the score value and the global rank during the period 2011-2015 (see Cornell University et al., Global Innovation Index, 2015). This hypothesis implies that there was a deterioration in terms of rank and score value, related to the overall GII, the GII input sub-index, the GII output sub-index, and the innovation efficiency ratio in Sudan during the period 2011-2015.

**Table 7: The Global Innovation Index (GII) for the Sudan Economy over the period 2011-2015**

| | **2015** | | **2014** | | **2013** | | **2012** | | **2011** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Score (0 –100)** | **Rank** | **Score (0–100)** | **Rank** | **Score (0–100)** | **Rank** | **Score (0–100)** | **Rank** | **Score (0–100)** | **Rank** |
| Total number of countries | | 141 | | 143 | | 142 | | 141 | | 125 |
| Global Innovation Index (GII) | 15.0 | 141 | 12.7 | 143 | 19.8 | 141 | 16.8 | 141 | 20 | 124 |
| GII (Lower-middle income countries) | 29.10 | | 29.53 | | 29.83 | | 28.31 | | 30.42 | |
| GII (Low income countries) | 25.35 | | 25.62 | | 26.43 | | 24.61 | | 25.91 | |
| Sub-Saharan Africa | 27.05 | | 27.45 | | 27.38 | | 26.16 | | 26.92 | |
| Northern Africa and Western Asia | 35.26 | | 35.73 | | 35.55 | | 35.96 | | 34.45 | |
| GII innovation output | 8.0 | 140 | 2.1 | 143 | 13.1 | 142 | 10.3 | 141 | 15 | 122 |
| GII innovation input | 21.9 | 141 | 23.2 | 142 | 26.5 | 136 | 23.3 | 141 | 26 | 124 |
| GII innovation efficiency ratio | 0.4 | 136 | 0.1 | 143 | 0.49 | 138 | 0.44 | 141 | 0.6 | 107 |

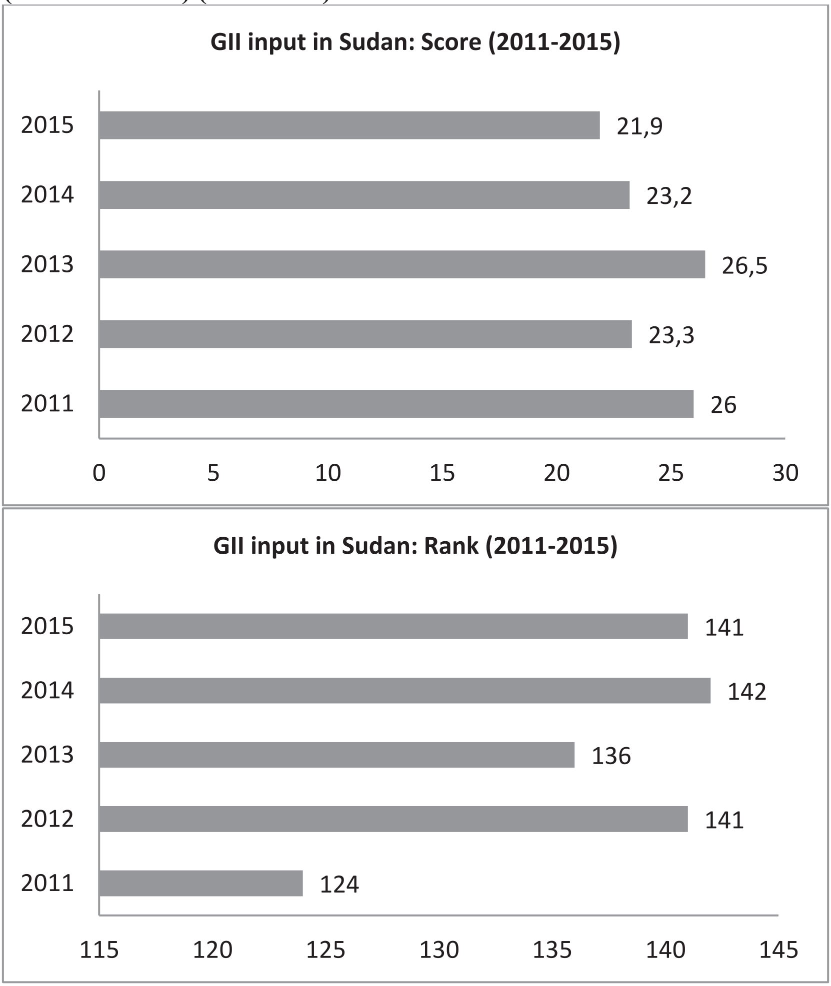
**Sources:** The Cornell University et al., GII Reports (for 2011-2015): Global Innovation Index Profiles: Country/Economy: Sudan.

**Figure 1: The Global Innovation Index (GII) in Sudan (score and rank) (2011-2015)**



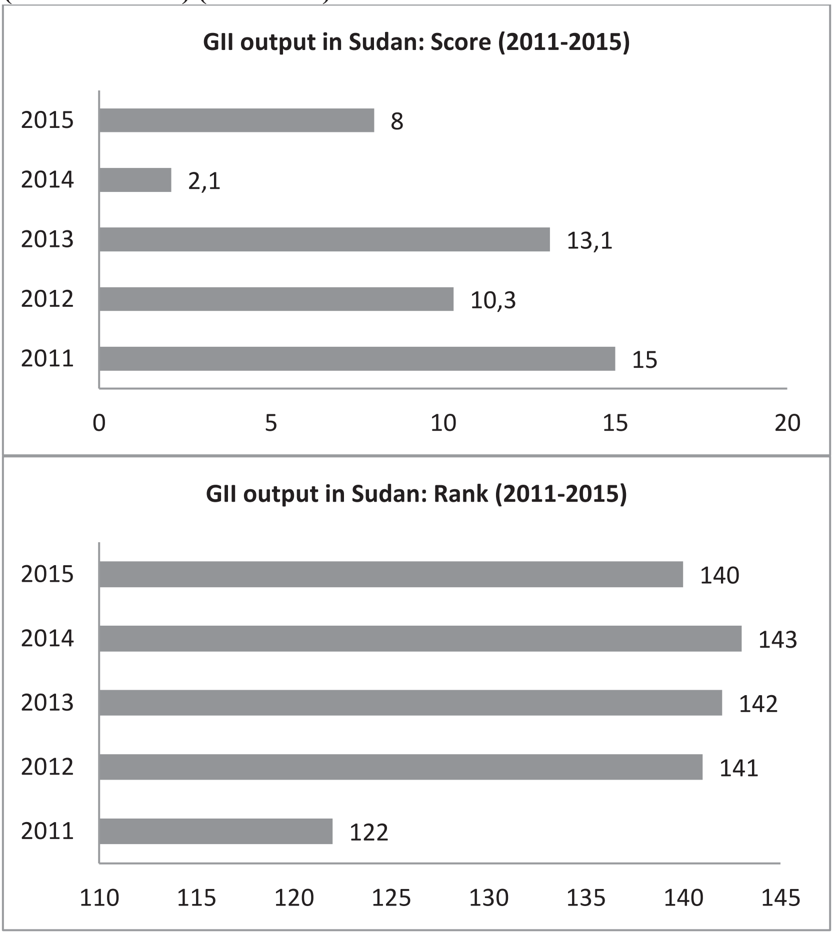

**Sources:** The Cornell University et al., The GII Report (2011-2015): The Global Innovation Index Profiles: Country/Economy: Sudan.

**Figure 2: The Global Innovation Index (GII) Innovation Input in Sudan (score and rank) (2011-2015)**



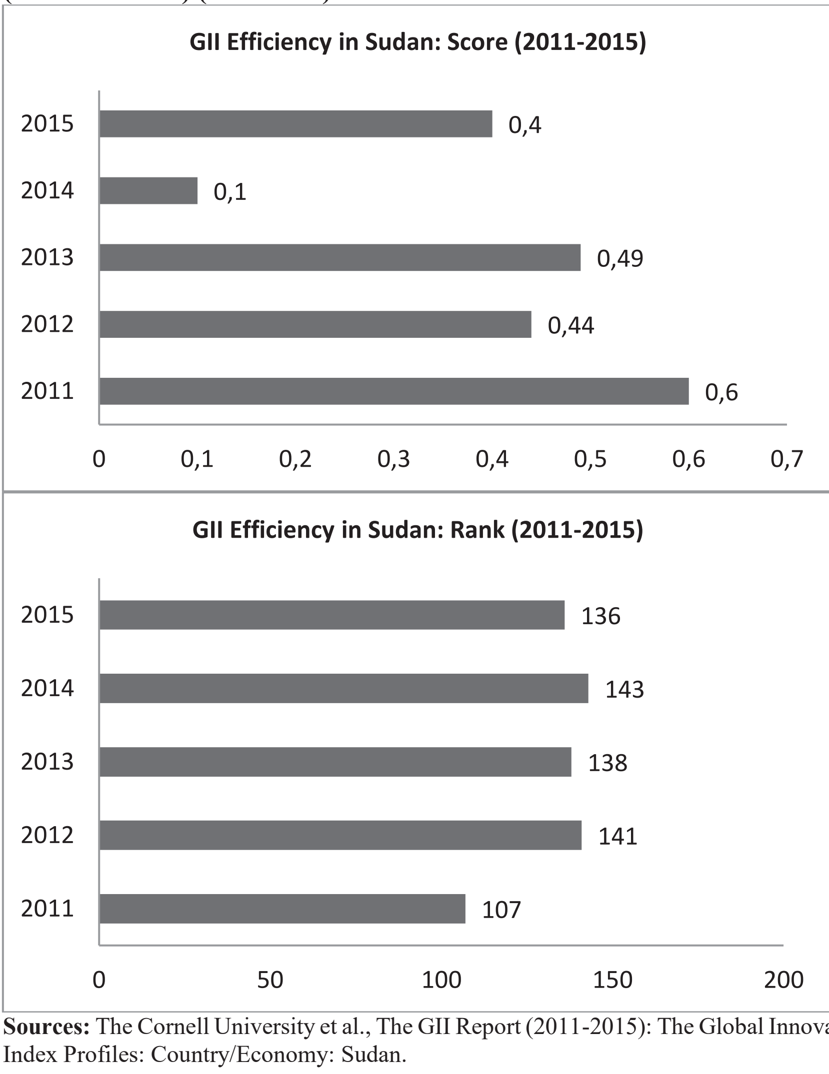

**Sources:** The Cornell University et al., The GII Report (2011-2015): The Global Innovation Index Profiles: Country/Economy: Sudan.

**Figure 3: The Global Innovation Index (GII) Innovation Output in Sudan (score and rank) (2011-2015)**




**Sources:** The Cornell University et al., The GII Report (2011-2015): The Global Innovation Index Profiles: Country/Economy: Sudan.

**Figure 4: The Global Innovation Index (GII) Innovation Efficiency in Sudan (score and rank) (2011-2015)**




**Sources:** The Cornell University et al., The GII Report (2011-2015): The Global Innovation Index Profiles: Country/Economy: Sudan.

**Figures 5 (5a, 5b, 5c, 5d): The Global Innovation Index (GII) in Sudan compared to World Regions and Income Status (score) (2011-2015)**

**Figure 5.a: Global Innovation Index in Sudan compared to Low income and Lower-middle income**

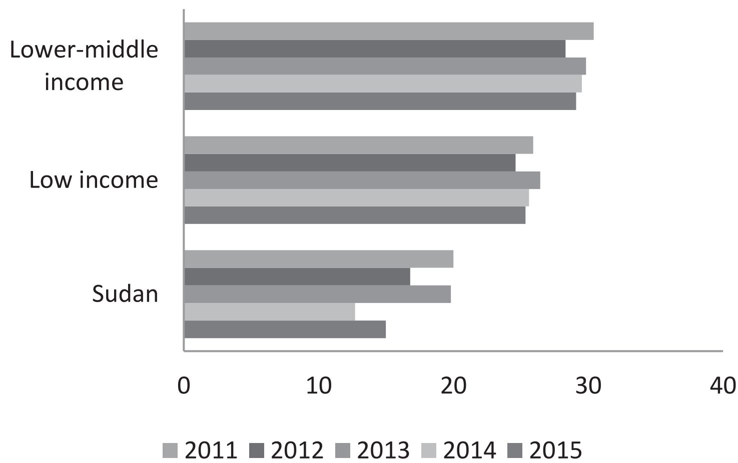



**Figure 5.b: Global Innovation Index in Sudan compared to North African and Sub-Saharan Africa**

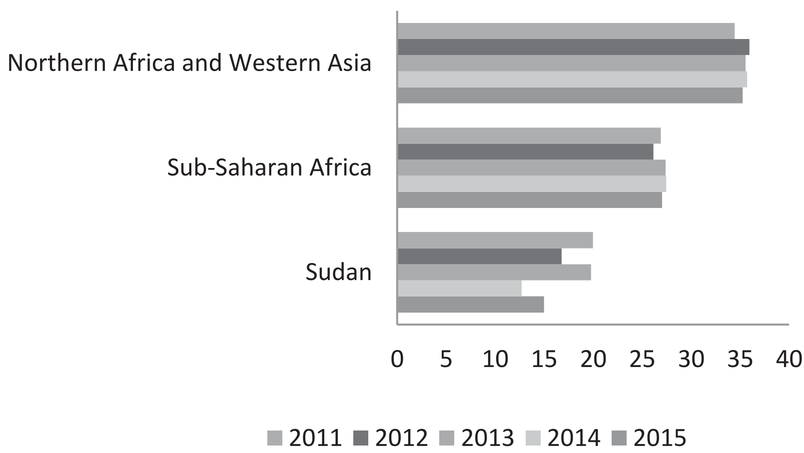


**Figure 5.c: Global Innovation Index in Sudan compared to Low income and Lower-middle income**

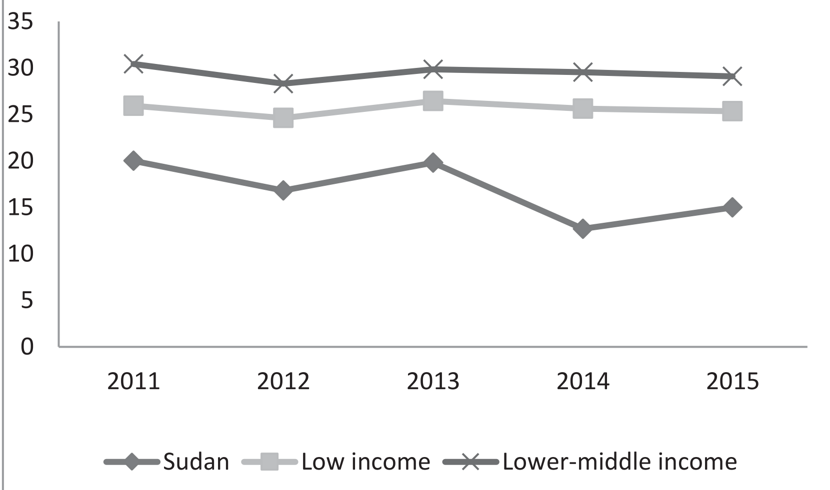
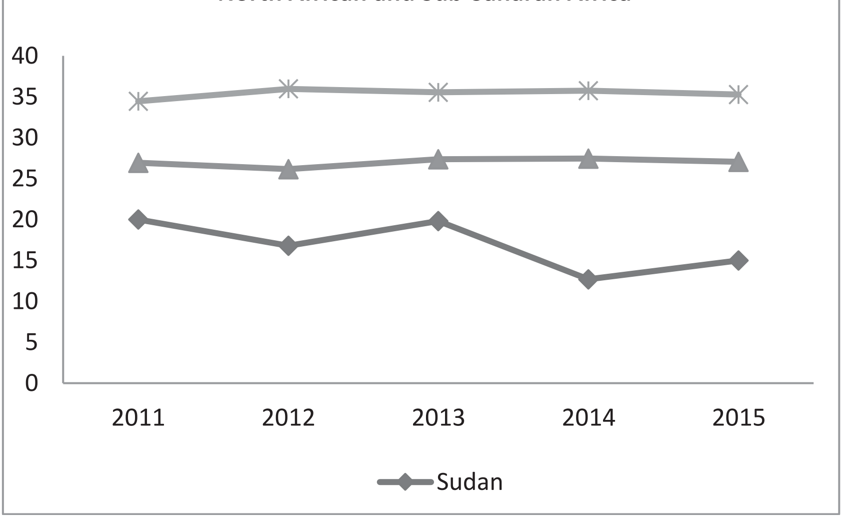



**Figure 5.d: Global Innovation Index in Sudan compared to North African and Sub-Saharan Africa**




**Sources:** The Cornell University et al., The GII Report (2011-2015): The Global Innovation Index Profiles: Country/Economy: Sudan.

Hence, the findings in this section support the second hypothesis that the innovation performance in Sudan has deteriorated during the period 2011-2015. This hypothesis implies that there was a deterioration in terms of rank and score value related the overall GII, the GII innovation input sub-index, the GII innovation output sub-index, and the innovation efficiency ratio in Sudan during the period 2011-2015 (see tables 6-7 and figures 1-5). The results in this section also support the hypothesis that Sudan shows a weak performance in terms of the overall Global Innovation Index (GII), the Innovation Input sub-index, the Innovation Output sub-index, and of the main pillars (score 0-100 and rank) (2015), mainly compared to the Northern Africa and Sub-Saharan Africa (see figure 5).

## 6 Consequences or implications of the inadequate national innovation system in Sudan

Based on our findings presented above regarding the characteristics and causes of the rudimentary national innovation system of Sudan the implications of the inadequate innovation systemin Sudan were considered. Such a defunct system has repercussions on the S&T output, on national competitiveness, on the integration of Sudan into the global economy, on the perspectives of a knowledge society, on high technology exports and imports, on the technology infrastructure, and on the capacity to create knowledge in Sudan. The previous results indicate that the national innovation system is hampered by key factors and characterized by serious weaknesses compared with many other countries in Africa, in emerging and in developing countries. It is obvious from the results presented that the innovation performance in Sudan has further deteriorated in the period 2011-2015.

STI policy impacts and results can be measured by several indicators, including the number of patent applications, the scientific publications, and the share of high-technology exports. Despite a slight increase in the number of scientific publications for Sudan over the period 2011–2013, Sudan performed less in this regard than South Africa, Egypt, Tunisia, Morocco, and Algeria respectively. This could be the outcome of the unsatisfactory performance of Sudan compared to these countries in terms of key STI input indicators, such as the expenditures on education and R&D, the number of R&D employees, and the number of R&D scientists and engineers. Concerning STI output indicators, the number of patent applications by residents and non-residents and the share of high-technology exports are substantially behind that of the world average, and especially so relative to the advanced Asian countries such as Singapore, Korea, China, and Malaysia. The low number of patent applications implies a low level of innovative activities in Sudan, that is probably due to the low percentage share of GDP spent on R&D, the small number of scientists and engineers in R&D sectors, and the insufficient overall science and technology infrastructure. Such a situation impacts on the competitiveness of Sudan - its economy and its firms.

The relationship between innovation and competitiveness is important for growth and living standards of Sudan and its people. The Arab Planning Institute (API) has published the Arab Competitiveness Report/ACR (2012) that gives useful indicators for the measurement of competitiveness indices and for measuring the capacity for innovation (see Table 8). The Arab Composite Competitiveness Index for Sudan and its sub-indicators are very useful to highlight the relationship between innovation and competitiveness in Sudan. By considering the regional rankings, Sudan is positioned behind North Africa and South Africa and the average for Arab countries and comparable countries in terms of the composite competitiveness index, the current and the intangible competitiveness indices, and the capacity for innovation and localization of technology index (see Table 8). Of the general ranking of the whole sample of 30 economies included in the calculation of the Arab Composite Competitiveness Index (ACCI), Sudan exhibits a weak position in terms of the composite competitiveness index (rank 28), especially because of its weak position at the bottom place in terms of the current competitiveness index (rank 30), and the third weakest position in terms of the intangible competitiveness index (rank 28). Sudan is also ranked at a bottom place in terms of the capacity for innovation and localization of technology index (rank 21), what is due to the weak position in terms of sub-indicators of the capacity for innovation and localization of technology index. These findings imply a weak position in terms of competitiveness, which implies a weak relationship between innovation and competitiveness in Sudan (see table 8).[8]

The trend of foreign direct investment (FDI) net inflows and of high-technology exports shows significant fluctuations in Sudan over the period 1995-2015 (see figure 6-9**)**. The FDI net inflows (% of GDP) (2013) to Sudan are above the World level and above the levels of North Africa, South Africa, Sub Saharan Africa and the Arab States, but below the levels of East Asia and Pacific, Latin America, the Caribbean, and advanced Asian countries (Singapore, China and Malaysia) (see figure 6**)**. Moreover, both high-technology exports in value (current US$) and

[8] The definition of the Arab Planning Institute's Arab Competitiveness Report (2012) implies that the Composite Competitiveness Index (CCI) is composed of two sub-indicators: first, the Current Competitiveness Index and second, the Intangible Competitiveness Index. The Current Competitiveness Index focuses on the current performance and the determining factors which influence the performance, such as the market structure, the business environment, and the firms' operations and strategies. Whereas the intangible competitiveness index focuses on intangible capabilities and in-depth effects which ensure sustainable competitiveness, sustainable growth, and the achievement of social and economic development objectives. The intangible competitiveness index includes factors such as human capital, localization of technology, and technological infrastructure

high-technology exports as a share (% of manufactured exports) of Sudan fall far behind advanced Asian countries (Korea, Singapore, Malaysia, China, and India), the World level, and all other World regions including the OECD members, Europe and Central Asia, Latin America and the Caribbean, South Asia, Middle East and North Africa, the Arab States, North Africa, South Africa, and Sub-Saharan Africa (see figure 7). The share of high-technology exports (% of manufactured exports) of Sudan has critically deteriorated from 29.37% in 2009 to 0.16% and to 0.70% in 2010 and 2011 respectively (see figure 9). The high fluctuation in the high technology exports is most probably related to fluctuations in economic performance and economic growth due to the changes in the global economies being the result of the global economic crisis of 2008-2010. This is alarming, although also in the past there were great fluctuations of the share recorded.

The results in this section support the third hypothesis that the rudimentary national innovation system has serious implications in Sudan. These weaknesses have serious implications for the S&T output indicators, the national competitiveness, the integration into the global economy, the knowledge economy, the share of high technology exports, the state of the technology infrastructure, the level of technology achievements, and the capacity to create knowledge in Sudan (see table 8 and figures 6-9).

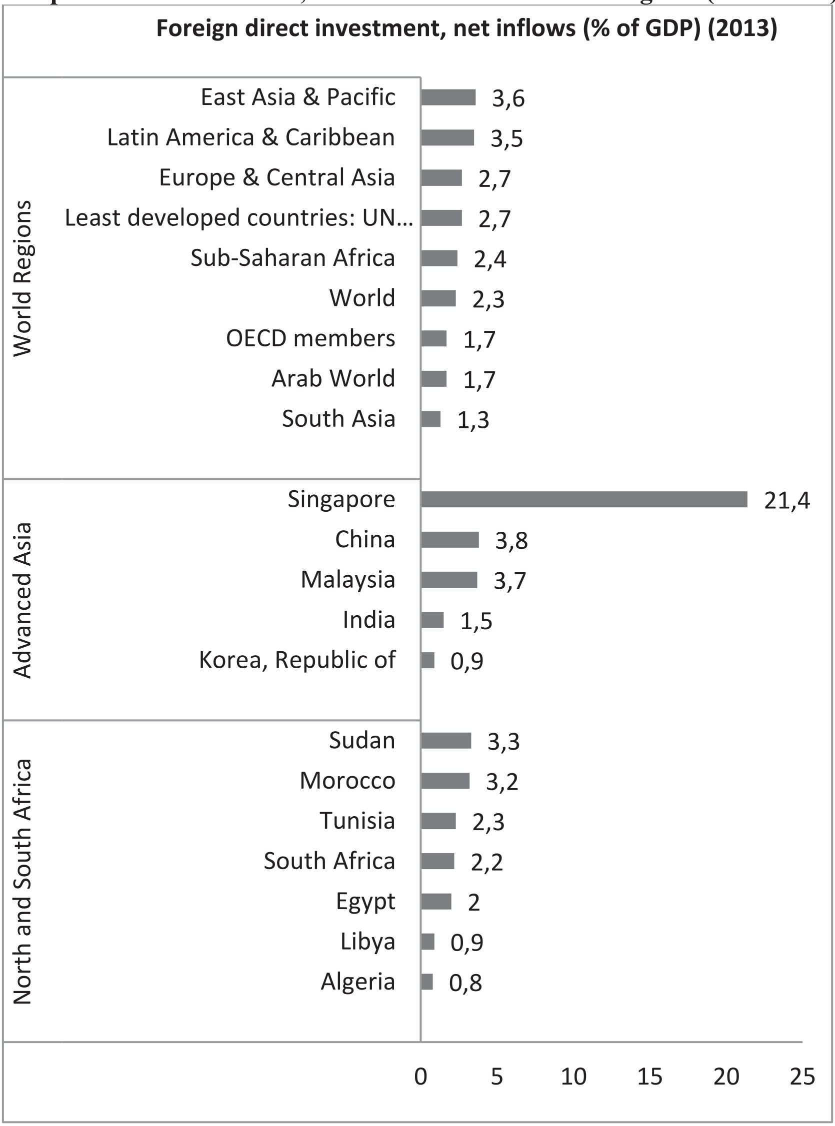
Next to the above analysis on various subsystems of the NIS, it is important to refer to NIS linkages with enterprises, innovative enterprises, innovation finance, and with the policy actors on STI, NIS and R&D. A weak institutional framework and a weak coordination of the various subsystems of the NIS in Sudan impede a proper functioning of the whole system. The findings of Nour (2013b, 2017) support the third hypothesis concerning the weak linkages with enterprises. The results of Nour (2013b, 2017) show a weak innovation output across industrial firms, and a weak interaction and cooperation between industry and universities in terms of R&D in Sudan. It is also shown that innovation in industrial firms is significantly constrained by the lack of financial and human resources and the lack of appropriate economic incentives. Based on these findings, it is necessary that enterprises link up with the subsystems of the NIS in Sudan. This requests to improve the interaction and cooperation between industry and universities in terms of R&D and providing adequate financial and human resources and appropriate economic incentives. The enterprise sector and the government need to act on these issues. Therefore, the NIS can be used to make the system adequate to support local private and public enterprises, start-ups and affiliates of MNCs in Sudan, and to enhance industrial diversification in Sudan. Therefore, an Agenda for Action is needed - for the short term, the medium term and the long term.

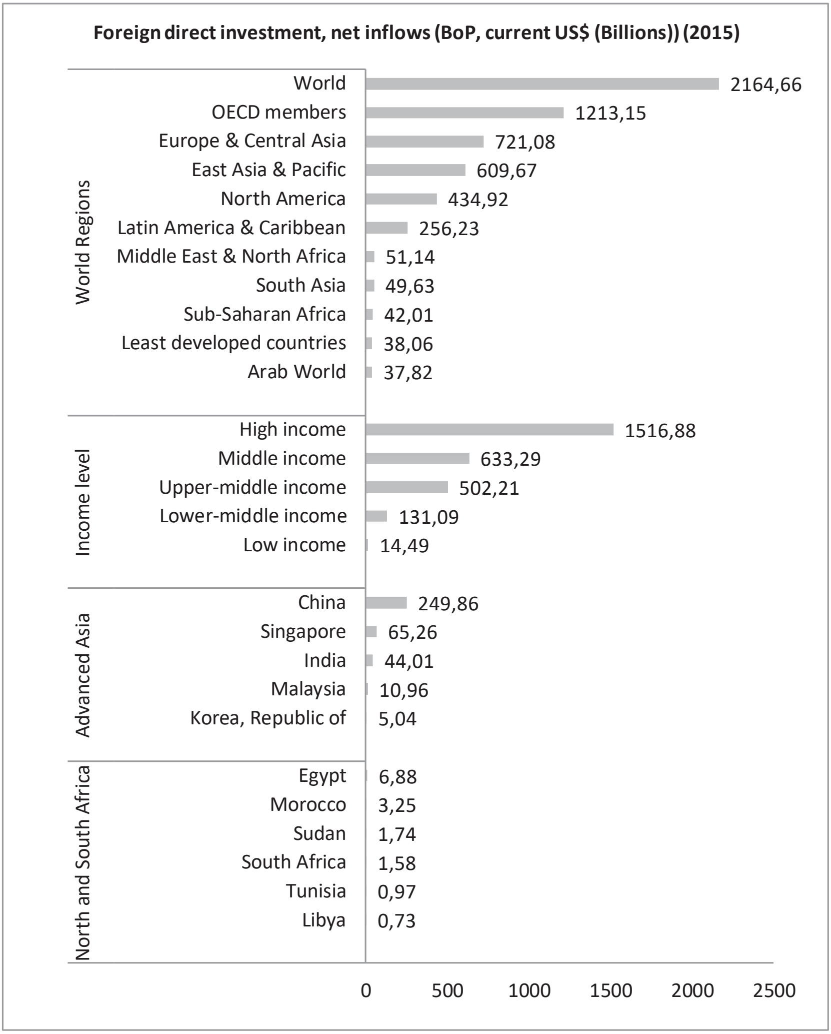
**Table 8: Composite Competitiveness Index, Current and Intangible Competitiveness Indices and Capacity for Innovation and Localization of Technology in Sudan compared to North Africa, South Africa and other Regions (2011)**

| Country | Composite Competitiveness Index | | Current Competitiveness Index | | Intangible Competitiveness Index | | Capacity for Innovation and Localization of Technology | Human capital | Technological infrastructure |
|---|---|---|---|---|---|---|---|---|---|
| | Score | Rank | Score | Rank | Score | Rank | | | |
| **Sudan** | **0.27** | **28** | **0.31** | **28** | **0.23** | **28** | **0.23** | **0.18** | **0.29** |
| North and South Africa | | | | | | | | | |
| Algeria | 0.36 | 24 | 0.39 | 24 | 0.33 | 22 | 0.16 | 0.48 | 0.36 |
| Egypt | 0.36 | 25 | 0.39 | 25 | 0.32 | 24 | 0.14 | 0.47 | 0.36 |
| Libya | 0.37 | 23 | 0.45 | 23 | 0.29 | 26 | 0.14 | 0.60 | 0.13 |
| Morocco | 0.34 | 27 | 0.40 | 27 | 0.27 | 27 | 0.21 | 0.31 | 0.29 |
| Tunisia | 0.45 | 16 | 0.47 | 16 | 0.44 | 11 | 0.32 | 0.60 | 0.41 |
| North Africa | 0.38 | 23 | 0.42 | 23 | 0.33 | 22 | 0.19 | 0.49 | 0.31 |
| South Africa | 0.41 | 19 | 0.44 | 19 | 0.39 | 20 | 0.22 | 0.62 | 0.33 |
| Average Arab Countries | 0.39 | | 0.44 | | 0.35 | | 0.19 | 0.48 | 0.37 |
| Other countries | 0.50 | | 0.50 | | 0.50 | | 0.38 | 0.66 | 0.47 |

**Source:** Arab Planning Institute - Arab Competitiveness Report (2012), Table 1, p. 28, Tables 2, 7, 13, pp. 29, 40, 51, Table 14, p. 53. Web Access: http://www.arab-api.org/publicationlists.aspx?publication_cat_id=3 and http://www.arab-api.org/publicationlists.aspx?publication_cat_id=3#prettyPhoto[iframe]/0/

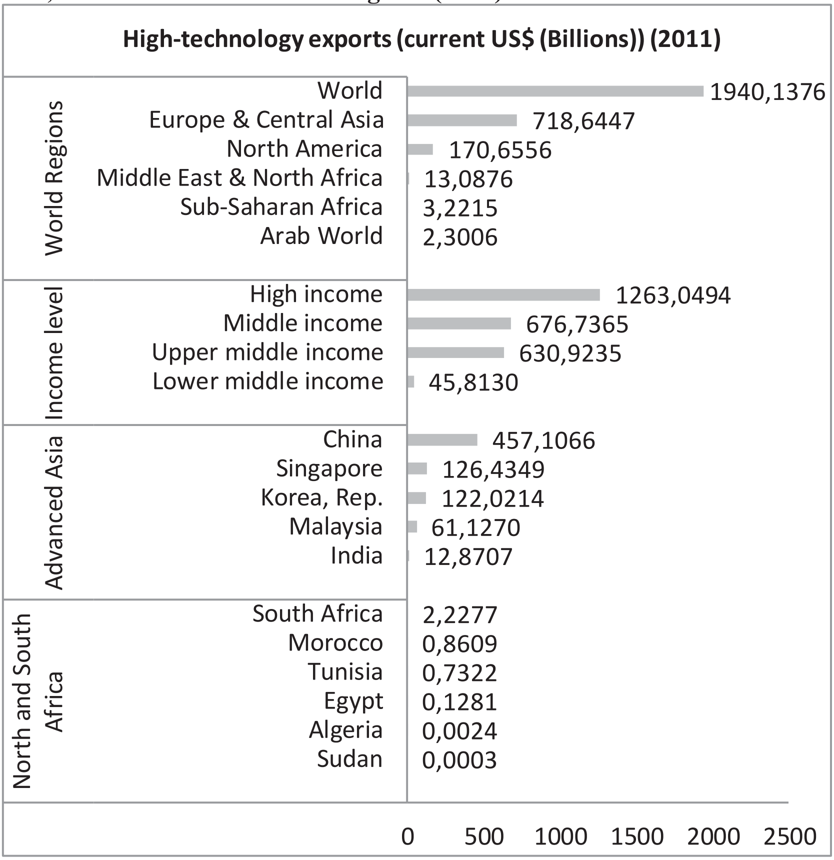
**Figures 6 (6a, b): Foreign direct investment, net inflows (% of GDP), in Sudan compared to North Africa, South Africa and World's regions (2013-2015)**

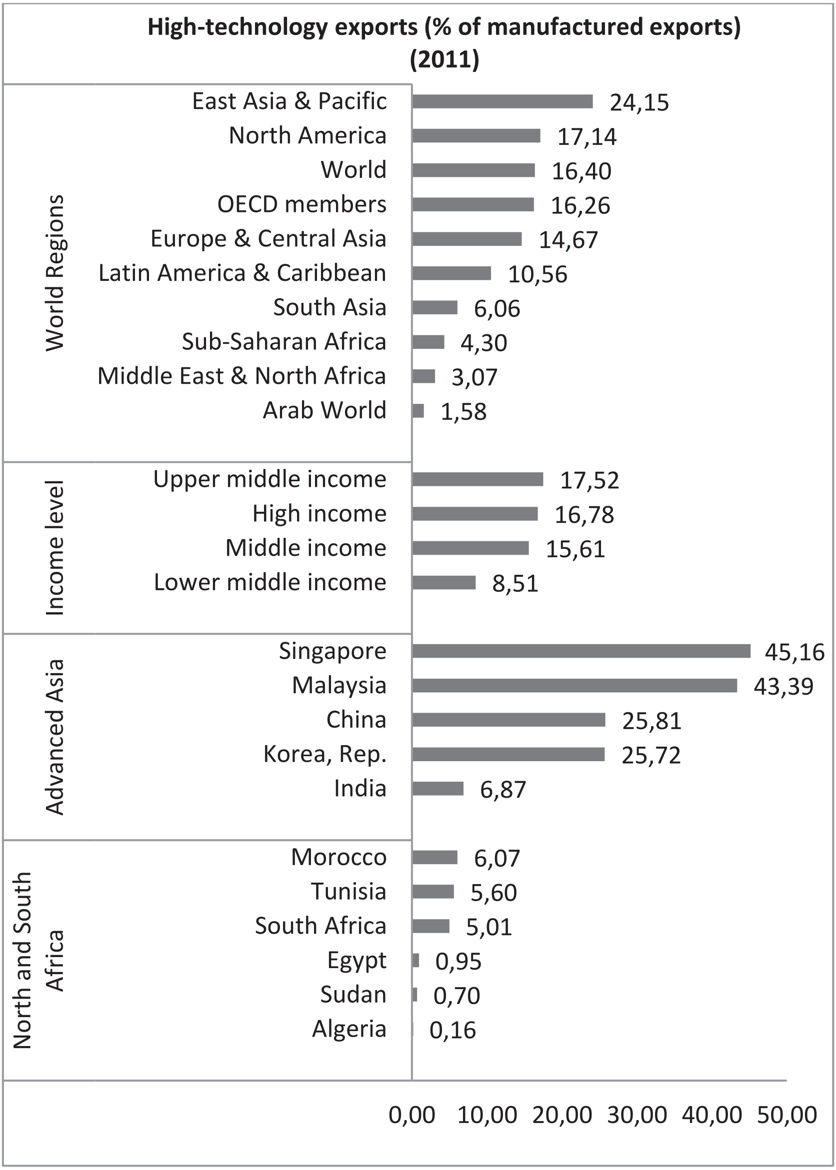





**Sources:** (1) The World Bank World Development Indicators (2017) (accessed 05 February 2017), and (2) UNDP Human Development Report (2015): Table 15: pp. 262-265.

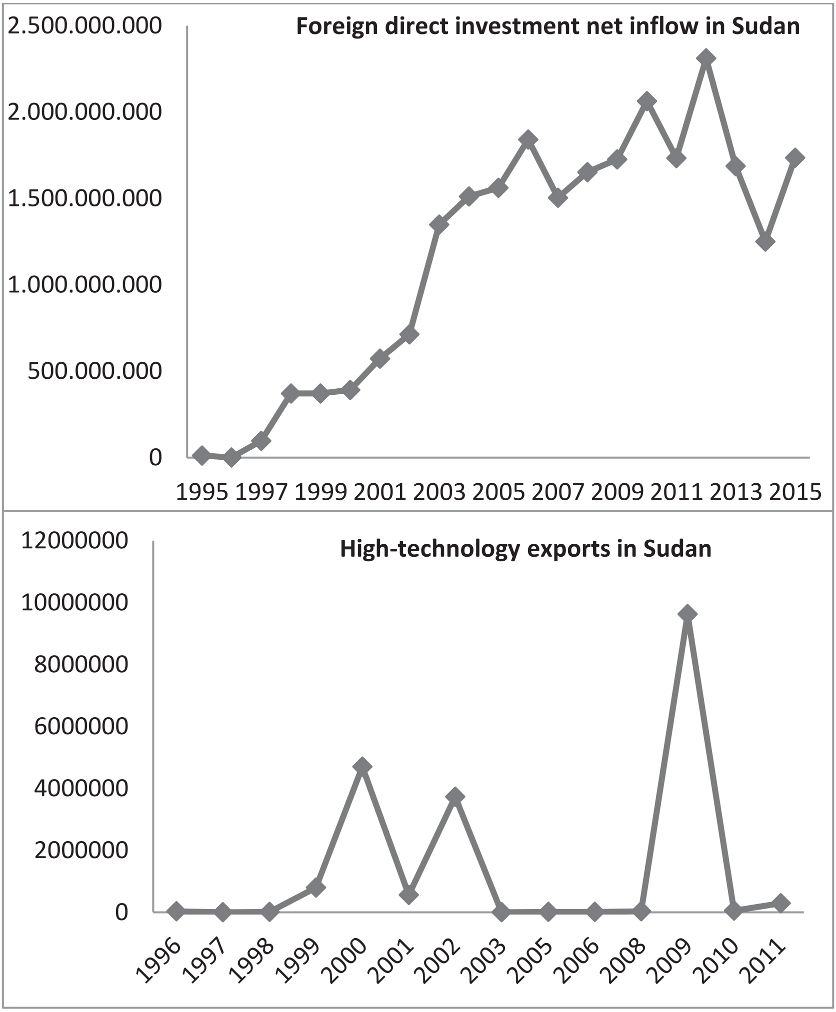
**Figures 7 (7a, b): High-technology exports (in current US$) and high-technology exports (in % of manufactured exports) of Sudan compared to North Africa, South Africa and World regions (2011)**





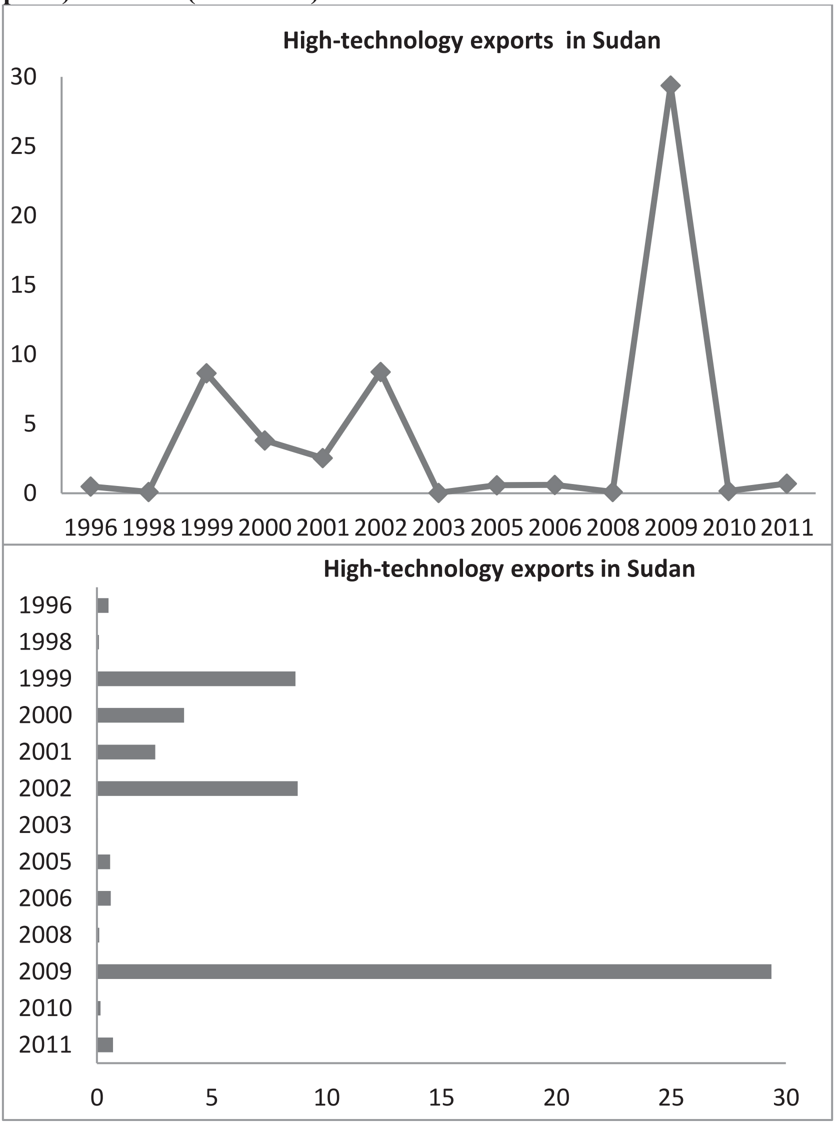

**Sources:** (1) The World Bank World Development Indicators (2017) (accessed 05 February 2017), and (2) UNDP Human Development Report (2015): Table 15: pp. 262-265.

**Figure 8: The Trend of Foreign direct investment, net inflows (in current US$) and high-technology exports (in current US$) in Sudan (1995-2015)**




**Sources:** (1) The World Bank World Development Indicators (2017) (accessed 05 February 2017), and (2) UNDP Human Development Report (2015): Table 15: pp. 262-265.

**Figure 9: The Trend of High-technology exports (in % of manufactured exports) of Sudan (1995-2015)**




**Sources:** (1) The World Bank World Development Indicators (2017) (accessed 05 February 2017), and (2) UNDP Human Development Report (2015): Table 15: pp. 262-265.

One major limitation of the analysis is related to the relevance of the innovation system approach for African and developing countries (see: Shulin, 1999). The conceptual and methodological difficulties of applying the innovation system approach of the developed countries to the developing countries, especially to low income and lower middle income African countries, are too obvious. Although the concept of the NIS has so far been used only rarely for developing countries (see: Shulin, 1999; Muchie, Gammeltoft, and Lundvall, 2003), the available literature, which is focussing on OECD countries mainly, still provides useful insights for the analyses of NIS in Africa. Such an application requires that a special emphasis is put on institutional settings for enhancing efficient systems of innovation. A second limitation is related to the scope of the analysis, since the aim of the present study is to explain the characteristics, the causes and the implications of the inadequate national innovation system in Sudan, by investigating in detail the subsystems of the educational institutions, the S&T and R&D institutions, and the information and communications technology (ICT) institutions. It is essential to investigate the linkages and the interactions between these institutions in a deep way; however, due to the scarcity of necessary information, the analysis does not cover the interaction between these institutions in detail. So, the paper is useful to improve the understanding of the characteristics, causes and implications of still rudimentary national innovation systems in Sudan and other African countries.

## 7 Conclusions and policy recommendations

The findings in this paper imply that the national innovation system (NIS) in Sudan is still very weak compared to other countries in Africa, emerging economies, developing and developed countries. This paper has examined the characteristics, the causes, and the implications of the rudimentary national innovation system (NIS) in Sudan as an effort to present a new case study of African countries. The findings support the first hypothesis that the national innovation system in Sudan is hampered by several key factors and is characterized by serious weaknesses compared with other African and developing countries. This hypothesis implies that Sudan has manifestly lagged far behind other African and World countries in terms of S&T input indicators and information and communications technology (ICT) indicators. The results also support the second hypothesis that the innovation performance in Sudan has deteriorated during the period 2011-2015. This hypothesis implies that the deterioration in terms of rank and score value relates to the Global Innovation Index (GII), the GII input sub-index, the GII output sub-index, and the innovation efficiency ratio in Sudan during the period 2011-2015. The results also support the third hypothesis that the current state of the national innovation system (NIS) has serious implications for the economy and the society of Sudan. The serious implications for Sudan appear in terms of unfavourable trends with regard of the S&T output, the national competitiveness, the integration into the global economy, the build-up of the knowledge economy, the share of high technology exports, the technology infrastructure, the level of technological achievement, and the capacity to create knowledge. The serious implications also appear in terms of weak linkages with enterprises, finance institutions, and the policy framework. Because of these weak linkages the system of innovation is quite rudimentary despite of some advances in sub-systems. The findings in this paper are useful from a policy perspective since it provides insights for stimulating new policies for enhancing the national innovation system, and hence for generating inclusive growth in Sudan and Africa. It is recommended to focus on the drafting of coherent policies and on the implementation of coherent and sound policies. It is necessary to establish sound economic structures to support innovation, to improve the allocation of financial and human resources, and to create incentives to encourage the public and private sectors to contribute to R&D activities. All these measures may help to enhance the national innovation system (NIS) to become a viable system in Sudan.

Coherent STI policies are highly important for Sudan to facilitate shifting from the prevailing Rent Seeking Economic Structure (RSES) to a Technology, Innovation and Knowledge - based Economy (TIKE), thereby enhancing national competitiveness, contributing to a higher business performance, reducing poverty and inequality, and achieving inclusive growth and sustainable development in Sudan. It is recommended that the National Innovation System (NIS) of Sudan would be improved by implementation of short, medium and long terms agendas for 13 years over the period 2018-2031 by putting priority to improve public spending on R&D as a percentage of the GDP, to promote human capital in R&D, and to support the ICT and STI infrastructure. Especially, the short-term agenda for one year over the period (2018-2019) should put priority to improve public spending on R&D as a percentage of GDP to 0.50%, to promote human capital in R&D by setting concrete targets, to promote ICT by setting concrete targets, and to promote STI infrastructure also by setting concrete targets. Medium term policy action for two years over the period (2019-2021) should put priority to improve public spending on R&D as a percentage of GDP to 1%, and to set more ambitious concrete targets to promote human capital in R&D, ICT development, and STI infrastructure. Long term for ten years over the period 2021-2031 should put priority to improve public spending on R&D as a percentage of GDP to 1.50%, and to widen broadly the programmes to promote human capital in R&D, ICT development, and STI infrastructure. In addition, the government of Sudan needs to establish a Science and Technology Observatory (STO) and an Innovation Fund (IF); these institutions should be established with the support from the government (public sector), the private sector (the firms), and the civil society (NGOs). All stakeholders, such as the government, the public and private institutions, and the scientific community should contribute to support a sustainable funding to build viable innovation systems in Sudan. Moreover, Sudan needs to implement a sound, sustainable and coherent strategy, to increase investment in higher education and training, to reduce the brain drain of qualified people, to involve scientists from the diaspora, to improve international co-operation on STI and R&D, to improve the transfer of innovative technologies, to encourage the private sector to contribute to the R&D effort, and to encourage scientists to engage in public-private partnership projects for the promotion of NIS and STI in Sudan.

It is recommended to focus in STI policies more on Agro-Based Industries (ABIs), as the Sudan has the comparative advantages in agriculture and agriculture-based products. Sudan would then exploit its comparative advantages with potential positive impacts on industrialization by focusing on STI areas of Agro-Based Industries. Agro-Based Industries are those industries which are based on agricultural raw materials or industries which depend on agricultural products as raw materials. For example, Agro-Based Industries, such as cotton, jute, silk and woollen textiles, sugarcane and vegetable oil, have a great potential in Sudan. Cotton textile industries use cotton as raw material and then process them to make dresses; Sudan has a history in such a production. However, to sustain such Agro-Based Industries considerable STI inputs are requested nowadays. In addition, it is recommended to focus STI in Sudan more on manufacturing industries which are based on the country's rich and diversified mining resources. Sudan has comparative advantages in mining, extractive and natural resources, such as gold, other metal, and oil. Sudan would gain comparative advantages with potential positive impacts on industrialization by focusing on extractive and manufacturing industries. Again, much more STI input is requested to sustain a competitive position. Furthermore, it is recommended to focus in STI more on green industries, environment-friendly industries, and especially on renewable solar energy. Sudan has comparative advantages because of a great potential for renewable solar energy sources. But, Sudan would gain comparative advantages with potential positive impacts on industrialization only when focusing STI more on green, environment-friendly, and renewable energy industries.

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# The Impact of Agricultural Research on Agriculture Yield in Sudan

**Migdam E. Abdelgani [*], Nazar M. Hassan[**]**

## 1 Introduction

Sudan is a low income and food deficit country with a population of approximately 36.2 million, of which two-thirds is rural. In 2012, agriculture accounted for nearly one-third of the total national GDP. In 2009, 34 percent of the total labour force was engaged in agriculture. Because of the secession of South Sudan that took place in July 2011 and which was accompanied by a serious downturn in the economy of Sudan, these developments translated into an increase of the annual inflation rate from 10 percent in 2010 to 37 percent in 2013. Together with the loss of human and land resources, and most of the oil wealth, the Government of Sudan started advocating agriculture as the engine to effectively contribute to economic growth to improve people's livelihoods and to promote food security.[1]

With over 70% of sorghum and millet been grown in rain-fed regions, food insecurity is strongly correlated to the country's rain-fed agricultural subsector, which, for example, yielded a 48% lower harvest in 2013/2014 compared to the year before. And due to the 2012 sharp drop in the United States Dollar (USD) exchange rate that led to increasing the local cost of imported goods and services, livestock, animal products and staple food crops (i.e. sorghum and millet) continuously deteriorated in terms of trade. Seed shortages and increased costs of agricultural inputs have reduced the overall area planted, with a consequence on the season's performances.

*The Agricultural R&D system needs to care for various sub-sectors*

In Sudan, crop production is practiced under three patterns: irrigated agriculture, semi-mechanized rain-fed agriculture, and the traditional rain-fed agriculture. The following is a brief on each of these patterns:

Large-scale irrigation (LSI) accounts for only nine percent of the cultivated land area (about 4 million feddans) and includes the main large agricultural

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[*] National Centre for Research (NCR), Khartoum, Sudan.

[**] UNESCO Regional Bureau for Sciences for the Arab States, Cairo, Egypt. Statement by the Co-Author: The ideas and opinions expressed in this article are those of the author and do not necessarily represent the views of UNESCO.

[1] FAO; Country Programming Framework (CPF) for the Republic of Sudan; CPF (2012--2016); pages 3-6; Report 2012, FAO

schemes, namely the Al Jazirah (Gezira) scheme, the New Halfa Scheme, the Ar Rahad Scheme, and the As Suki Scheme. Irrigated agriculture receives the lion's share of public agricultural spending, receiving up to 87% of all Agricultural Bank of Sudan funds, while the rain-fed subsectors contributed three-quarters of foreign exchange earnings from agricultural exports. The main crops of the irrigated sector include sugar, cotton, sorghum, groundnuts, wheat, vegetables, fruits, and green fodders. The bulk of the cotton crop is grown on the Gezira Scheme, which is one of the largest irrigation projects for agriculture in the world. It covers an area of 2.4 million feddans.[2]

Semi-mechanised rain-fed (SMR) farming is practiced by large farmers and companies with low rent leases granted by the federal government, allowing for a low-input/low-output system with limited concern for sustainable land management. Investors are planting according to market prices and availability of loans and subsidies. Semi-mechanised rain-fed farming causes rangeland encroachment and competes with pastoralists over traditional pastures and water sources, creating conflicts over access. Semi-mechanised rain-fed farming dominates over 14 million feddans[3], where both, commercial sorghum grain for food security and sesame for export are being produced. The SMR subsector mainly produces 40% of total sorghum and 62% of total sesame produce, about 90% of the sunflower harvest, and all the short-staple cotton produced in the country.

Traditional rain-fed (TR) farming covers around 24 million feddans and is practiced by family households with farms ranging from 2 to 120 feddans in size; the farming is for income and subsistence. Traditional rain-fed grain and oilseeds farming covers about 18 million feddans, growing about 95 percent of the country's millet, 38 percent of sorghum, 67 percent of groundnuts, and 38 percent of sesame. The subsector also grows gum Arabic, rosella and melon seeds for export.

Productivity in rain-fed cropping systems is declining due to land degradation, reduced soil fertility, traditional tillage practices, lack of seed quality control, and lack of knowledge on improved management practices. Use of improved seeds, zero tillage, and water harvesting in pilot projects have clearly demonstrated room for major improvements in crop yields. Other challenges facing rain-fed crop production include unpredictability of rainfall that typically allows only 40 to 80 percent of the area planted to be harvested, as well as pests and diseases (including locusts). There is an urgent need for households to diversify their sources of income and to add value to what they produce. The lack of accessible rural financial services and of appropriate extension services are also major impediments.

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[2] FAO; FAO/GIEWS Crop and Food Supply Assessment Mission to Sudan; pages 7-9; Special Report; January 2015.

[3] 1 feddan = 24 kirat = 60 metre × 70 metre = 4200 square metres ($m^2$) = 0.42 hectares = 1.038 acres

Livestock production (LP), being an important component of the traditional rain-fed sector, has consistently contributed a large share of the agricultural GDP (i.e., reaching 56 percent of agricultural exports in terms of value in 2012). In addition to meat, milk and skins, livestock is of value for transport and as a mobile source of capital and insurance. In 2013, the livestock population of Sudan was estimated at 105 million heads, consisting of sheep – 40 million; goats – 30 million; cattle – 30 million; and camels – five million.

Livestock is raised mostly by nomadic or semi-nomadic pastoralists practicing transhumance within Sudan or crossing borders into neighbouring countries. In addition to the difficulties faced by livestock herders in regard of land tenure, the customary practice of allowing nomads to graze crop residues after the harvest has mostly disappeared, and herders are expected to pay lease-holding tenants for grazing and access to water, especially in eastern Sudan. In general, livestock productivity is low – although information thereon is scattered and variable – due to diseases and parasites, suboptimal breeding, poor herd management practices, reduced access to traditional range resources, stock routes, crop residues, insufficient water sources, and overgrazing of remaining rangelands.

*The Agricultural R&D system in Sudan is confronted with complex environmental conditions*

Sudan – particularly the country's traditional rain-fed farming subsector – is prone to most of the risks, hazards and stresses known to mankind, including conflict and displacement, droughts, prolonged dry spells and erratic rainfall, floods, soaring food and agricultural input prices, transboundary plant and animal diseases and pests and wildfires, as well as conservative cultural practices, restricted access to land, water and pastures by smallholder farmers, agro-pastoralists and pastoralists, and land degradation and desertification. Key elements of a livelihood risk profile include: hazard identification and mapping (what and where?); seasonal calendars (when?); hazard impact on vulnerable groups (who?); coping capacity (how?); and risk ranking (prioritization?).

In terms of Science, Technology and Innovation (STI), Sudan has had its own Academy of Sciences since 2004, but otherwise has struggled to consolidate its science system over the past decade. One impediment is the loss of young talent to brain drain: between 2002 and 2014, Sudan lost more than 3,000 junior and senior researchers to migration, according to Jalal (2014). Researchers and university academic staff are drawn to neighbouring countries, mainly the Arabian Gulf Countries, Eritrea, and Ethiopia by the better pay. For the agricultural R&D subsector especially, a growing number of foreign trained senior scientists have been retiring during the last decade, a strong reason that could explain why the overall quality of Sudan's research work and research output are believed to be deteriorating. Loss of experienced, well qualified researchers, accompanied by their slow replacement, constitutes an important future challenge. In 2006 alone, the Agricultural Research Corporation (ARC) lost 42 PhD qualified senior scientists when the official retirement age of 60 years was enforced by the government. In 2009, ARC has employed only 134 PhD qualified FTE scientists compared to 196 FTEs in 2005.[4] Many more senior scientists are scheduled to retire in the coming years, so that a key strategic objective for ARC will be how to intensify recruitment to build the necessary critical mass of researchers to be able to fulfil its mandates. It is worth mentioning that the retirement age of university academic staff and of researchers in Sudan was raised in 2013 to 65 years.

In 2013, the Ministry of Science and Communication of Sudan embarked on a revision of its Science and Technology Policy (2003) with the technical assistance of UNESCO.[5] A number of consultation meetings were organized with high-level experts from around the world; these produced a series of recommendations, including those advocating for:

- The re-establishment of a Higher Council for Science and Technology, to be headed by the First Deputy President of the Republic, which would coordinate and oversee relevant institutions and research centres affiliated to various ministries, with the Ministry of Science and Communication acting as a rapporteur of the Council;
- The establishment of a fund to finance government research, with a focus on employing the proceeds of Awqaf and Zakat[6]; this should be combined with the adoption of legislation increasing the financial allocations to scientific research and other benefits, such as exemptions from some or all of customs duties on imported goods and equipment that support research; these measures should enable Gross Expenditures on Research and Development (GERD) to rise to 1% of GDP by 2021; and
- The establishment of an Observatory of STI indicators, with the technical support of UNESCO. UNESCO is supporting the development of a new Science, Technology and Innovation Policy for Sudan.[7]

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[4] Source: Gert-Jan Stads et al., Sudan, Agricultural R&D Indicators Factsheet, Agricultural Science and Technology Indicators, Agricultural Research Corporation (ARC), December 2013.

[5] Hassan, N., Science, Technology and Innovation (STI) Development in Selected African Countries – A UNESCO Experience Perspective, in this volume 20 of the African Development Perspectives Yearbook, Unit 1.

[6] Awqaf and Zakat: Islamic endowments (awqaf) and alms-giving (*zakat*) have been in existence for centuries in Islamic countries all over the world.

[7] See on the UNESCO-supported most recent STI activities in Sudan: http://www.unesco.org/new/en/natural-sciences/science-technology/sti-systems-and-governance/sti-policy-development/arab-states/sudan/

Similar to the case of Egypt, Sudan has a fairly diverse institutional framework, with a number of major research centres and institutes, such as the Agricultural Research Corporation (ARC), the Industrial Research and Consultancy Centre (IRCC), the Animal Resources Research Corporation (ARRC), the Sudanese Meteorology Authority (SMA), and the Social and Economic Research Bureau (SERB), which do not fall under the umbrella of the Ministry of Higher Education and Scientific Research, and hence this situation is causing a serious lack of coordination within the R&D platform.

This study aims to investigate the correlation between the work being done in Sudan in the four agricultural research components, namely crop breeding and improvement; pest management; husbandry practices; and organic farming, and the productivity of the Sudanese agricultural sector. The study will research whether frequent droughts coupled with government neglect of the agricultural sector for decades while focusing on oil production have led the sector to become a main contributor to an unprecedented level of poverty and food insecurity in Sudan, or whether the sector is lacking the necessary improved technologies and the science basis to foster higher levels of productivity that could match the growing food demand of an increasing population. The study will consider other impediments that are stifling innovations in the agricultural sector and the entrepreneurial agricultural culture in Sudan, such as a lack of adequate innovation policies, a lack of adequate "knowledge to economy" mechanisms, and general underfunding.

After the introduction in section 1, the section 2 presents an overview of agricultural research in Sudan. The section 3 is on the dissemination prospects of agricultural research results in Sudan. Section 4 gives as an example an analysis of the Action Plan for Promotion of Rice Production in Sudan in comparison with the Rice Production Campaign in Egypt. Section 5 concludes and gives policy recommendations.

## 2 Agricultural R&D in Sudan

### 2.1 Status and Structure of Agricultural R&D

Despite remarkable, oil- driven economic growth of about 8 percent per year during 2000–2010, Sudan has experienced unprecedented poverty and food insecurity over the past two decades, brought about, in part, by the poor and inconsistent performance of the agricultural sector, which employs roughly 80 percent of the country's work force. The increase in the frequency of droughts, the decline in rainfall and the desertification, together with the imminent risk of climatic change, is expected to worsen the current reduction in crop and food production and increase pest and pathogen outbreaks.

During the 1990s, agricultural research and development (R&D) investments in Sudan declined rapidly, but this trend was reversed later; the secession of South Sudan in 2011 again led to changes, although the national government was aware of the importance of agricultural R&D for agricultural development.[8] Various reforms have led to increased R&D investments between 2000 and 2008, resulting in an increase in agricultural R&D expenditures from a low of 37.3 million Sudanese pounds (or 34.6 million purchasing power parity (PPP) dollars) in 2000 to 53.6 million pounds (or 49.8 million PPP dollars) in 2008 (both in 2005 constant prices). This increase again showed a downturn to 32.3 million pounds (or 30 million PPP dollars) in 2012 (in 2005 constant prices). Agricultural R&D capacity levels in Sudan have also risen since the turn of the millennium. The country employed 962.5 full time equivalent (FTE) researchers in 2008 compared with only 724 FTE researchers in 2000, but again this increase showed a downturn to 932.8 fulltime equivalent (FTE) researchers in 2012. In 2012, and out of the 932.8 FTE researchers, Sudan had 344.3 researchers holding PhD degrees, 476.5 holding MSc degrees, and 112 researchers holding BSc degrees. Currently, most MSc and PhD training at ARC occurs locally. The ARC predominantly hires young BSc qualified research assistants and supports their educational training. Table 1 presents an overview of the agricultural R&D spending and of the number of FTE researchers by agency.

**Table 1: Overview of Agricultural R&D Spending and Research Staffing Levels**

| | **Percentage Spending** | **Total FTEs** |
|---|---|---|
| **Type of Agency** | **2008** | **2008** |
| ARC | 48.6 | 473 |
| ARRC | 18.6 | 199 |
| Other governments (2) | 2.4 | 38 |
| Higher Education (31) | 30.4 | 310 |
| **Total Public (35)** | **100%** | **1,020** |

**Source**: Gert-Jan Stads/Kamal El-Siddig, 2010, and Gert-Jan Stads et al. 2013. In brackets is the number of institutions.

[8] Gert-Jan Stads et al., Sudan, Agricultural R&D Indicators Factsheet, Agricultural Science and Technology Indicators, Agricultural Research Corporation (ARC), December 2013.

External training is limited to foreign scholarships sought independently by researchers. Many local universities accept post-graduate level ARC and ARRC staff as students. Traditionally, the German Academic Exchange Service (DAAD) has been the main provider of scholarships to agricultural scientists in Sudan. Each year, 12 Sudanese agricultural scientists are invited to apply for PhD grants at German universities. DAAD also sponsors local training. Ten scholarships for PhD training at the University of Gezira are issued each year. As of June 2010, ARC staff were undertaking training in Germany (3 researchers), China (5 researchers), Japan (3 researchers), and in Turkey and in Malaysia (1 researcher each). During the period 2007–2010, 27 scientists from the University of Khartoum's Faculty of Agriculture received scholarships for PhD training at German, Turkish, Japanese, and Italian universities.

Established in 1967, the Agricultural Research Corporation (ARC) is Sudan's principal agricultural research institute, and is charged with crop and forestry research, along with cross-cutting disciplinary research on soil and water management, crop protection, agricultural engineering, plant biotechnology, food technology, genetic resources, and socio-economics.[9] The ARC operates 22 research stations, 10 research centres, and 3 research units across the country. In 2012, ARC employed 432 FTE research staff compared to 445 FTE research staff in 2008. In 2001, the ARC was (temporarily) moved from the Ministry of Agriculture and Forestry (MAF) to the newly established Ministry of Science and Technology (MOST), which paved the way for a large influx of new scientists. However, many of the ARC's senior scientists subsequently retired, causing an overall decline in research staff levels, accompanied by a deterioration in qualification levels.

Established in 1995, the Animal Resources Research Corporation (ARRC) was mandated to merge all the research activities of existing public veterinary agencies, making it responsible for overseeing the Central Veterinary Research Laboratory (CVRL), the Animal Production Research Centre (APRC), the Fisheries Research Centre (FRC), the Wildlife Research Centre (WRC), and a network of 22 regional veterinary laboratories and animal production research stations. The ARRC is mainly charged with improving animal production research (including fisheries); and conducting research on wildlife within their ecosystems. Its research also focuses on identifying diseases and epidemics which negatively affect animal health, production, and export; this research work is associated with efforts

[9] Gert-Jan Stads and Kamal El-Siddig, Recent Development in Agricultural Research, Sudan Country Note, Agricultural Science and Technology Indicators, Agricultural Research Corporation (ARC), October 2010.

to improve disease control mechanisms. In 2012, ARRC employed 182 FTE research staff, up from 188 in 2008. Like ARC, ARRC was temporarily moved to MOST for the period 2001−2010.

The R&D work of the Hydrology Research Station (HRS) focuses on the conveyance systems of irrigation water, along with investigating issues of weed control and siltation in the irrigation canals of the Gezira Scheme. On the other hand, the National Centre for Research (NCR) oversees four units which conduct agricultural research: The Environment and Natural Resources Research Institute, the Medicinal and Aromatic Plants Research Institute, the Biotechnology and Genetic Engineering Corporation, and the Arid and Dry Lands Research Institute. Both, the HRS and the NCR conducted agricultural research activities, accounting for a combined 3.8 percent share of Sudan's total public agricultural R&D capacity. In 2012, the HRS and the NCR employed a total of 35 FTE researchers in agriculture respectively, compared to a total of 38 FTE researchers in 2008.

Thirty-one higher education agencies were identified which conduct agricultural R&D in Sudan. Combined, these institutions employ about 30 percent of the country's agricultural R&D FTE researchers with a staff totalling about 300-310 FTE researchers. The largest agencies in this category are the Faculty of Agriculture (about 53 FTE researchers) and the Faculty of Veterinary Medicine (about 35 FTE researchers) of the University of Khartoum, and the Faculty of Agricultural Sciences (about 30 FTE researchers) of the University of Gezira. The remaining higher education institutions each employ about 15 FTE researchers or less. Many of the 31 higher institutions were only established in the 1990s within the expansion of the higher education sector programme that took place in that decade. These institutions conduct poor quality agricultural research, which is mainly due to the lack of research management structures as well as the common underfunding issue that generally characterize R&D in Sudan. A new higher education sector strategy is requested to make these regional universities workable as agents of change in the respective regions.

Agricultural R&D performed by the private sector in Sudan is minimal. Many of the larger companies outsource their research to ARC, ARRC, and to the universities. The only private companies identified as carrying out their own R&D are the Kenana Sugarcane Company (KSC)[10] and the Guneid Sugar Company (GSC)[11], both of which conduct applied research to promote and maintain high sugarcane yields and to reduce production costs; these programmes are also well coordinated with ARC. In 2008, the KSC and the GSC were estimated to employ 13 and 4 FTE researchers, respectively. The reduction of production costs is an important matter as imported sugar is cheaper than the locally produced one. The

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[10] See: http://www.kenana.com/

[11] See on the Sugar Cane Research Centre (SCRC) at Guneid of Sudanese Sugar Co. LTD: http://sugarcaneres.sd/enn/researshers/drawad.htm

gap of 50% between local consumption and local production needs to be filled by imports.[12] In situations of increasing local sugar prices the government allows for imports.

The institutional structure of agricultural R&D in Sudan has changed little since the turn of the millennium. ARC and ARRC continue to dominate the country's agricultural R&D system, although the relative contribution of the higher education sector has gradually increased over the past two decades in terms of expenditures and staffing. Table 2 presents a comparison between the average percentage of FTE researchers that each crop area has received within the different research institutions in Sudan. It is worth noting that while ARC and ARRC are only dedicated to their area of specialty (either crop research or livestock research), the new research institutions have a variety of research work which is depending on the human resources and the research facilities available for them.
A strategy to coordinate and to specialize in research programmes is needed for all the research institutions. So far, the coordination is not working smoothly. Beside of the lack of coordination the underfunding of agricultural research in all these institutions is a major problem.

## 2.2 Imbalances of Agricultural R&D allocations to the Agriculture Sector in Sudan

The number of FTE researchers for each crop and livestock items depicted in figure 1 and figure 2 respectively resembles the whole research activities of the agricultural R&D sector in Sudan, but the irrigated sub-sector receives most of the R&D budget which is spent within the agriculture sector. And despite of over 25 million feddans of land which are cultivated in both, the semi-mechanized and the traditional rain-fed sub-sectors, little R&D activities and/or extension services are rendered to these two important sub-sectors. Therefore, the impact of R&D on the productivity of the agriculture sector is almost non-existent in regard of these two sub-sectors. In addition, most of the R&D activities undertaken within the irrigated sub-sector are implemented in the form of pilot projects, with no adequate and effective strategies on how or when to implement the outstanding research results that could substantively increase the productivity and solve serious problems within the agriculture sector. On the other hand, the performance of crop production in the irrigated, the semi-mechanized, and the traditional rain-fed farming sub-sectors has varied across those farming systems during the last decades and has largely been hit by various negative factors. The crop mix, the varieties, the yields, the quality, and the risks in rainfall, the credit supply and the marketing of produce

[12] See on the serious production situation of KSC: http://www.sudantribune.com/spip.php?article51689

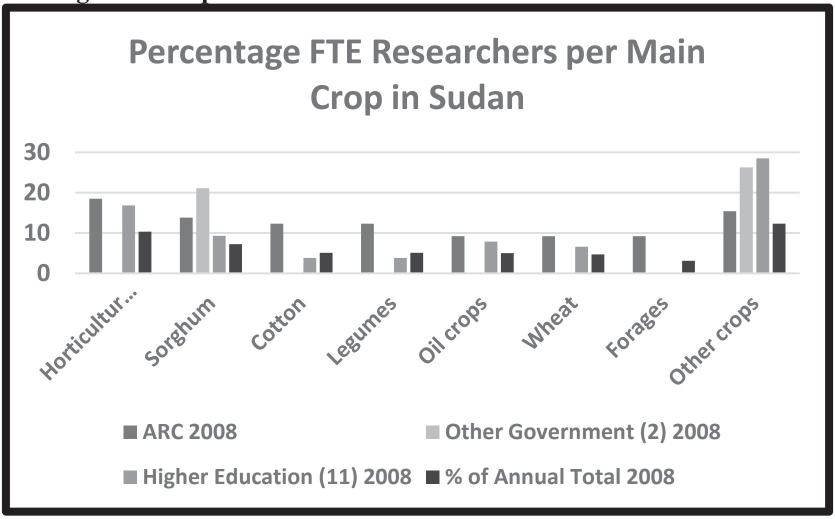
domestically and for exports are some of the factors which were responsible for the poor performance of the agricultural sector and which need a revision of policies and of research activities. So, the research strategy is not addressed to these major problems of the agricultural sector.

**Table 2: Crop and Livestock Research Focus by Major Items (Share in % of FTE Researchers)**

| | ARC | AARC | Other Government (2) | Higher Education (31) | % of Annual Total |
|---|---|---|---|---|---|
| **Crop Items** | **2008** | **2008** | **2008** | **2008** | **2008** |
| Horticulture crops | 18.5 | — | — | 16.8 | 10.3 |
| Sorghum | 13.8 | — | 21.1 | 9.3 | 7.2 |
| Cotton | 12.3 | — | — | 3.8 | 5.1 |
| Legumes | 12.3 | — | — | 3.8 | 5.1 |
| Oil crops | 9.2 | — | — | 7.9 | 5 |
| Wheat | 9.2 | — | — | 6.6 | 4.7 |
| Forages | 9.2 | — | — | — | 3.1 |
| Other crops | 15.4 | — | 26.3 | 28.5 | 12.3 |
| **Livestock Items** | **2008** | **2008** | **2008** | **2008** | **2008** |
| Sheep & Goats | — | 42.1 | 36.8 | 8.7 | 19.7 |
| Poultry | — | 21.1 | 15.8 | 5.8 | 10.2 |
| Beef | — | 21.1 | — | 4.2 | 9.6 |
| Other livestock | — | 15.8 | — | 4.6 | 7.6 |
| Total crop & livestock | 99.9 | 100.1 | 100 | 100 | 99.9 |

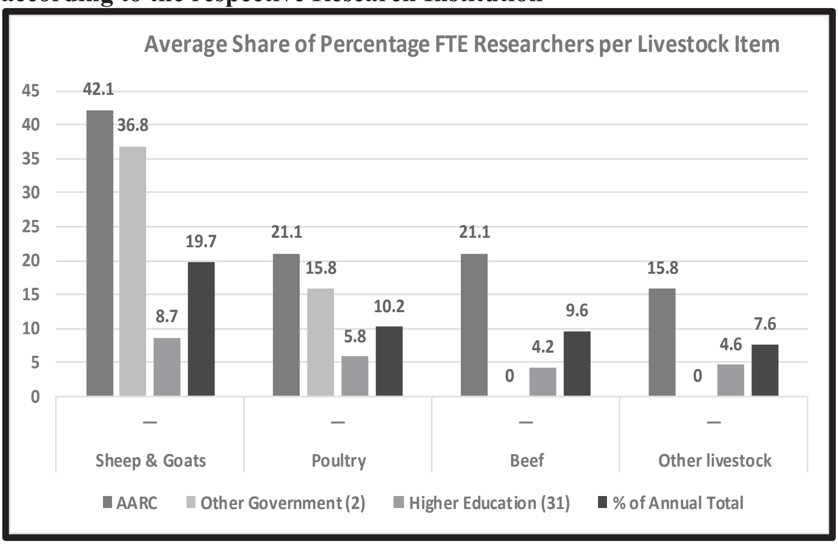
**Source**: Gert-Jan Stads/Kamal El-Siddig, 2010, and Gert-Jan Stads et al. 2013. In brackets is the number of institutions.

**Figure 1: Percentage of FTE Researchers per Main Crop in Sudan and according to the respective Research Institution**




**Source**: Gert-Jan Stads/Kamal El-Siddig, 2010, and Gert-Jan Stads et al. 2013

**Figure 2: Percentage of FTE Researchers per Livestock Item in Sudan and according to the respective Research Institution**




**Source**: Gert-Jan Stads/Kamal El-Siddig, 2010, and Gert-Jan Stads et al.2013

The agricultural system of Sudan is hence in dire need for an in-depth investigation for the identification of the main factors behind the existing weakness of these three sub-sectors, and this is so important as the major share in the crop-related GDP contribution is coming from the two rain-fed subsectors, the semi-mechanized and the traditional rain-fed sub-sectors. Similarly, the semi-mechanized farming subsector with a high crop growth rate but an extremely low share in the agricultural GDP requires an in-depth consideration. This is so because the semi-mechanized and the traditional rain-fed farming sector have almost the same size of area under cultivation but have a quite different share in the agricultural GDP. The livestock subsector, another subsector with a comparable share in the agricultural GDP as that of the crops subsector, is experiencing a sharp drop in its growth rate. The conflicts during droughts and civil wars affect negatively the normal flow of livestock from production to consumption areas. Forestry and fisheries are subsectors that are treated as marginal activities, although these two subsectors could both be sustainable sources of livelihoods in improving the income level of households in the rural areas and could as well reduce the high cost of living in the country (especially for low income groups). Improving the poor performance of all these sub-sectors could be an important vehicle to addressing the poverty reduction at large with reference to the 2030 Agenda SDG 1.[13] It is worth noting that while Sudan is generally self-sufficient in sorghum and millet, which are the main staple crops of the mass of the population, the biased economic growth in Sudan has disadvantaged the rural areas which accommodate large numbers of tenants and peasants in the country. It is hence the urban and modern agricultural spots that are benefitting from the agriculture sector, as most of the crops and livestock commercial benefits are accumulated in the metropolitan areas. So, the agricultural research activity is related to the irrigation sub-sector of agriculture and to activities which benefit urban and modern agricultural spots.

Nour (2013: p. 166) has concluded that the problems hindering R&D in Sudan are mainly the unavailability of sufficient finance and human resources in the field of R&D. In this essay, it is argued that the unavailability of funds and of human resources are only intermediate factors resulting from the inefficient design of the national R&D system and its associated operational processes within a specific economic sector. This is evident when analysing the Agriculture R&D System (ARDS) and its weak impact on the evolution of agricultural yields in Sudan. The agricultural R&D system is neither set to serve the priorities of the agricultural system in terms of optimal resources management, nor do its activities address the sector's priorities to improve on its yield and productivity. In addition, defining national R&D priorities in parallel to the needs assessment of a specific economic sector in many developing countries, including Sudan, is politically controlled at

[13] FAO; Country Programming Framework (CPF) for the Republic of Sudan; CPF (2012--2016); pages 3-6; Report 2012, FAO.

the highest political level instead of being a high-level political coordination process that fully engages the science community. This politically-controlled process also lacks the necessary coordination between the different government sectors and institutions to ensure coherence between the different strategies/policies of different economic sectors in any specific country. A good illustration for the mismatch that can take place is the fact that while the irrigated agriculture subsector receives the lion's share of public agricultural spending, receiving up to 87% of all finance from the Agricultural Bank of Sudan, the rainfed subsector is the subsector contributing three-quarters of foreign exchange earnings from agricultural exports.

The 2012 FAO Country Programming Framework (CPF) report (FAO 2012: pages 3-6) clearly indicated that the policies and the plans are always based on crash-programmes without long-term strategies that draw a road map into the future. The existing policy analyses and the planning institutions and bureaucratic machineries in the different line ministries are not involved in delivering reliable and dependable information for senior decision-making. The implementation of the government plans is always behind target dates as they are carried out by different non-coordinated ministries and government institutions. Moreover, resource utilization and transfers may be wasted because of duplicate mandates of those line ministries, as those resources transactions are not properly monitored or documented. The serious consequences of the frequent occurrences of drought and the low productivity of crop and livestock production are directly related to poor policy and mismanagement, to the prevailing land tenure system, and to the environmental and climatic changes which are associated with the deterioration of biodiversity.

The report (FAO 2012) also refers to the issues of Research and Technology Transfer (RTT) as critical prerequisites for agricultural growth, development, and enhanced productivity. But R&D have been largely overlooked for a long period in Sudan, while the role of the private sector in supporting this R&D has been completely absent. Most of the R&D activities undertaken by ARC and ARRC, and among other research institutes, have been focussed on implementing pilot projects, which have produced outstanding results that were never taken further for application in the field except for a few examples.

## 2.3 Tools for Effective Economic Development in the Agriculture Sector

The 2030 Agenda for Sustainable Development, together with the Addis Ababa Action (AAA) Agenda, successfully defines "What" needs to be done over the next fifteen years in terms of national priorities to achieve global sustainable development. While the scene is not currently promising in developing African countries, the 17 goals to achieve this 2030 agenda presents itself as a golden opportunity for these countries to catch up with the developed world and to leapfrog into

Inclusive Growth, if things were done in a scientific fashion. The Sustainable Development Goals (SDGs) problem is indeed a mathematically complex problem with a total of 17 goals and 194 objectives to achieve, a situation which would require mathematical modelling techniques, such as combinatorial optimization or the use of algorithms to solve. Even the attempt of addressing a set of inter-related 3-4 goals/objectives at a time in a specific country would mean that the full co-operation and coordination of at least 4-5 ministries within a national government is ensured; this is one matter that is rarely seen in developing countries, where for most of the time wasteful inter-agency rivalries are prevalent.

To successfully address a set of inter-related 3-4 goals/objectives as a multi-sectoral problem, the nexus approach would clearly articulate the practical benefits which an interdependent approach to these different sectors can offer - such as facilitating integrated planning and decision-making, informing the efficient allocation of resources between competing needs, and highlighting cross-sectional interactions that produce more synergy levels between these different actors. But what is more important is the modality of implementation and the successful utilization of strategic management tools, such as the Integrated Whole System Design (IWSD) Approach and the Dynamic Strategic Fit (DSF) Approach, which could be applied as a useful perspective for coherent planning across the different economic sectors, and which would lead to achieving the sought objectives. In this context, successful actions should be characterized with necessary pre-design conditions for attaining the associated objectives towards sustainable development in the targeted developing countries such as Sudan.

While the Water-Energy-Food Security (W-E-FS) Nexus is well known among the stakeholders of the related 3 sectors (water, energy, and agriculture), proposed is here the new Novel Technologies – Equal Partnership – Ensured Equity (NT-EP-EE) Nexus, which is another demonstration of power of the nexus approach, and which could be effectively achieved when science and the proper set of values are jointly utilized. With reference to the 2030 Agenda, the NT-EP-EE Nexus has been designed to address the practical implementation of programmes leading to the achievement of SDG 1 on poverty reduction, through food security achievement of SDG 2, then the provision of decent work and job opportunities (SDG 8), also building the necessary industry, innovation and infrastructure (SDG 9), especially in the rural impoverished areas, and creating new sustainable cities and communities (SDG 11), by developing the right partnerships and active engagements of all stakeholders and targeted groups alike in utilizing the participatory approach.

The proposed programme, which is to be implemented by using the NT-EP-EE Nexus approach, is basically a Special Purpose Vehicle (SPV) to encourage participation of thousands of rural poor farmers in a nationwide sustainable and commercial scaling up of crop and livestock production in the different regions of Sudan within the traditional and semi-mechanized rainfed subsectors. Through an affordable and innovative development programme that uses the latest cost-effective agricultural technologies, the project guarantees, through individually signed contracts with the involved farmers, the following benefits:

1. Free quality seeds and fertilizers for the contracted land size as a start-up package;
2. Free livestock for the contracted land size as a start-up package;
3. A Good Guarantee Buy-back of the harvest at a gratifying price compared with the international prices;
4. Splitting the financial return of the project into two portions, where the price of the harvest is paid to the farmers, while the investing cooperative(s) is/are satisfied with the financial return of selling the agro-industry products which are produced;
5. Access of farmers to the crucial know-how and the best practices that have been acquired in the field, particularly from the many implemented research pilot projects on enhanced productivity of the different crop and livestock products, and which is a must-have factor for the success of this project;
6. Signing contracts with the impoverished farmers will bring the sense of partnership and ownership into these farmers and hence will ensure a high success rate for the project.

In Sudan, cooperatives play an important role in development, especially in the distribution of essential consumer commodities.[14] By the early 1980s an estimated 4,000 primary cooperatives were fully developed, with 700,000 members and a turnover of at least US$ 50 million per year. The primary goal of many of these cooperatives in agriculture is it to gather small farmers, after paying registration fees, into groups that are held responsible for the repayment of loans and the costs of other services which are advanced to them by the Agricultural Bank of Sudan (ABoS). But the overall lack of modern inputs and the low level of technology in the traditional rain-fed agricultural subsector has resulted in a very inefficient utilization of land and labour when compared with other subsectors; the cooperatives under consideration involve neither forms of land nor labour pooling. There is hence a dire need for many of these farmers' organizations to be re-designed to introduce improved methods of farming, extension services, joint purchase of inputs, joint marketing, and the provision of other services to members, each of whom could operate a farm independently.

The potential of agricultural cooperatives to solve the problems of poor farmers and to be used as a vehicle for agricultural and rural development has been

[14] Muneer, Siddig EI Tayeb, Agricultural cooperatives as a means for agricultural development: The case of western Sudan small farmers' cooperatives; PhD Thesis, Iowa State University, 1989.

recognized by international development organizations and governments alike. Drawing from its own practical experience in rural and agricultural development, the International Fund for Agricultural Development (IFAD) has indicated (IFAD, 1984) that when poor farmers are organized into cohesive and functional groups they will benefit from the economies of scale, raise their bargaining power, be able to present their needs very clearly, be able to counter the pressures of those who exploit them, can provide collateral and will enforce financial discipline for repayments. Also, the Food and Agriculture Organization (FAO) argued that agricultural cooperatives enable farmers to assume an active role in determining, as well as in carrying out, measures to raise production and productivity; to provide means for distributing income more widely, and to promote social betterment. Furthermore, and since the 1980s, the FAO has been taking practical steps for adopting cooperatives as a development approach being relevant for small farmers, by disseminating experiences and models of cooperatives and of other rural organizations which are engaged in agricultural development to increase the agricultural production. In the case of Sudan, and although agricultural cooperatives in Western Sudan provided limited resources and services to farmers, they had a statistically significant positive effect on agricultural income. This has been achieved through its positive effect on modernization measures (extension service, use of pesticides, and hiring labour) and through the reduction of exploitation of farmers by others (interest rate paid, working as agricultural labourers for others, and marketing crops at low prices).

The six key components of a complex but integrated proposal to restructure the rain-fed sectors of agriculture in Sudan (see above) can benefit from these developmental contributions which agricultural cooperatives may offer. This proposal is intended to create a different source of livelihoods to most of the rural poor through a sustainable size of income-generating small enterprises (involving 25 feddans each). For each household involved in this business opportunity, living standards will be improved through the development of a complete Agro-politan Cooperative Community (ACC) system. The project will at the start include the plantation of 500,000 feddans with different varieties of essentials/strategic crops and livestock. The second phase starts with the gradual establishment of the required light agro-industry to process most of the harvest, allowing these rural areas to leap forward to agro-industry manufacturing. With an average of 25 feddans per farmer (household), the project will contract about 20,000 farmers/households to receive the seeds and fertilizers (free from the farmer's perspective), and the contract will clearly stipulate a buy-back guarantee for the harvested seeds at a special gratifying rate and with a gradual annual increase to encourage the famers for optimal productivity. The programme will also be committed to provide all other basic metropolitan services within the developed plantations cluster, i.e. schools, hospitals, and recreation facilities, project housing, and a well-equipped research institute, together with possibilities for other sources of income, e.g. breeding of cattle, sheep, poultry, and fish. In other words, the output of this programme will be the development of a complete Agro-politan Cooperative Business Cluster (ACBC).

### 2.4 The Agro-politan Cooperative Business Cluster (ACBC) Model

Intensifying agriculture and reaching food security is vital to ensure reversing the decline in agricultural capability in Sudan and increasing agricultural production through soil and plant selection, water provision, and fertilizers, along with opportunities to market food products.  Integrated farm management developed for utilization of crop varieties that need less pesticides, use less fertilizers, less water, and can adapt to climate change needs to be introduced. But again, the aim in achieving the above goal(s) should also be tied with the high importance of successfully offering food access to the poor, and which also means to emphasize the importance of increased food security through income and other entitlement enhancement opportunities.

Generally, a sound agricultural development is one that realizes both increases in agricultural production and justice in its distribution (that is, growth with equity). It is the equity part that seems to be difficult to achieve. There is hence a mandate to strategically devise an agriculture system that will make it possible to formulate a development strategy that can realize both growth and equity. The development of the Agro-politan Cooperative Business Cluster (ACBC) community, as suggested in this paper, will lead to newly enabled markets for many other businesses in the area. Growing of vegetables will be facilitated by using the intercropping techniques within the plantations. Markets of fertilizers, for animal feedstock, for poultry, and for fish will all be supported by the new Agro-politan Cooperative Business Cluster (ACBC) community. And with the creation of new market(s), many new businesses will boom in each of the targeted regions. In addition, the targeted population will enjoy their new stay in the Agro-politan Cooperative Business Cluster (ACBC) that will be built within the plantations to include schools, hospitals, recreation facilities, project housing, a research institute with needed extension facilities and services; and there will be other sources of income in the regions, e.g. breeding of cattle, sheep, poultry, and fish.

To successfully implement the ACBC programme, funding will be sought using the cooperative business venture model as the most suitable organizational strategy.[15] Cooperatives offer many advantages that make them suitable for solving problems such as the ones to link agriculture production, industry development and social inclusion. With or without federal assistance, and in the face of yet more federal cutbacks and troubled economies, like it is the case in Sudan, experiences

[15] See: Hassan 2003: pages 292-294

with the cooperative business model have offered many examples in which communities have assumed the responsibility of caring for the well-being of their constituents. Being owned by its members who have a direct voice in their management and practices, the cooperative model will be able to overcome an important obstacle facing many new businesses: the lack of start-up capital. Over the long run, the cooperative business model can further finance a range of education and advocacy activities, while creating income-generating and self-sustaining initiatives that can take many forms and will fulfil many functions to best suit each regional or local community needs. Using such a versatile business model, the ACBC project will be adaptable to the wide range of available agricultural technologies and will have the unique ability to address local/national social and economic issues. Cooperatives have the disadvantage of depending on its members participation and expertise, and if participation is inadequate this may result in unsophisticated management. The ACBC project is designed to address this issue by ensuring that quality management with proper corporate experience and expertise, including freelance extension officers, is hired to lead and to manage the different arms of the ACBC project.

Through the implementation of the new and innovative Agro-politan Cooperative Business Cluster (ACBC) development approach, all the rural agriculture plantations of a total of the 25+ million feddans within the rainfed two sub-sectors are to be re-designed into large agro-politan clusters. All stakeholders in those plantations deserve a high-quality living standard that ensures treating humans with dignity and respect, a basic human right for all. To that effect, the ACBC approach calls for the creation of agro-politan societies within and around these plantations, where all metropolitan services are guaranteed to all inhabitants. These services shall include hospitals, schools, project housing, recreational facilities, as well as various economic projects of importance for living standard, such as fish and dairy products production facilities. Furthermore, and depending on the location of the region(s) developed, touristic attractions could also be included in these development plans to ensure further sustainable wealth generation in those rural regions.

## 2.5 Raising the Employability of Human Resources and the Private Sector Engagement in STI

The low priority accorded by the government during the past decades to agriculture and natural resource conservation and development and the huge displacements of population caused by droughts and civil conflicts are among the main challenges facing Sudan today. And although Sudan is endowed with rich and diversified natural resources, due to poor management and unsustainable utilization of the resources occurrences like desertification, land degradation, water pollution, deforestation, violent conflicts, and deterioration of biodiversity have emerged as serious threats to its natural resources base. A paradigm shift in the way the agriculture sector, including its R&D arm, is being operated is a precondition to make the sector exhibit any positive development. Such a paradigm shift should of course consider all the shortcomings identified, including the critical mass requirements for any sector in both investment and human resources development terms.

Lemarchand (2016) indicated that any "system" needs a critical mass of experts and a critical mass of investment to start showing earnings, which means that STI activities must become visible within the economy. Below this minimum threshold, the empirical analysis of individual countries at global level shows little economic impact. When a country has around 1,200 FTE researchers per million inhabitants, this will scale a GERD investment of around 1% GDP. Below that threshold, research activities in any specific economic sector usually have little impact on the global economy of a given country. Other countries, for example Brazil or Argentina, did not reach those thresholds yet (Brazil needs more FTE researchers and Argentina needs more R&D investment). This is consistent with the fact that it takes decades of continuous investment on research activities by a given country to create qualified human resources and good laboratories (supply side) and to realize strong interactions with the "productive system of the country" (demand side). When countries have more than 1,200 FTE researchers per million inhabitants, the result is that the critical mass of researchers, who are working in the country, are spreading their knowledge into the society. One can also see that, when a country is reaching the 1,200 FTE researchers per million inhabitants' milestone, the shares of the private sector investment on STI activities also start to match the public-sector investment levels. Similarly, countries with a strong manufacturing base indicate that they have high FTE technicians.

Currently, most of the graduates from the different Faculties of Agriculture in Sudan are usually unable to land a job within their field of expertise, and hence are considered a wasted valuable resource. We suggest that these graduates are given the chance to sit for a qualifying examination towards a certification for an extension officer profession. Once certified, s/he could open his/her own business to offer extension services in the different regions where vast farming land has been cultivated within the three agricultural sub-sectors in the absence of dire-needed extension services.

These self-employed extension officers could prove useful as focal points for the State ministries of Agriculture and the different enterprises within the 500,000 feddans' ACBC project, in terms of implementing training for farmers to transfer the required knowledge and research findings to the field. Freelance extension officer professionals could also collect useful and vital field data for the different crops. Transferring knowledge to and from the field would then be facilitated and sustained. The fees charged by these businesses can be easily negotiated and justified against the estimated and resulting increase in crops' yield and productivity. In addition, these professionals could be of great support during any national crops campaign that the State government would annually implement. National Crops Campaigns are a successful practice that Egypt has been implementing since 2004 to effectively transfer and apply research results in the field for key crops. Once the ACBC project proves successful, its national replication could be extended to the remaining of the 25+ million feddans within the rainfed two sub-sectors. In addition, the private sector should be invited to support the building of the agro-industry infrastructure to ensure that Sudan leaps forward towards agro-business manufacturing. The newly formed cooperatives will then be able to develop the necessary partnerships with the national and international private sector.

## 3 Proven Practices for an Effective Dissemination of Research Results

To improve the dissemination of R&D results into the fields, the main agriculture research institutions, namely ARC, ARRC, two other government research institutions, and the 31 academic higher education institutions, should form a solid national research and extension network that expands beyond their individual walls to outreach for millions of poor farmers within the rain-fed sectors who are striving for a decent level of livelihood. Building on the infrastructure of the academic institutions within each State, these institutions could create and develop extension offices at municipalities' level, where they can train independent experts and technicians to prepare them for a certification for an extension officers' profession. This could be considered as a fast-track path to build up the necessary critical mass of agriculture expertise which is then equally-dispersed around Sudan. These independent self-employed officers would hence facilitate the knowledge transfer to and from the field and hence would build a new effective track for the dissemination of research results, allowing for sustained field feedback on the outcome of applying the research results on agriculture productivity.

Box 1 presents a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis which was carried out to evaluate the great potentials that lie within the current Agricultural R&D system in Sudan, and which could lead to unprecedented transfer levels of proven research output and of new and adapted technologies. These opportunities could be lumped into an institutional framework to form a robust national knowledge transfer and diffusion system as will be discussed in the following section.

**Box 1: SWOT Analysis for the Possible Upgrade of the Agricultural R&D System in Sudan**

| STRENGTHS | WEAKNESSES |
|---|---|
| ✓ Crop production is practiced under three patterns; large-scale irrigation (LSI), semi-mechanized rain-fed (SMR) agriculture, and the traditional rain-fed (TR) agriculture;<br>✓ The main crops of the irrigated sector (LSI) include sugar, cotton, sorghum, groundnuts, wheat, vegetables, fruits and green fodders;<br>✓ The bulk of the cotton crop is grown on the Gezira Scheme, which is one of the largest irrigation projects for agriculture in the world; it covers an area of 2.4 million feddans;<br>✓ SMR farming dominates over 14 million feddans, where both commercial sorghum grain for local food security and sesame for export are been produced;<br>✓ In the SMR subsector, the low rent leases which are granted by the federal government allow for a low-input/low-output system;<br>✓ TR agriculture covers around 24 million feddans and is practiced by family households, with farms ranging from about 5 to 120 feddans in size, and the farming is for income and subsistence;<br>✓ The country's agricultural R&D system is active in addressing national issues, through calls for proposals in pre-selected strategic economic priority sectors;<br>✓ There is a large depository of reports of implemented R&D projects. | ➢ In the SMR subsector, there is a limited concern for sustainable land management;<br>➢ Semi-mechanised rainfed farming (SMR) causes rangeland encroachment and competes with pastoralists over traditional pastures and water sources, creating conflicts over access to resources;<br>➢ Productivity in rainfed cropping systems is declining due to land degradation, reduced soil fertility, traditional tillage practices, lack of seed quality control, and lack of knowledge on improved management practices;<br>➢ Seed shortages and increased costs of agricultural inputs have reduced the overall area planted, with a consequence on the season's performances;<br>➢ Irrigated agriculture (LSI) receives the lion's share of public agricultural spending, receiving up to 87% of all Agricultural Bank of Sudan loans;<br>➢ The lack of accessible rural financial services and of appropriate extension services are also major impediments;<br>➢ Livestock productivity is low, mainly due to diseases and parasites, suboptimal breeding, poor herd management practices, reduced access to traditional range resources, stock routes, crop residues, insufficient water sources, and overgrazing of remaining rangelands. |

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| OPPORTUNITIES | THREATS |
|---|---|
| ✓ The SMR subsector produces 40% of total sorghum and 62% of total sesame produce, about 90% of the sunflower harvest, and all the short-staple cotton produced in the country;<br>✓ Traditional rainfed farming (TR) covers about 18 million feddans, growing about 95 percent of the country's millet, 38 percent of sorghum, 67 percent of the groundnuts, and 38 percent of sesame;<br>✓ The TR subsector also grows gum Arabic, and rosella and melon seeds for export;<br>✓ In the TR subsector the use of improved seeds, zero tillage, and water harvesting in pilot projects have clearly demonstrated room for major improvements in crop yields;<br>✓ The rainfed subsectors contributed three-quarters of foreign exchange earnings from agricultural exports;<br>✓ Livestock production, an important component of the traditional rainfed sector, has consistently contributed a large share of the agricultural GDP and the largest share of agriculture exports, i.e. 56 percent of agricultural exports in terms of value in 2012;<br>✓ There is room for a much better financial resources management between the three agricultural subsectors;<br>✓ The introduction of extension services to SMR and TR subsectors is important for increased productivity. | ➢ Over 70% of sorghum and millet are grown in rain-fed regions, so that food security is strongly correlated with the situation of the country's rain-fed agricultural subsector;<br>➢ Staple food crops (i.e. sorghum and millet) continuously deteriorated in terms of trade, so that food security is affected;<br>➢ Other challenges facing rain-fed crop production include unpredictability of rainfall that typically allows only 40 to 80 percent of the area planted to be harvested, but also pests and diseases (including locusts) are problems;<br>➢ Customary practices of allowing nomads to graze crop residues after the harvest have mostly disappeared, and herders are expected to pay lease-holding tenants for grazing and access to water, especially in eastern Sudan;<br>➢ Investors plant according to market prices and availability of loans and subsidies;<br>➢ The lack of FTE researchers in terms of a critical mass per crop item is a problem for increasing yields;<br>➢ There is an urgent need for farmers' households in the TR and SMR subsectors to diversify their sources of income and to add value to what they produce. |

**Source**: Authors

From the above SWOT analysis, it is obvious that there are great opportunities to increase the yields of the agricultural sector, taking into consideration the implementation of any or all of the following vital measures:

1. Devising a mechanism to allow the implementation of positive research outputs of pilot projects on a large scale in the open field. This could comprise the basis of a national campaign to improve productivity of every crop;

2. Setting up training and informal education for the farmers in the rain-fed sectors to address issues such as land degradation, reduced soil fertility, traditional tillage practices, lack of seed quality control, lack of knowledge on improved management practices, livestock diseases and parasites, suboptimal breeding, and poor herd management practices;
3. Introducing intensive extension services in the rain-fed subsectors;
4. Increasing the number of FTE researchers per crop by designing the proposed national campaigns for the different crops, utilizing all available knowledge and expertise within the many universities, i.e. faculty staff, and not just the researchers;
5. Increasing the financial support to the rain-fed subsectors by making available all necessary agricultural inputs, e.g. quality seeds and fertilizers, for the agricultural season of each crop and for all the farmers within the rainfed sub-sectors;
6. Introduction of drought-tolerant breed of seeds for all crops in the rain-fed subsectors to address the unpredictability of rainfall;
7. Introducing integrated pest control and insect control methods to reduce the use of pesticides to maintain grain quality, a clear environment, and to reduce the agricultural costs of the different crops;
8. Levelling the competition grounds for all crops by designing and implementing a national campaign for each crop, while providing subsidies and/or loans to all crops.

The implementation of experimental development research projects acts as a "win-win-win" situation for developing countries including Sudan, and should have priority over other types of research. Making use of the outcomes of the many nationally-applied research programs being executed over the last decades, experimental development in these research areas could lead to a great deal of new products and/or industrial processes developed and marketed, especially if implemented in collaboration with the private sector. This could turn into the development of a series of spin-off companies that could generate a substantive cash flow which could further support R&D activities. Implemented in the form of pilot projects, hands-on training and learning by doing for fresh college graduates would facilitate the building of a critical mass of experts in these selected fields, while also making use of national experts from the Diaspora. Pilot development research projects could also bring on board academia, the private sector, and various ministries for an unprecedented inter-agency coordination and collaboration. However, it is necessary to continuously move from pilot projects to a wider range and coverage of actions for disseminating research results for yield increases.

To build the national capabilities to be able to introduce many of the above measures within the agricultural sector, the proposed mechanism should allow for the utilization of the systems approach, which should facilitate an integrated approach towards addressing and solving all the identified problems within the agricultural sector. Successful experiences and best practices from around the subregion, the region, or the globe should be envisaged and considered for their adequacy and appropriate fit to be implemented at the national level. Since the early 1980s, there have been excellent success stories of implementing national campaigns for the agriculture of different crops in Egypt. In the following section, the example of the Egyptian national rice campaign is presented which was implemented during 2012; spectacular results were obtained in terms of transferring and localizing of R&D results in the field to improve on the agricultural yield of this crop. The Sudan can learn from these experiences.

## 3.1 Rice Cultivation in Sudan: Room for Improvement

National Crops Campaigns are a successful practice that Egypt has been implementing since 2004 to effectively transfer and apply research results in the field for various crops, including rice. It is argued that utilizing the modality of national crops campaigns will enhance crops cultivation in terms of harvested area, as well as it will increase the production yield (as depicted in table 3 below). This effect is mainly due to the transfer of R&D results to the field, through the process followed during the campaign as illustrated in the following subsections 3.2 to 3.7. Taking the rice crop as one example, it can be seen that - when the national rice campaigns started in Egypt in 2004 - the paddy rice harvested area, the paddy rice production, and the paddy rice yield have increased by 18%, 13%, and 3.3% consecutively during the period 2003-2007; Egypt has much higher rice yield values when compared to the same crop production in Sudan.

Before 2007 rice cultivation in Sudan was limited to Upland rice cultivation that is specifically compatible with areas that are completely inundated by floods during the rainy season. This is relevant for Sudan which has valleys and lowlands (Khiran) in, for example, the state of White Nile with an area of 350 million feddans that are flooded annually with the waters of the White Nile. This is in addition to many other sites in South Sudan which are famous for their production of rice, such as the Aweil region and the Malakal District. During the period 2008 – 2011 FAO, together with the Sudanese Ministry of Agriculture, commissioned a project for testing and selecting the best rice varieties that could be successfully cultivated in the different regions of Sudan. The project was initiated by using plots of 20 feddans each in several regions such as Eldueim and Medani. The results were then transferred to plots of 200 feddans as demonstration for extension. The project led to various rice varieties that are well suited for rain-fed agriculture of rice. Another important finding was that the weather conditions in Sudan favour two annual harvests of the rice product, and hence the country could be self-sufficient with its rice production, while rice could also become a main food item in the country. Since 2011, Sudan has been inviting investors, for example from Japan and Vietnam, to expand in rice cultivation in the country.

**Table 3: Comparison of Paddy Rice Production and Yield in Egypt and Sudan**

| Year | Sudan Rice Harvested Area ('000 Feddan) | Egypt Rice Harvested Area ('000 Feddan) | Sudan Paddy Rice Production ('000 t) | Egypt Paddy Rice Production ('000 t) | Sudan Paddy Rice Yield (t/Feddan) | Egypt Paddy Rice Yield (t/Feddan) |
|---|---|---|---|---|---|---|
| 2000 | 2.29 | 275.10 | 8.00 | 6100 | 0.62 | 3.91 |
| 2001 | 2.59 | 236.46 | 11.00 | 5500 | 0.75 | 4.10 |
| 2002 | 2.00 | 246.96 | 8.00 | 5700 | 0.71 | 4.07 |
| 2003 | 3.36 | 258.30 | 15.75 | 6000 | 0.83 | 4.10 |
| 2004 | 3.18 | 270.90 | 36.00 | 6351 | 2.00 | 4.14 |
| 2005 | 2.47 | 280.98 | 20.00 | 6362 | 1.43 | 3.99 |
| 2006 | 2.97 | 280.98 | 26.00 | 6743 | 1.54 | 4.23 |
| 2007 | 2.63 | 281.40 | 23.00 | 6746 | 1.55 | 4.23 |
| 2008 | 2.82 | 282.24 | 30.00 | 6772 | 1.87 | 4.23 |
| 2009 | 2.65 | 281.40 | 22.50 | 6614 | 1.50 | 4.15 |
| 2010 | 2.69 | 189.00 | 23.35 | 4493 | 1.53 | 4.19 |
| 2011 | 2.82 | 294.00 | 25.00 | 6159 | 1.56 | 3.70 |
| 2012 | NA | 323.40 | NA | 6775 | NA | 3.70 |
| 2013 | NA | 323.40 | NA | 6884 | NA | 3.75 |
| 2014 | 6.56 | 273.00 | 16.90 | 6565 | 0.45 | 4.24 |
| 2015 | NA | 273.00 | NA | 5797 | NA | 3.75 |
| 2016 | NA | 357.00 | NA | 6957 | NA | 3.44 |

**Source**: USDA Data on World Rice Statistics; Web Access: www.ricestat.irri.org:8080/wrs2/entrypoint.htm; query results generated on Oct 15, 2017 08:13.

In early 2012, Sudan announced the launch of its largest rice cultivation project in cooperation with Vietnam, in which Sudan plans to use Vietnamese expertise to achieve self-sufficiency in agricultural crops and to contribute to food security.[16] The Vietnamese - Sudanese programme coordinator Dr. Mohammed Adel Abdul Razzaq praised the Sudanese environment as suitable for the cultivation of crops, leading to acceptable economic returns as the area is free of epidemics and diseases. It was also noted that the earlier experience of rice cultivation in Sudan showed positive indicators, with the possibility of expanding the production of the crop after achieving a productivity level of 23 sacks per feddan. Table 3 above indicates that the paddy rice harvested area in 2014 was threefold the harvested area in 2011, yet the yield and the production have drastically dropped. This could be due to the different methodologies of measuring performance of rice cultivation that the Vietnamese and the Egyptians possess. The consultant to the programme,

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[16] See: http://www.middle-east-online.com/?id=125209

Professor Osman Al-Obeid, argued that there are prospects for business and investment in the future, indicating the efforts of the undertaken. Taking care of research and taking advantage of the Vietnamese - Sudanese programme may lead to the settlement of various crops, not only rice. He also pointed out that the project needs some specific regulations to attract investments, looking especially to attract local capital to achieve economic and social development in Sudan and the region. Since then, Vietnam and Sudan have been implementing effectively the programme on rice production and the development of other crops in Sudan.

An agreement was lately signed between the Ministry of Agriculture and Forestry and the Japan International Cooperation Agency (JICA), on the basis of a grant from the Japanese Government, to build capacity, training and promotion of aerial rice cultivation, focusing on the production, localization and development of local varieties of rice.[17] To support the rice cultivation in Sudan and the continuation of existing projects, the need was stressed to develop a strategic plan to grow rice as one of the strategic crops of the country which are reliable enough to increase national income. The project targets various states for expansion in rice cultivation, including the states of Sennar, White Nile, and River Nile, in collaboration with the Agricultural Research Corporation (ARC). A strengthening of ARC is important for realizing this strategy. What can Sudan learn from the Egyptian model of rice cultivation and the respective national campaign?

### 3.2 The National Rice Campaign of 2012 in Egypt

To cover the domestic consumption and to export about 300,000 to 500,000 tons of white rice to maintain Egypt's position in international markets, a national rice technology transfer and dissemination campaign plan for improving the rice crop and maintaining the high productivity which was achieved in the previous years was launched in 2012.[18] The Ministry of Water Resources and Irrigation identified the area for rice cultivation in 2012 at about 1,067 million feddans. This area is distributed among centres and some villages in eight governorates.

A Ministerial Decree No. 439 of 2012 was issued to form the National Campaign for the Promotion of Rice Crop 2012 season, which included the formation of the following committees:

- A Coordinating Committee: It included the Chairman of the Supervisory Committee (President of the Egyptian Agricultural Research Centre), the

[17] See: http://akhir-lahza.com/index.php/news/65-latest-news/603-2017-07-10-09-09-13

[18] The Egyptian Agriculture Research Centre (EARC); Report on the 2012 National Rice Campaign (Arabic); EARC, Cairo, Egypt 2013.

head of the National Campaign, the Campaign Vice-President, the Campaign Rapporteur, and the Head of the Technology Transfer and Extension Unit.

- A Supervisory Committee: It included agents of the Agricultural Research Centre, representatives of the Academy of Scientific Research and Technology, professors of the regional agricultural colleges, heads of the agricultural sectors for extension and services, directors of the institutes of crops, diseases, prevention, land, environment, water, agricultural engineering, extension and economy, heads of central administrations (seeds production, environment and land and water), and the heads of the members of the scientific supervision teams in the eight governorates where rice was cultivated.
- A Voluntary Support Initiative: It included researchers from the different disciplines, such as production, diseases, insects, and heads of the sectors, the directors of extension, production, and inspection and certification of seeds and control in the different governorates, rice specialists and advisers, and other supporting bodies in the ministry's sectors, the Agricultural Research Centre, and the agricultural directorates in the governorates.

So, a great number of experts was involved from the very beginning to share experiences and expertise.

## 3.3 The National Rice Campaign Objectives

According to the Egyptian authorities, the campaign objectives enlisted were as follows:

1. Increase the productivity from an average of 3.8 tons per feddan to 4.12 tons per feddan;
2. Firm commitment to the rice area determined by the Ministry of Water Resources and Irrigation (MWRI), by raising the farmers’ awareness on soil fertility, the spread of rice pests, the low productivity, and the lack of irrigation water for other summer crops;
3. Production of certified seeds, free of red and exotic rice, to grow 60% to 70% of the rice area in coordination with the central management of production;
4. Rationalizing the use of fertilizers of all kinds by adhering to the recommended fertilizer rates in the guidance leaflet and to the techniques of addition methods and their timing, and working to spread the techniques of using organic fertilizers instead of mineral fertilizers to reduce production costs;
5. Application of integrated pest control and insect control methods to reduce the use of pesticides to maintain grain quality and a clean environment and to reduce production costs;

6. Encouraging and increasing the productivity of rice through direct farming methods, which contribute to the provision of more irrigation water compared to the normal way of planting; promoting the cultivation of underage rice, which provides 25% less water consumption compared to other methods of rice cultivation, while also applying modern techniques to resist weeds in a timely manner before and after agriculture;
7. Working to confirm the success of cultivating selected and drought-tolerant breeds, which consume only about 5 thousand cubic meters of water, and which were derived through the rice research programme in the fields of farmers to gradually reduce the water consumption; the rice yield is expected to be about 30-50% higher than the current rates;
8. Confirmation of the promising research produced from the rice research programme of the Agricultural Research Centre and the universities to work on the transfer of modern rice cultivation techniques to farmer fields;
9. Promoting the quality of genetic purity of hybrid rice seeds to restore farmers' confidence to grow in the future and to reduce the rice area of normal varieties; this is equivalent to the expansion of hybrid rice cultivation to the advantage of hybrid rice in productivity by about 1 ton/feddan for traditional varieties;
10. Following up the provision of production requirements at the rates and dates recommended in coordination with the various sectors of the ministry.

To achieve the above important 10 objectives, the following work plan was adopted and implemented:

- The national campaign started in the first week of May 2012 by forming the scientific supervision teams to follow up on the rice crop in the eight governorates. During the period from planting nurseries to the harvest, scientific supervision teams were to weekly pass and inspect rice cultivation in the eight governorates, where each team head was asked to submit a report on the visitation days to the Vice President of the campaign, and to submit a monthly report to the Supervisory Committee.
- The head of the scientific team in the governorate shall report on the daily results on the state of the crop and the availability of production requirements (seeds, fertilizers, and pesticides), the irrigation situation, especially the places of bottlenecks, and solving the farmers' problems on the ground. During the meetings of the National Rice Campaign Supervisory Committee the focus is on taking the necessary recommendations to solve the problems and to overcome the obstacles facing the crop in all governorates, especially the problems with regard of lack of production requirements, diseases, and lack of water.

- The reports from the main rice provinces showed that the cultivation of nurseries started earlier due to the response of most farmers to the implementation of the recommendations of the ministry; training seminars and training programmes held in the governorates under the supervision of the Rice Research and Training Centre (RRTC) created awareness for the need of early agriculture and its benefits as follows:

a. Early agriculture by planting in the first three weeks of the month of May (1-20 May) will lead to an increase of yields ranging from crop to crop by 10-20%,
b. Results of research that was performed by the Rice Research Centre over the past decades show that early agriculture is compatible with the Egyptian environmental conditions,
c. Early farming is followed by early harvest in the last week of August or early September, enabling farmers to grow clover early and to get an early cut ration during the first month of November; at the national level, planting rice nurseries in a short period (May 1 to May 20) has led to a saving of 10-15% of the water needs of the rice crop, instead of planting long periods (from the second half of April until the first half of June).

- The Egyptian Government has spent a total of 800,000 pounds to implement the National Rice Campaign implemented in 2012. The return on investment was at the high rate of 1,000 pounds for each pound spent, which was mainly because of higher prices of rice for export.
- The national rice campaign's final report included the objectives, the work plan, the results and the achievements of the technology transfer component of the national rice crop campaign during the 2012 season, as indicated in the following section.

### 3.4 Components of technology transfer and extension services

The purpose of these components is to disseminate and to apply technical recommendations to increase rice productivity, as well as to disseminate the results of promising research from breeds, varieties and agricultural transactions, to control weeds and diseases, to train specialized rice instructors and farmers, and to guide them through extension seminars and field days during the different crop growth stages, and to work on solving the problems of rice farmers from agriculture to harvesting.

The Components' Goals:

1- Increasing the productivity of the rice crop by implementing the technical recommendations package for modern rice varieties in different agricultural methods and by solving the farmers' field problems on the ground.

2- Follow up the cases of damages in the fields of the farmers from agriculture to harvest, and to identify the problems facing them during the rice-growing season and to provide appropriate solutions to those problems, especially concerning the production requirements in accordance with the appropriate dates and quantities, by coordination with the scientific supervision teams during the rice growing season.
3- Training extension engineers, zero specialists and engineers to carry out experiments on rice cultivation technology, and to provide them with the latest information and technical recommendations for various types and methods of agriculture.
4- Confirming the results of research and modern techniques, especially in the areas of the development of modern varieties of early spice and hybrid rice and of the techniques of rationalization of water use by applying the best agricultural practices for each method of cultivation, as well as following up the implementation of the water compatibility system to reduce losses in irrigation water.

A total of 346 pilot fields were set up as follows:
a. A total of 301 pilot fields of 2-5 feddans each were set up with the main objective to provide guidance information and to implement technical recommendations for increasing rice yield, especially by introducing new short-lived varieties, high-productivity rice casks, and modern techniques when applying optimal agricultural practices to different farming methods. This aims to rationalize water use and to provide water for other summer crops, and for farmers, especially those in villages and communities away from major roads.
b. A total of 45 extended extension fields were set up as agricultural seasonal indicative fields with the objective to apply the technical recommendations in larger areas ranging from 10 to 40 feddans, so that the number of extension fields can be increased with the reduction of costs. There are no incentives for farmers other than obtaining guidance information so that they can swiftly apply the technical recommendations in their fields.
c. In addition, four experiments were conducted in 21 sites to confirm the results obtained from the research components of the national rice programme in the fields of the farmers, to train them in the development of guidance information for the dissemination and evaluation of modern techniques in the farmers' fields to confirm their superiority before such information is circulated at a broader scale.

These experiments included five areas:
1) Evaluation of the yield of modern varieties under the level of 69 kg recommended Azot/feddan;

2) Study the fertilizer needs of some modern rice cultivars, cultivated by the method of planting;
3) Weed control in rice;
4) Bacteria traps; and
5) Evaluation of irrigation systems.

Farmers of the experimental field were encouraged and financially supported by the government represented in the senior management of the national campaign, to assign some of their land as experimental field and to carry out the necessary preparations. During the 2012 campaign, these financial incentives were as follows:

1) All production requirements are free of charge for the farmers (seeds, fertilizers, pesticides) as they are financed by the government;
2) The cost of labour for the establishment of nurseries of 150 pounds per site was financed by the government;
3) The cost of labour for the operations on the experimental field of 200 pounds per site was financed by the government;
4) The harvest costs and the costs of yield estimates of 200 pounds per site were financed by the government.

All these costs need to be budgeted properly to make the experimental field work a successful undertaking. This is so in Egypt and also if the Sudan has plans for such a campaign.

### 3.5 Training Activities of the Technology Transfer Component Programme

1 - Training (Central Administration for Guidance):

a. The specialized rice instructors and the engineers of experiment implementation (135 trainees) were trained at the Rice Research and Training Centre in Sakha during the period from 9/5/2012 to 13/5/2012;

b. The specialized rice instructors (20 from each governorate) and the land engineers were trained through a training course during the last half of May 2012 and the first half of June 2012, which were held at the headquarters of the directorates of agriculture in the eight governorates.

2 - Seminars and field days (Guidance Central Administration):

a. General Seminars

In coordination with the Guidance Central Administration at the beginning of the planting season, 8 public symposiums were held in the governorates. The scientific team of the national campaign from the Rice Research Centre, representatives of the Guidance Central Administration, and senior officials of the directorates of agriculture participated.

b. Field Days (Guidance Central Administration)

200 days of field presence for training were carried out in four stages, depending on the stages of rice growth from agriculture to harvest to inform the village and farmers' guides about the technical recommendations of the rice crop: first, recommendations for the preparation of the nursery land as well as the permanent land; second, recommendations for irrigation, fertilization, and weed control, with regard of the most important insects and diseases affecting the rice crop; and third, recommendations for harvesting, storage and recycling of rice waste, in the extension centres and extension fields in the eight governorates, in coordination with the Guidance Central Administration, to be attended by the rice specialists and the farmers from the eight governorates.

The aim of the training project was to educate farmers on the methods of providing irrigation water, introducing new varieties and breeds, on the technical recommendations package for each variety, and on the method of cultivation in different stages of growth from agriculture to harvesting.

3 - Harvest Days in the Governorates (Central Administration for Guidance):

Eight days of training on harvesting were held in each governorate in the presence of senior officials of the departments of agriculture, researchers from the rice research centre, representatives of the central administration of agricultural extension, university professors, specialists, and farmers. The purpose was, when selecting extension fields and adjacent fields, to illustrate the role played by the national campaign and its programmes. The transfer of technology in the promotion of rice crop, through the provision of extension services for farms through various activities, including the establishment of extension fields, had the purpose to reduce the gap between yields by crops and fields of the farmers.

4 - Guidance (academic):

5,000 brochures were distributed, including all technical recommendations for rice yield increases, according to different agricultural methods, by considering optimal agricultural practices and water conservation techniques, weed control, disease resistance, insects control, harvesting, research, and storage.

### 3.6 Achievements of the 2012 National Campaign

The following statements indicate the main achievements of the 2012 National Rice Campaign:

1) Increasing the productivity of this year's yield to 4.15 tons/feddan, what is an increase of about 200 kg/feddan over the previous years; a return on the national economy of about 850 million pounds, an export of about one million tons of white rice, as well as revenue of one billion pounds, as

each ton brought thousand pounds, in addition to the export license fee of 75-150 pounds per ton.

2) Spreading and propagating the cultivation of new varieties of high productivity rice, with early perfusion and resistance to blight disease (Sakha 105 - Sakha 106) to replace Sakha 101 and Sakha 104 in addition to other varieties which have been circulated since 2001 to reduce the water consumption further from 25% to 30%, compared to the old items which were cancelled.
3) Decreasing the quantities of pesticides used for pest control due to the farmers' greater awareness and the training in the integrated pest control method, especially on this blight disease, as well as the decrease of areas infected with the disease to 31,000 feddans, representing 2% of the cultivated area, a decrease when compared to previous years.
4) Rationalizing the quantities of nitrogen fertilizer use by educating farmers not to overuse the nitrogen fertilizer, facilitated through the guidance fields and seminars.
5) Rationalizing the use of the quantities of irrigation water through the dissemination of irrigation water-saving technology, through seminars and training courses, especially the courses which have trained the guides on how to apply the water compatibility system, and thus to raise the environmental awareness and the water conservation habits of the farmers.
6) Encouraging the farmers to cultivate hybrid rice after restoring farmers' confidence in the genetic purity of the hybrid rice seed.
7) Increasing the areas cultivated by direct farming methods in all governorates, and thus reducing the production costs, providing irrigation water, and increasing the income of farmers.
8) Reducing the problems of water quality and the shortage of irrigation water in most cultivated areas through a process of continuous coordination with the central administration of water distribution and the scientific supervision teams.

### 3.7 Campaign Recommendations

Out of the results of the 2012 National Rice Campaign, various recommendations to further support the productivity of rice cultivation in Egypt could be listed as follows:

1) Increase the number of extension fields in proportion to the target area for cultivation and dissemination of rice cultivation technology in all governorates of rice cultivation.
2) Increase the certified seed varieties and reduce the amount of seed varieties suffering from blight disease.

3) Intensification of extension programmes (seminars, field days, and training), extension of the scientific supervision teams in the cultivated areas of North Delta in saline-affected areas, working on the low quality of irrigation water to increase the productivity of the farms, disseminating the technical recommendations being appropriate to the quality of these lands as well as the areas of agrarian reform, and increasing the awareness of the impact of irrigation water quality on public health.
4) Produce the production requirements according to the area cultivated early on the dates and at rates recommended before the start of the season.
5) Initiation of the seminars in early March to introduce farmers to the new varieties of rice cultivation before the beginning of the season.
6) Provision of land laser equipment and machinery to encourage the use of direct farming methods which could better contribute to the provision of irrigation water.
7) Coordinate with the central management of seeds in the distribution of varieties according to the policy to provide the appropriate category according to the conditions of the soil to be cultivated, especially of land affected by salinity in the regions of the North Delta.
8) Awareness and guidance on increasing the area cultivated with hybrid rice as a main objective to increase the national yield average and to reduce the area needed for rice cultivation.
9) Increasing the number of guidance fields for rationalization of water use and creating awareness of modern techniques of rice irrigation systems, depending on the methods of agriculture to work on water supply.
10) Increase farmers' participation in the implementation of the policy of classification and selection of modern techniques used in rice cultivation, and for the rationalization of water use through the tests of confirmation; and include the opinion of farmers on the system of cultivation and marketing of rice in the economic evaluation for the following year(s).

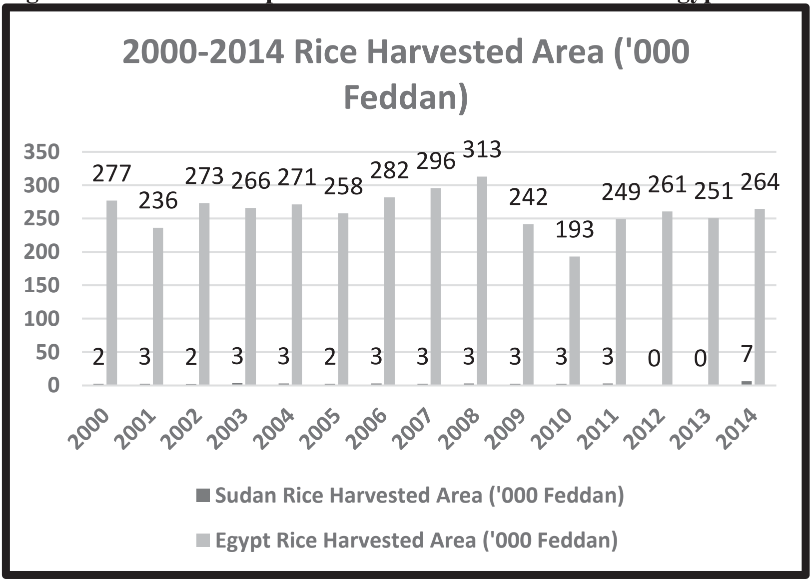
Egypt has undergone this campaign approach during 2004-2007 and then came back to it after 2011. The main reason was that the productivity and the yield were both falling behind. Of course, there are also numbers of uncontrollable factors that come into play to skew the results as in the case of 2014 when a heat wave hit Egypt and was reflected clearly in the results. So, the campaign approach is not always a straight forward answer. But having an increase of about 100,000 - 200,000 feddan plus having an increase of 700,000 tons of rice and a slight increase in the yields reveals that this approach is a successful one. But, in the case of Sudan the national crops campaign will have to be modified and augmented by other factors, such as increasing the extension services, improving farmers’ education and training opportunities, and raising the productivity values in the rainfed subsectors to much higher levels. This action would indeed make a huge difference for Sudan's food security and for poverty alleviation.

### 3.8 National Crops Campaigns: Lessons to be Learned in Sudan

From the 2012 national rice campaign that took place in Egypt, there are many lessons to be learned as well as many skills and technologies that could be transferred and localized in Sudan, not just for the rice crop but for all other priority crops such as sorghum, ground nuts, vegetables and fruits. Observing the results obtained through the 2012 national rice campaign in Egypt, it is argued that the national crops campaigns model as practiced in Egypt since 2004 could be successfully utilized as the vehicle to implement many of the innovative ideas described earlier in this paper, such as the Agro-Politian Cooperative Business Cluster (ACBC) model, the use of the Novel Technologies – Equal Partnership – Ensured Equity (NT-EP-EE) Nexus approach, and the creation of the required critical mass of extension officers for training local farmers to better serve the rain-fed subsectors in Sudan. The rain-fed subsectors have over 35 million feddan and could easily offer the required land expansion in terms of harvested areas for the priority crops in Sudan, such as rice, sorghum, groundnuts, vegetables and fruits. Figure 3 illustrates the wide gap that currently exists in the harvested area of rice in Sudan as compared to Egypt. In 2014, Egypt's harvested area totalled to 264.430 million feddan as compared to only 6.600 million feddan in the same year (less than 2.5%).

Figure 4 confirms the positive impact of the national crops campaigns on the production of many crops that Egypt has been practicing since 2004. In both periods 2003-2007 and 2011-2015, the paddy rice production recorded an increase of an additional 700,000 tons, while the yield in both periods also showed a rise from a low of 3.7 t/feddan to 4.24 t/feddan (see figure 5). The involvement of local farmers in hands-on training on new agriculture techniques and proper pesticides usage, through the implementation of the national crops campaigns in Egypt, is considered as the main factor that is reinforcing the transfer of knowledge between the research institutes and the field.

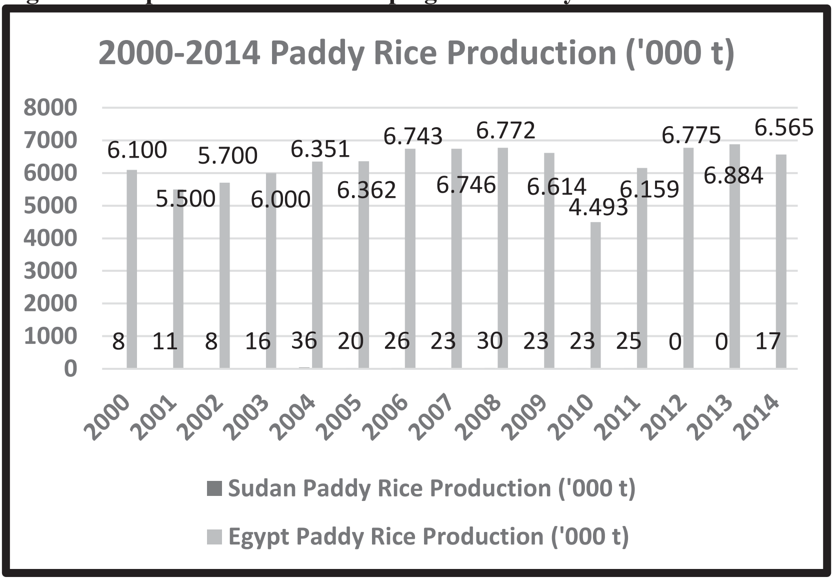
**Figure 3: The Wide Gap in Rice Harvested Area between Egypt and Sudan**




**Source**: USDA Data on World Rice Statistics; Website: www.ricestat.irri.org:8080/wrs2/entrypoint.htm

Again, Figure 4 and Figure 5 illustrate the wide gap that exists in the paddy rice production and yield between Sudan and Egypt for the same period. Sudan is keen to develop its agriculture capacities to ensure food security for its people and its neighbours in the region. The country leadership has many times declared that the agriculture sector is one of the main pillars for building up the country's wealth and economy. It is argued in this paper that utilizing a model such as the National Crops Campaigns as practiced in Egypt could be the necessary bridge to close the current wide gap in production and yield that Sudan is experiencing with many crops relative to Egypt. In the case of paddy rice, Sudan's yield was as low as 0.45 t/feddan in 2014 compared to 4.24 t/feddan in Egypt for the same year. Even during the last 14 years, during the period 2000-2014, the highest recorded paddy rice yield of 2.0 t/feddan in Sudan (still less than half of the yield recorded in Egypt for that year) occurred in the year 2004, and this yield was achieved within a FAO demonstration project that was utilizing Egyptian expertise in rice production. These are all indications of the vast opportunities that Sudan is offered in terms of bilateral and regional cooperation that could also lead to better regional integration, poverty eradication and sustainable development led by the agriculture sector.

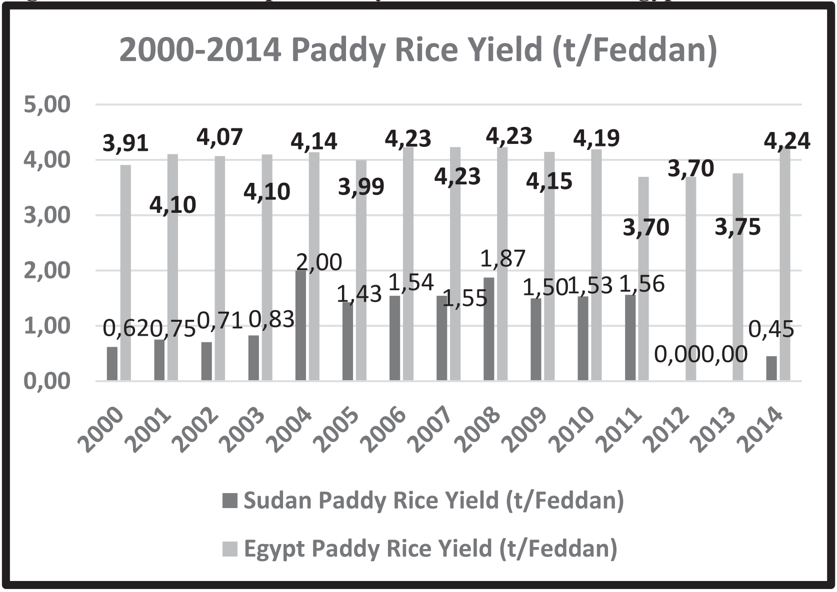
**Figure 4: Impact of National Campaigns on Paddy Rice Production**




**Source**: USDA Data on World Rice Statistics; Website: www.ricestat.irri.org:8080/wrs2/entrypoint.htm

It is important to review such success cases occurring at the regional level; in this case in Egypt. This is especially important now as Sudan needs to reorient its economic and agricultural policy quickly towards accelerating food production. It should be noted that the National Crops Campaigns approach might not immediately show substantial results in yield and/or productivity, but the process itself is important as it optimizes the information flows to and from the field and the research institutes regarding new R&D results. The cycle of experimentation takes a few years and of course not all results in regard of yield and/or productivity increases are according to expectations. But these National Crops Campaigns have important learning effects in the whole research and production chain and strong mobilizing effects at the level of farmers and agribusiness.

**Figure 5: The Wide Gap in Paddy Rice Yield between Egypt and Sudan**




**Source**: USDA Data on World Rice Statistics; Website: www.ric-estat.irri.org:8080/wrs2/entrypoint.htm

## 4 Conclusions and Policy Recommendations

The agricultural R&D system of Sudan is neither set to serve the priorities of the agricultural system in terms of optimal resources management, nor do its activities address the sector's priorities to improve on its yield and productivity. For the agriculture sector in general, the frequent occurrences of drought and the low productivity of crop production and livestock raising are directly related to poor policy and mismanagement, the land tenure system, and the environmental and climatic changes associated with the deterioration of biodiversity. In the previous sections, various new and innovative ideas were introduced to address the issues raised within the agriculture sector and its R&D arm. The main recommendations are listed below:

1. The 2030 development agenda presents itself as a golden opportunity for the developing countries, including Sudan, to catch up with the developed world and to leapfrog into Inclusive Growth, if things were done in a scientific fashion;
2. To successfully address the issues identified within the agriculture sector and its R&D arm, the Novel Technologies – Equal Partnership – Ensured

Equity (NT-EP-EE) Nexus approach should be implemented. The resulting program will allow the creation of a sustainable source of livelihoods to most of the rural poor through the development of Agro-politan Cooperative Business Clusters (ACBCs) in the two rain-fed sub-sectors;

3. Through the implementation of the new and innovative Agro-politan Cooperative Business Cluster (ACBC) development approach, the rural agriculture plantations of a total of 25+ million feddans within the two rain-fed two sub-sectors are to be re-designed into large agro-politan clusters. To that effect, the ACBC approach calls for the creation of agro-politan societies within and around these plantations, by using the historical experiences with cooperatives in Sudan, and creating an environment where all major metropolitan services are guaranteed to all inhabitants. These services shall include hospitals, schools, project housing, recreational facilities, as well as various economic projects, such as fish and dairy products production facilities;
4. It is necessary to devise a mechanism to allow the implementation of positive research outputs of pilot projects on a large scale in the open field. This could comprise the basis of a national campaign to improve the productivity of every crop. This could basically follow the example of the 2012 National Rice Campaign of Egypt;
5. Setting up training and informal education for the farmers in the rain-fed sectors to address issues such as land degradation, reduced soil fertility, traditional tillage practices, lack of seed quality control, lack of knowledge on improved management practices, livestock diseases and parasites, suboptimal breeding, and poor herd management practices;
6. Introducing intensive extension services in the rain-fed subsectors. To swiftly build up the critical mass of experts in the agriculture field, graduates of the Faculty of Agriculture are to be given the chance to sit for a qualifying examination towards a certification for an extension officer profession. Once certified, s/he could open his/her own (self-employment) business to offer extension services in the different regions where vast farming land is still been cultivated within the three agricultural subsectors in the absence of dire-needed extension services.
7. It is necessary to increase the number of FTE researchers per crop by designing the proposed national campaigns for the different crops and utilizing all available knowledge and expertise within the many universities, i.e. the faculty staff and not just the researchers;
8. Increasing the financial support to the rain-fed subsectors by making available all necessary agricultural inputs, e.g. quality seeds and fertilizers, for the agricultural season of each crop and for all farmers within the rain-fed sub-sectors. The ACBC project proposal calls for the utilization

of the cooperative business venture model as an effective means of funding enhanced agricultural activities in Sudan;

9. Introducing of drought-tolerant breeds of seeds for all crops in the rain-fed subsectors to address the unpredictability of rainfall;
10. Introducing integrated pest control and insect control methods to reduce the use of pesticides to maintain the grain quality, a clean environment, and to reduce the agricultural costs of the different crops;
11. Levelling the competition grounds for all crops by designing and implementing a national campaign for each crop, while providing subsidies and/or loans to all crops, utilizing the cooperative business venture model.
12. It is also necessary to improve the Agricultural Information and Documentation System, so that more knowledge is generated with ongoing projects, programmes and national campaigns.

A fundamental reform of the agricultural R&D system is requested by linking such researches also to large-scale testing programmes. Despite of a long history of agricultural research in Sudan, the neglect of large-scale testing of research results has affected negatively the overall outcomes of agricultural development. So, the problems are not only lack of financial and human resources, but also conceptual weaknesses along the research & development to production, distribution, processing and marketing chain.

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# Innovation in Industrial Firms in Sudan

**Samia Satti Osman Mohamed Nour**[1]

## 1 Introduction

The central theme of this paper focuses on enhancing the sectoral system of innovation in Sudan as a new case study of African countries. The core themes discussed in this paper examine the existence of innovations in selected industrial firms in Sudan. The paper investigates the size and intensity of innovations (product and process innovations), assesses the innovation capacity, evaluates the innovation and R&D strategies, considers the human resources (training) strategies, and investigates the main factors which are hindering and those which are contributing towards the promotion of innovation in the selected firms. It examines the intensity of cooperation between private firms, industry, universities, and the public sector for promoting innovation, R&D, and human resources development (training), and provides some recommendations for promoting innovation and strengthening the innovative capacity for industrial firms in Sudan.

Beginning with the general socio-economic characteristics of Sudan, data from the United Nations Development Programme (UNDP)'s Human Development Report/HDR (2015) illustrate the substantial gap between Sudan, Africa and the world regions in terms of standards of economic development, as measured by GDP per capita and the human development index (HDI). In general, Sudan is characterized by low standards of economic development together with high population numbers. According to the World Bank classification of economies, Sudan is classified among the lower middle-income economies. According to the classification of UNDP's HDI, the human development index for Sudan is classified among the world's low-human development index group and is lower than the average for world countries. Furthermore, average life expectancy, mean years of schooling, expected years of schooling, literacy rate and gross enrolment ratios in primary, secondary and tertiary education for Sudan fall behind the standard rates of the world regions, the advanced Asian countries, North Africa and South Africa (see the United Nations Development Programme's Human Development Report 2015).

Sudan was the largest country in Africa and the Arab world until 2011, when South Sudan separated as an independent country, following an independence referendum. Sudan is now the third-largest country in Africa (after Algeria and the

[1] Samia Satti Osman Mohamed Nour, Professor of Economics, University of Khartoum, Sudan, E-mail: samia_satti@hotmail.com; samiasatti@yahoo.com

Democratic Republic of Congo), and it is also the third largest country in the Arab world (after Algeria and Saudi Arabia). Data from Sudan's Central Bureau of Statistics (CBS) and the Central Bank of Sudan/CBS (2013) about the structure of Sudan's economy indicate the dominance of the services sector (49%, 46.7%) and the agricultural sector (30.6%, 30.6%), while there is a low share of the industrial sector (20.4%, 21.1%) in GDP in the years 2012 and 2013, respectively (See Central Bank of Sudan/CBS, 2013, p. 120). The Sudanese economy is a primary exports economy, that suffers from uncertainty and high fluctuation in economic growth, Sudan's economy has been characterized by a low GDP per capita income, and the rates of poverty, unemployment and inequality are high, with implications for the sharing of the benefits from natural resources. The independence of the South Sudan has had immediate negative fiscal and balance of payments implications for Sudan (because of the loss of the bulk of the oil production and of a great share of the export revenues, because about 75 percent of Sudan's oil revenues are generated from southern oil fields).[2] Thus, the prevailing economic structure in Sudan hinders the allocation of sufficient resources to support the development and promotion of effective sectoral systems of innovation.

The debate concerning the of availability of national innovation systems (NISs) in Sudan implies that despite the existence of the various subsystems forming the national innovation system, including education and higher education institutions, science and technology and research and development institutions, and information and communications technology institutions, the systematic relationship and interaction between these subsystems is very weak. Due to problems related to the availability of reliable information it is problematic for researches on Sudan to examine the role of central government ministries and local governments on STI policies, the role of human resources development agencies for employment of researchers and skilled persons, the role of clusters and techno-parks, and the role of multinational corporations (MNCs) and of foreign direct investment (FDI) for knowledge creation and transfer in Sudan. Because of these data limitations, various case studies of industrial are used to highlight the issue and the working of sectoral innovation systems in Sudan.

We examine four hypotheses: the first hypothesis is that innovations take place also in industrial firms in Sudan. This hypothesis implies the existence of both product and process innovations. The second hypothesis is that the degree, magnitude and intensity of innovations (product and process innovation) in Sudan is determined by firm size; this hypothesis implies that the performance, magnitude and intensity of innovations (product and process innovation) in Sudan increases

[2] See: International Monetary Fund/IMF (2013), "Sudan Interim Poverty Reduction Strategy Paper", IMF Country Report No. 13/318, October 2013; Web Access: http://www.imf.org/external/pubs/ft/scr/2013/cr13318.pdf, accessed on September 04, 2014, p. 6.

with firm size; it is assumed that the large size firms show better performance, magnitude and intensity of innovations (product and process innovation) compared to medium size firms working in the manufacturing industries in Sudan. The third hypothesis is that the industrial firms in Sudan are characterized by limited performance, magnitude and intensity of innovations (product and process innovation); it is assumed that the industrial firms have a limited innovation capacity, limited innovation and R&D strategies and limited human resources (training) strategies. The fourth hypothesis is that the inadequate availability of human resources and the inadequate availability of financial resources are the major constraints for innovations, for the development of local technologies, and for the adaptation of foreign imported technologies in the industrial manufacturing firms in Sudan. This hypothesis implies that the adequate provision of both human and financial resources is essential for the promotion of innovation and for the strengthening of the innovative capacity in industrial firms in Sudan.

As for the research methodology, this essay examines the existence of innovations in industrial firms in Sudan as a new case of Africa. This paper uses the conceptual framework of the innovation systems approach, the "sectoral innovation system" approach which is often used in the international literature; this approach uses the descriptive, comparative and analytical instruments to provide an empirical investigation of the still inadequate innovation performance of industrial firms in Sudan. The essay uses a combination of primary and secondary data. The secondary data were collected from online background information about the manufacturing industries in Sudan obtained from the Ministry of Industry and the Ministry of National Economy and Planning and the selected cases of large size firms which are included in this paper. The essay uses primary data based on a Firms Survey (March 2017) which were collected from two large size firms (chemical and food) and two medium size firms (metal and textile) operating in the manufacturing industry sector of Sudan. As usual in the studies on innovation, a broad definition of innovation is used, including both product and process innovations to investigate the performance, size and intensity of innovations (product and process innovations) in industrial firms in Sudan. Also, Science and Technology (S&T) input indicators, including Research and Development (R&D) and Full Time Equivalent Researcher (FTER) indicators, S&T output indicators (including patents), and human resources indicators (including training) are used. The Firms Survey is a very relevant source for the analysis in this essay since it provides a more recent set of information about several relevant indicators, including: R&D, FTER, patents, and training, allowing it to examine the innovation performance, the innovation strategies, and the human resources strategies of industrial firms in Sudan.

Different from previous studies in the Sudanese literature which focus on the analysis of science and technology indicators, innovation policy, intellectual property rights (IPRs), and interaction between technological change and skill development in Sudan (Nour 2005, 2012, 2013a, b, c, 2014, 2015) this study focuses on the sectoral system of innovation and on innovation in manufacturing industrial firms in Sudan using a combination of new primary and secondary data. Previous studies in the Sudanese literature based on a Firms Survey (2010) show that both skill and technology indicators, product and process innovations, the channels of technology transfer and their respective effects vary enormously across firms and seem to be determined by both firm size and industry level. Furthermore, it shows that skill levels, technology input-output indicators (R&D and patent), the provision of training (up-skilling), the dependence on imported technology, the degree of automation, and the use of sophisticated and advanced technology vary across firms and increase with firm size and industry level (see: Nour, 2013a). Different from previous studies in the Sudanese literature which focus on technology and innovation in manufacturing industrial firms in Sudan based on a firm survey (2010), this study examines innovation in manufacturing industrial firms in Sudan based on a recent firm survey (2017). Our analysis is intended to add new aspects to the existing few studies in the Sudanese literature and the few studies in the African literature on the sectoral system of innovation in the African countries (see: M'henni, 2010), particularly, because we provide a more recent analysis of the sectoral system of innovation in Sudan as a new case study of African countries. We fill the gap in the Sudanese and African literature by providing an empirical investigation of the characteristics, the incidence and the constraints of innovation in the manufacturing industrial firms in Sudan. This paper is useful from a policy perspective since it provides insights for stimulating new policies for enhancing innovation in manufacturing industrial firms in Sudan.

One major limitation of our analysis in this paper is related to the small coverage of firms in the survey; however, the firms included in the survey still provide useful insights for our purpose and analysis in this paper, mainly because of a special emphasis on training and human resources development for enhancing efficient systems of innovation. While we admit that it is also essential to investigate the sectoral system of innovation in all manufacturing industrial firms in Sudan, due to a time constraint the analysis will not cover all manufacturing industrial firms in Sudan; we leave that for more in-depth analysis in the future. Apart from these limitations the paper may be useful to improve the understanding of the characteristics, the incidence, and the constraints of innovation in industrial firms in Sudan.

The paper is organized as follows: Section 1 presents an introduction and briefly provides the background about the general socio-economic characteristics of the Sudan economy, and it shows the aims, the methodology and the structure of the study. Section 2 presents the conceptual framework and the literature review; this section examines the conceptual framework of "the sectoral innovation system" as discussed in the international literature. Section 3 examines the characteristics of the sectoral innovation system by looking at the cases of two large size manufacturing industrial firms working in Sudan; information is based on self-assessment by the companies. Section 4 explains the characteristics, the incidence, and the constraints of innovation in large and medium size manufacturing industrial firms working in Sudan; analysis is based on a Firms Survey. Finally, Section 5 provides the conclusions and policy recommendations.

## 2 Conceptual Framework and Literature Review: Sectoral Innovation Systems

Before examining the characteristics of the sectoral innovation systems (SISs) in Sudan, it is convenient to show briefly the definition of the concepts and to review the literature on sectoral innovation systems. The concept ‘innovation system’ has been widely used in the international literature to reflect the interrelationship between technical and institutional change. Several studies in the literature examine the concept of an "innovation system" from different points of view – focussing on regional, national and sectoral levels. There is a considerable debate in the literature about focussing the analysis of the innovation system at national rather than other scales. Much of the literature was addressing the national innovation system approach, while several studies also examine different approaches of the innovation systems, starting from the sectoral, local and regional perspectives. For instance, Malerba (2002) examines sectoral systems of innovation and production; he finds that the concept of the sectoral system of innovation and production provides a multidimensional, integrated and dynamic view of sectors. He finds that a sectoral system is a set of products and the set of agents carrying out market and non-market interactions for the creation, production, and sale of those products.[3] Moreover, Malerba, ed. (2004) examines the concept "sectoral systems of innovation", and analyses six major sectors in Europe. He finds that innovation and technological change show different rates, types and trajectories depending on the sector in which they take place. Agents and institutions of a sector all exert a major influence on innovation. He proposes the framework of the “sectoral systems of innovation” to analyse the innovation process, the factors affecting innovation, the relationship between innovation and industry dynamics, the changing boundaries and the transformation of sectors, and the determinants of the international performance of firms and countries in different sectors. He explains why innovation differs so greatly across industrial sectors and services. He finds that innovation in a sector is affected by three groups of variables: knowledge and technologies; actors

[3] See Malerba, F. (2002) "Sectoral systems of innovation and production": Research Policy: Volume 31, Issue 2, February 2002, pages 247–264.

and networks; and institutions. In addition to the general framework, he examines innovation in six major sectors in Europe, including pharmaceuticals and biotechnology, telecommunications equipment and services, chemicals, software, machine tools, and services.[4]

Malerba and Mani (2009) examine the actors, the structure, the features, the evolution, and the dynamics of the sectoral systems of innovation and production in developing countries. They show that processes of rapid growth are usually associated with specific sectors such as automobiles, electronics, or software, as well as with the transformation of traditional sectors such as agriculture and food. They show, however, that the variations across all these sectors in terms of structure and dynamics are so great that a full understanding of these differences is necessary if innovation is to be encouraged and growth sustained.[5] Malerba and Adams (2014) examine the sectoral systems of innovation and production and examine sectoral differences in innovation and in the organization of innovative activities. They argue that understanding the differences across sectors is relevant for any analysis that aims to foster innovation in firms. They propose a systemic, dynamic and evolutionary framework for the analysis of sectoral differences, and therefore: sectoral systems of innovation. Their framework attempts to broaden the scope of analysis for firm strategies aimed at innovation and growth and lays the bases for a more solid understanding of the dynamics of innovative activities both within and across existing sectoral boundaries. They find that, by using this framework, managers may better understand both the forces that drive innovative activities in their sectors and how these forces change over time.[6]

Most of the studies in the African literature investigate the systems of innovation at the national level (See: Djeflat, 2002; 2010), whereas few studies in the African literature examine the systems of innovation at the sectoral level (see: M'henni, 2010). For instance, M'henni (2010) presents an empirical study to examine the determinants of innovation at the Tunisian firm level. Based on an innovation survey on Tunisian firms, his results show the existence of an inverted "U" type relationship between the decision to innovate and two variables: "traditional" determinants of innovation which are the size of firms and the market structure. On the other hand, it seems that neither skills of workers nor public incentives were significant to explain the innovation behaviour of Tunisian firms. No studies on innovations in Sudan are yet available at the sectoral level.

[4] See Malerba, F. (2004) (ed.), "Sectoral Systems of Innovation: Concepts, Issues and Analyses of Six Major Sectors in Europe", Cambridge, Cambridge University Press, 2004.

[5] Malerba, F.; Mani, S. (2009) (eds.), "Sectoral Systems of Innovation and Production in Developing Countries: Actors, Structure and Evolution", Edward Elgar Publishing.

[6] See Malerba, F.; Adams, P. (2014), "Sectoral Systems of Innovation", in: Mark Dodgson, David M. Gann, and Nelson Phillips (eds.) (2014), "The Oxford Handbook of Innovation Management", Print Publication, January 2014

## 3 Characteristics of the sectoral innovation systems related to large size food industry firms in Sudan (Self-Assessment by the Companies)

This section examines the first research hypothesis concerning the existence of innovations in industrial firms in Sudan, by using relevant secondary data obtained from online information on the websites of two large size food manufacturing industrial firms in Sudan, namely Kenana Sugar Company (KSC) and DAL Group of Industries.[7] The information in this section is therefore based on self-assessment, presenting what the companies release in terms of information about their activities. This section focuses on the common characteristics of two large size food manufacturing industrial firms in Sudan, namely Kenana Sugar Company (KSC) and DAL (Daoud Abdel Latif) Group of Industries. It is shown that the large size industrial firms in Sudan, such as the Kenana Sugar Company (KSC) and the DAL Group of Industries share several common characteristics. For instance, they are characterized by large size business and by long-standing establishments which operate across many business units and sectors and produce diversified products with well recognized trademarks in the domestic market of Sudan. Also, they are characterized by the adoption of explicit policies to enhance Training and Research & Development (R&D). They are characterized by an increasing awareness about their commitment to contribute to economic and social development, human resources development, education, environment, and sustainable development.

*Large size business and long-standing establishments that produce diversified products and well recognized trademarks in Sudan*

Kenana Sugar Company (KSC) and DAL Group of Industries are large size firms in Sudan which are characterized by large size business and long-standing establishments that operate across many business units and sectors and produce diversified products with well recognized trademarks in the domestic market in Sudan.

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[7] In this paper the Section 3 covers two large size (food) industrial firms in Sudan (KSC and DAL Group), whereas Section 4 covers two other (different) large-size (food and chemical) and medium-size (metal and textile) industrial firms which were included in the Firms Survey (2017). Due to lack of adequate background information this section did not include the profiles of the two large-size (food and chemical) industrial firms and the two medium-size (metal and textile) industrial firms covered in the Firms Survey (2017), and covered in Section 4. It would be good to give also the profiles of the two large-size firms and the two medium-size firms already covered in the Firms Survey (2017) in section 3, also in the form of a self-assessment by the firms. But it would not be possible to do that mainly due to lack of adequate secondary data and information about these firms.

For instance, the history behind DAL Food and Beverages Industries (one company of DAL Group of Industries) is dating back to its beginnings in 1951 as an engineering dealership under the name Sayer & Colley. DAL's history is rich with success stories, out of which DAL Group of Industries has emerged as Sudan's largest and most diversified privately-owned conglomerate which operates across many business sectors and industries, including agriculture, automotive, earth moving and construction, education, energy, food and beverages, health care, industrial gases and mining, and real estate, and it offers a wide range of products and services to businesses and consumers. DAL Agriculture (established in 1984) is one of the bedrocks of the DAL Group of Industries, supplying and sourcing much of the raw materials for DAL Food Industries from alfalfa[8] and sorghum to milk. In 1996 the Sayga Investment Company was established and has grown since then to become the foremost flour milling and packaging company in Sudan, with a leading position in the supply of flour to bakeries and a dominant position in supplying packaged flour, sorghum and pasta to consumers. In 1997 the DAL Dairy Factory was established to pioneer the provision of pasteurised fresh milk and ultra-heat-treated milk in Sudan, and eventually became the leading dairy company in the country. DAL Food Industries was then set up in 2002 to produce, pack and distribute Coca-Cola products. It also incorporates the leading water brand Safia, and an array of fruit juices. In December 2013, the four DAL Group companies operating in agriculture, dairy, flour and grains, and soft drinks merged to form the agri-food company. Since its establishment, the company has operated to international standard and has grown its own brands to be the leader in most of the industries they operate in, and it has positively contributed to the success and growth of each of their partners' brands.[9]

The roots of the Kenana Sugar Company (KSC) go back to the 1970s when Sudan was identified as one of the countries that could potentially help in meeting the food supply shortage in the Arab world. This is because Sudan is blessed with resources such as vast tracts of land suitable for cultivation and agricultural production, abundant water supply from the Nile, the Blue Nile and the White Nile, bountiful rainfall and huge reservoirs of underground water. All this pledged on turning Sudan into the Arab world's breadbasket to achieve food security. In June 1972, the Sugar Agreement was signed between the Government of Sudan and Lonrho Limited to do a feasibility study on the establishment of a large sugar company. The Founders' Agreement was signed in February 1975 to form the company with a crushing capacity of 17,000 MT of cane per day to produce 300,000 MT of sugar by 1978-79. The Government allocated 168,000 acres of land at a concessional price, and granted customs and taxation concessions to the company.

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[8] See: https://en.wikipedia.org/wiki/Alfalfa

[9] See on the DAL Group of Companies: http://www.dalgroup.com/index.php/food-beverages-industry/, accessed on 12 February 2017.

Since its establishment the KSC has established several business units and departments to support and to facilitate an increasing quantity and an improving quality of a wide range of products and services, including food products, biofuel, equipment manufacturing, engineering and agricultural services. For instance, initially, the Kenana Engineering and Manufacturing (KEM) Business Unit was commissioned in 1986 to produce locally sugar industry equipment and spare parts. Activities include specialized workshops and foundry[10], capable of meeting rehabilitation and fabrication requirements of the industry; activities also include specialized expertise in industrial plants erection. The main activities include specialised agricultural farm equipment and implements, the fabrication of a wide range of equipment, industrial plants erection, and the installation of various spare parts. Next, the Farm Produce Business Unit was commissioned in 2003. It leverages on Kenana quality animal feed and farming infrastructure. It is part of Kenana's innovative vision to produce low cost, high quality food based on integrated modern farming, and it consists of five main activities: milk, poultry, fattening, horticulture, and forestry. Each activity is managed as a separate profit centre. Next, the Animal Feed Business Unit was commissioned in 2004. It uses sugar byproducts, molasses and bagasse as main ingredients. The unit is a fully computerized plant with high flexibility to cater for customized specifications. It produces complete animal feed diets without the need for supplements. The Ethanol Business Unit is the first bio-ethanol plan in Sudan which was commissioned in 2009. It produces high-value added products with high export potential. The Unit operates a modern, technologically advanced, and fully computerized plant; it uses molasses as feedstock with flexibility to use juice. The production capacity is estimated at 200,000 Litres/day = 65 Million Litres/year). The Certified Seeds Business Unit was commissioned in 2009 to produce certified seeds for several crops with emphasis on grains and oilseeds. The Certified Seeds Business Unit operates a multi-location certified seeds production using up-to-date methods, techniques, and specialised resources. The Unit ensures high yields for all agricultural schemes by using certified seeds. It meets an increasing demand for certified seeds driven by the expansion of agricultural schemes across Sudan. Its products include certified seeds of peanut, sorghum, sunflower, corn, millet, and others.

In addition, the Quality Control and Assurance Department is responsible for the provision of its services, the provision of the quality control, and for the quality assurance to all business units, departments and subsidiaries of the company, all company inputs, products, services, and processes. It is also responsible for controlling the central laboratories and for issuing of all export certificates for all products. The Quality Control and Assurance Department consists of two main sections, the Quality Control section and the Quality Assurance section. The Quality Control section is responsible for the quality of all Kenana products and inputs,

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[10] Foundry: Microelectronic activities which are related to manufacturing

and for the supervision of several specialized laboratories (Sugar lab, Animal Feed lab, Ethanol lab, Dairy products lab, Water treatment lab, Civil works lab, Foundry lab, Fuel and Petroleum lab, Special analysis lab, and the Microbiology lab). The Quality Control section ensures that each lab is equipped with well trained staff and with the proper instruments to serve its goals. The Quality Assurance section is responsible for benchmarking and monitoring of every process, activity and service in all the business units and departments. The Quality Control and Assurance Department is powered with more than 30 graduates of different specializations to cover all the activities. Moreover, the Research & Development (R&D) Department plays a crucial role in ensuring the sustainability of the businesses. R&D was established well before the commissioning of the sugar factory in 1974 to conduct and promote applied research on different disciplines, including: breeding, agronomy, weed science, pathology and entomology, irrigation, crop monitoring, management of industrial by-products, and agricultural mechanization. [11]

*Contribution to economic and social development and sustainability*

KSC and the DAL Group, the large size innovative firms in Sudan considered in this essay, are characterized by its increasing awareness and commitment to contribute to economic, social and sustainable development. For instance, concerning the contribution to economic development KSC and DAL Group provide diversified products to satisfy the demand for local market consumption in Sudan. This is important as the Food Industry in Sudan is characterized by focusing on basic, staple foods in a market where many products are still sold in loose, unbranded form bulk packaging. Companies such as DAL Food have been at the forefront of introducing improved production and distribution facilities for staples such as Flour, Water, Dairy, Sugar and Pasta, contributing to rising levels of quality and reliability for a nation where food is central to their daily lives. DAL Food is Sudan's largest and most diverse food company, focused on providing high quality, reliable, affordable, basic, staple foods and drinks products for the mass market consumption in Sudan. For instance, DAL food produces 200,000 Yoghurt Cups Daily; and, the company has trained more than 60,000 people across the country in baking and bread making.[12]

[11] See for the Kenana Sugar Company (KSC): http://www.kenana.com/pagecontents.aspx?pageid=13, http://www.kenana.com/pagecontents.aspx?pageid=14 , http://www.kenana.com/pagecontents.aspx?pageid=15 , http://www.kenana.com/pagecontents.aspx?pageid=43 , http://www.kenana.com/pagecontents.aspx?pageid=16 , http://www.kenana.com/pagecontents.aspx?pageid=47 , accessed 18 April 2016; see also on the history of KSC: http://www.kenana.com/pagecontents.aspx?pageid=1 , accessed on 18 April 2016.

[12] See http://www.dalgroup.com/index.php/food-beverages-industry/, accessed on 12 February 2017.

Since its establishment, KSC is increasing quantity produced and improving the quality of a wide range of products and services, including food products, bio-fuel, equipment manufacturing, engineering and agricultural services, to meet the demand for the domestic market in Sudan. The structure of the markets implies that the whole product of the KEM Business Unit and the whole product of the Farm Produce Business Unit (including milk, poultry, fattening, horticulture, and forestry) are directed to meet the demand of domestic markets (100%). The majority and more than two thirds of the product of the Certified Seeds Business Unit (70%) are directed to meet the demand of the domestic markets, whereas nearly one third of the product (30%) is directed to meet the demand of foreign markets. The structure of the markets implies that half of the product of the Animal Feed Business Unit (50%) is directed to meet the demand of domestic markets, whereas the other half of the product is produced to meet the demand of foreign markets (50%). The majority and nearly nine-tenth of the product of the Ethanol Business Unit, producing 200,000L/day = 65 Million L/year, is directed for export to meet the demand of foreign markets (90%), whereas a small part and about one tenth of the product is produced to meet the demand for domestic markets (10%).[13] This implies that KSC contributes to exports since the Ethanol Business Unit directs the majority and nearly nine-tenth of the product to foreign markets (90%).

In addition, KSC and DAL Group provide considerable employment opportunities. For instance, in terms of job provision, as the largest integrated and diversified sugar factory, the farm and the factory are under one management, creating a huge demand for labour, for both agriculture and agro-industry activities. KSC provides jobs and employs more than 16,000 people from unskilled labour to technicians and engineers in all different work fields and specialties (i.e. agronomists, mechanical, electrical staff, civil engineers, research staff, accountants, doctors, store keepers, and administrators). As for the contribution to social development, Kenana Sugar Company (KSC) is concerned about sustainability. For instance, in terms of social sustainability, since the social dimension is an integral part of the sugar industry, KSC represents an effective model of rural development with proven success in offering basic infrastructure and services to the growing community. These services are provided free of charge, including education, electricity, treated water, roads, transport and healthcare. KSC started the social development activities long before the factory's establishment. KSC is committed towards the development of social sustainability beyond the factory area reaching out to neighbouring villages, as KSC provides to these villages jobs, social ser-

[13] See: http://www.kenana.com/pagecontents.aspx?pageid=13, http://www.kenana.com/pagecontents.aspx?pageid=14, http://www.kenana.com/pagecontents.aspx?pageid=15, http://www.kenana.com/pagecontents.aspx?pageid=43, accessed 18 April 2016.

vices, water treatment plants, electric power supply and disruption, and other social services. Due to the rapidly growing nature of the sugar industry, remote large areas of land were required for growing sugar cane; therefore, in these remote villages all social services needed by employees were to be provided, including housing, potable water supply, power supply, network connections, education, medical health care, clubs, and mosques. In addition, KSC has developed six agricultural headquarter villages and provides houses, water, electric supply, schools and clinics to those villages.

Furthermore, in terms of provision of water treatment plants, KSC provided water treatment plants for four surrounding villages with an overall population of 100,000 persons and a daily total production of 3,000 M3 of treated water. All operating expenses are covered by KSC. In addition, KSC provided treated water distribution points for other remote areas, which are supervised by the government authorities. Moreover, in terms of the provision of electric power supply and disruption, KSC supplies 3.5 MW of electricity to all KSC's townships, and 1.5 MW of electricity to area villages. KSC also provides other social service premises, like schools, clubs, mosques, hospitals and clinics. In terms of other social services, KSC has built mosques, clubs, and a football stadium; in addition, KSC maintains and manages all those facilities. KSC's participation in supporting social development and activities at the national level have always been recognized by the society.

*Enhancing human development, education and human resources development*

In addition, KSC and DAL Group emphasize their commitment to corporate social responsibility (CSR) through contributions to human development by enhancing education and human resources development. For instance, concerning contribution to human resources development, the DAL Group has initiated the DAL Graduate Development Programme as a fundamental component of the strategic initiatives identified to support the Group's ambitious growth plan. The Graduate Development Programme plays an important role in building a viable leadership pipeline for the company organisation in line with DAL Group's overall talent management strategy. It aims to attract, develop and retain high potential distinguished graduates who have obtained high academic standards from recognised universities (locally and abroad) and who have not more than two years of work experience. The design of this programme takes the "graduate trainees" through a rigorous but structured selection process which includes also psychometric assessments, an English language proficiency test, interviews, and formal presentations. Subsequently, successful candidates are provided with the opportunity to begin and to progress their careers with the DAL Group Companies in an environment that fosters professional development through training, coaching, mentoring, on-the-job exposures, and project participation. There are currently two tracks on the programme; first, a general graduate development programme and second, a finance graduate development programme. Regarding the contribution to education, the DAL Group has established the Khartoum International Community School (2004) to provide a first class, international education to the local and international communities in Khartoum. In terms of education, prior to KSC's establishment in 1975 there were no schools in the Kenana area, so that people were obliged to send students to Kosti town (40 km from Kenana). In 1984 the construction of schools started at Kenana. The number of schools and the number of students has increased considerably (see table 1). KSC has a far-reaching impact on the area. KSC has participated in developing the surrounding villages by the construction of two primary schools at Abutoggaba and two primary schools at Elhejra, in addition to establishing two new classes and the complete rehabilitation of the primary school at Fangoga.

**Table 1: The number of schools and the number of students supported by Kenana Sugar Company (1980-2010)**

| | **Number of Schools** | | | **Number of Students** | | |
|---|---|---|---|---|---|---|
| **Year** | **1980** | **1990** | **2010** | **1980** | **1990** | **2010** |
| Kindergarten schools | 5 | 10 | 23 | 239 | 489 | 1,824 |
| Primary schools | 5 | 10 | 23 | 1,433 | 2,980 | 8,096 |
| Secondary schools | 1 | 2 | 5 | n.a. | 240 | 1,719 |
| **Total** | **11** | **22** | **51** | **1,672** | **3,700** | **11,639** |

**Source:** KSC Website (www.kenana.com/), accessed 18 April 2016

*Enhancing environment and sustainable development*

In addition, KSC and DAL Group are committed to corporate social responsibility (CSR) through the contribution to sustainable development and environment. For instance, the DAL Group shows commitment and adherence to corporate social responsibility and sustainability concepts, especially through its adherence to environmental responsibilities and through the creative and value-driven integration of sustainability concepts into business strategies and processes. The DAL Group is committed to contribute to sustainable development and to improve community well-being through responsible and discretionary business practices. For instance, concerning the commitment to sustainable development, the DAL Agricultural Services Company is committed to employ sustainable farming practices, to look after the environment, and to care for the communities around the farms. The DAL Agricultural Services Company farms follow a strict sustainability policy, avoid using genetically modified or engineered seeds, and provide employment, education and outreach initiatives to their communities. The DAL Agricultural Services Company farms adhere to principles of strict water protection, by minimising runoff into streams, by avoiding the use of any chemicals that could contaminate communities' water supplies or could damage the water eco-system, by water conservation to preserve and nurture the water resources, by using the right irrigation systems to minimise wastage, by using water management efficiency practices by applying the right amount of water at the right time, by employing moisture monitoring systems, and by practicing the responsible use of pesticides and herbicides. Where pesticides and herbicides are necessary, the farms follow best practice applications, and adhere to all application guidelines. They practice an integrated farming approach at the Ailafoun farm.[14] This includes self-sufficiency in alfalfa for the dairy herd and combining vegetable matter and animal waste for use as organic fertiliser.

Moreover, as for the environment, KSC shows awareness and commitment to the environment; environment is considered as an in-built part of KSC operations, KSC positively contributes to sustaining the environment, and this is done in various ways. For instance, KSC's estate includes 100,000 acres of irrigated cane fields. In addition, KSC grows in the surrounding area a total of 8,000 acres of different species of trees. It includes indigenous trees, different acacia species, Eucalyptus, etc. Those forests are commercialized to reduce human deforestation practices and to work as a wind break to reduce the negative effects of desertification. Also, the green wet fields reduce the average temperature in the surrounding areas by about two degrees centigrade. KSC's green fields of 100,000 acres work as a huge lung which takes carbon dioxide and releases oxygen to the atmosphere. KSC's agricultural practices have always been developed around environmental awareness. Hence, KSC uses filter mud, vinasse, and animal residues as a fertilizer to reduce the use of non-organic fertilizers. This reduces the impact of chemical fertilizers by efficient utilization of local resources. KSC is the first company to introduce green harvesting in the country. It is implementing a green harvesting programme across its harvesting operations, supported by the acquisition of appropriate mechanical harvesters which allow eliminating of cane burning prior to harvesting. The waste cane leafage is now converted into green fodder. To ensure irrigation efficiency, KSC has developed a water efficient Hydro-flume system based on drip irrigation techniques to manage water resources efficiently. KSC is utilizing Sugar by-products, such as molasses and bagasses to produce animal feed and Ethanol as environment-friendly energy sources. KSC is working with the Government of Sudan to produce a clean fuel to meet Sudan's international commitments as a signatory to the Kyoto Protocol. KSC is also working hand in hand with car manufacturers in Sudan to produce the first flexi-fuel engine. KSC is also reviewing its fleet of vehicles with the goal of replacing conventional fuel with Ethanol.[15]

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[14] See on this integrated farm project as a model of development: http://www.aaaid-conf.com/field-trip

[15] See http://www.kenana.com/pagecontents.aspx?pageid=31, accessed 18 April 2016.

*Enhancing Research and Development (R&D)*

Large size innovative firms in Sudan are characterized by active Research and Development (R&D). For instance, the Kenana Sugar Company (KSC)'s Research & Development (R&D) Department plays a crucial role in ensuring the sustainability of the business. R&D was established well before the commissioning of the sugar factory in 1974 to conduct and promote applied research on different disciplines, mainly: Breeding, Agronomy, Weed Science, Pathology and Entomology, Irrigation, Crop Monitoring, Management of Industrial By-products, and Agricultural Mechanization. For instance, applied research on Breeding aims at breeding and selection for continuous development of elite new varieties being able to produce sugar at low cost, at variety diversification to safeguard environmental hazards, and at the search for alternative crops such as sugar beet. The base plan includes the proper selection of parents, efficient cross pollination, and efficient seed sowing techniques to produce as much hybrid seedlings as possible. Moreover, applied research on Agronomy aims to provide a differential fertilizer response of sugarcane varieties (N, P and trace elements), a balanced nutrient approach, and an optimum cultural practice. Furthermore, applied research on Weed Science aims to provide intensive investigations on changes in weed flora, the herbicides screening for weed control, the flowering control to save yield losses, the ripeners application to improve cane quality, and a research strategy for striga eradication. In addition, applied research on Pathology and Entomology aims to provide rigid quarantine measures to safeguard against entry of pests or diseases, intensive screening of varieties for prevention and control through using immune diagnostics, intensive pest and disease surveys for earliest detection of build-up, and biological control for major insect pests. Moreover, applied research on Irrigation aims to improve water adequacy and equity, reduction of runoff, improvement of water use efficiency, and water application efficiency and management capacity. Moreover, research on Crop Monitoring aims to provide for measurement of the pre-harvest cane quality, measurement of cane losses at harvest, measurement of crop stands (gaps), and investigations on oil and grain crops. Furthermore, research on Management of Industrial By-products aims to investigate a conversion of cane trash filter cake, of vinasse into eco-friendly bio-fertilizers and co-generation, adoption of organic farming to produce organic products, making sugar industry environmentally sound, other research activities, and researches on oil, leguminous and grain crops. In addition, research on Agricultural mechanization aims to help in the development of suitable implements for sugarcane and other crops, and farm machinery management.

Research and Development (R&D) in KSC facilitate the achievements of product and process innovation that appears from continuous breeding and development of improved sugarcane varieties, optimization of harvest age within planting dates of commercial and pre-commercial varieties for maximum sugar yield, introduction of the fallow system in sugarcane cropping, development of effective and economical weed management strategies, development of insecticides used for control of termites, intensive pest and disease surveys in the estate, and application of filter mud as an organic fertilizer.[16] As a result, for the innovative activities KSC has successfully obtained several certificates and international representations. For instance, KSC is well-known, famous and recognized for its trademark; Kenana has registered its trademark worldwide in over 75 countries, to protect its brand since 1981 when the company commenced commercial production of sugar. Today, Kenana has registered several cane sugar varieties and more than 27 agricultural implements, besides the new water treatment units branded Aqua-Sudan which are operating efficiently in Kenana at the site and in other rural areas in Sudan, in Ethiopia, and in Nigeria. Moreover, KSC has successfully obtained several international representations; for instance, Kenana, as the largest domestic producer of sugar, has played a major role in establishing strategic links with the agro-industry worldwide. KSC is an active member of several international organizations, including the International Sugar Organisation (ISO), where KSC is representing the Sudanese Government, the World Association of Beet and Cane Growers (WABCG)[17], the World Sugar Research Organisation (WSRO)[18], the Sugarmark International[19], the Refined Sugar Association (RSA)[20], The Sugar Association of London[21], and the Grain and Feed Trade Association (GAFTA)[22]. KSC is playing an active role in these organisations, especially in the International Sugar Organisation (ISO), in which the Managing Director of KSC was elected as chairman of the Sugar Council. Significantly, the 27th session of the ISO was held in Khartoum in May 2005, and KSC is one of the regular sponsors of the ISO annual seminar. KSC has a cooperation agreement with sugar research centres around the world, namely Coimbatore in India and CIRAD in France. KSC is a member of the Sudan national negotiating team for WTO accession. KSC is one of the founding members of the Least Developed Countries (LDC) Commercial Group in London, overseeing the implementation of the "Everything But Arms" (EBA) initiative between LDCs and the EU.

Concerning DAL Group's Research and Development (R&D) activities, DAL Food operates the DAL Food Research Centre (DFRC) which operates as an extensive consumer research and retail audit unit, has modern and technologically advanced facilities, investigates and formulates innovative basic food and drink

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[16] See http://www.kenana.com/pagecontents.aspx?pageid=10, accessed 18 April 2016.
[17] See: http://www.wabcg.org/index.php?lang=en
[18] See: http://www.wsro.org/
[19] See: http://www.sugarmark.co.uk/responsibility.html and http://www.comitesucre.org/site/home/about-sugar-2/sugarmark/
[20] See: http://www.sugarassociation.co.uk/rsa-home.html
[21] See: http://www.sugarassociation.co.uk/
[22] See: http://www.gafta.com/

products, and establishes and controls the strict quality measures required for DAL Food products in Sudan. Within the DFRC, the scientific office supports product development activities, including a world-class product performance evaluation process for sensory evaluation and product characteristics testing. DAL Food pursues a strategy of reducing the reliance on imported raw materials in favour of developing farming and sourcing solutions with the local market, thereby increasing food security and developing local farmers and businesses. The DAL Group Al-Waha farm produces quality fodder such as Alfalfa and Rhodes grass, and DAL Group Alifoun farm supplies a large portion of DAL Group cows' milk input for the DAL Group Dairy factory. DAL Food supplements this through advanced contract farming, and partnerships with local farmers, to supply them with additional crops such as Sorghum, as well as milk through the DAL Group milk collection centres. DAL Group also partners closely with the DAL Group sister company, DAL Engineering, for expertise in farm management and equipment, giving the DAL Group a distinct edge in integrated farming in Sudan. The company works with local dairy farmers of varying sizes to provide milk to its numerous collection centres at guaranteed prices to enable them to plan their business. DAL Food also provides veterinarian support and animal husbandry consultancy services to improve animal health, quality and yields. In addition, the Sayga[23] bakery flour value stream provides technical support and training to bakers and was instrumental in migrating a significant proportion of bakers from traditional wood-fired ovens to modern liquid-gas powered ovens that not only improve their yields but are also more environmentally friendly.

Concerning manufacturing, the DAL Group has been at the forefront of revolutionising the food production industry in Sudan, from the first mass-milled and packaged grains and quality long-life dairy products, to the most advanced Coca-Cola bottling plant in the region. The DAL Group's commitment to quality has resulted in various ISO accreditations and praise came from various DAL international suppliers, including Tetrapak and Bühler mills. Concerning advanced technology, DAL Food has always been a pioneer in the Sudanese food industry, and a demonstration of its commitment to excellence is to be found in the investment in state-of-the-art technology, facilities, and specialist skills. From the high-tech Bühler milling machinery to the modern Tetrapak dairy plant to the region's most advanced Coca-Cola bottling plant, advanced technology and international quality standards are hallmarks of the DAL Food approach. Concerning retail distribution, DAL Food has the broadest reach and the most extensive sales and distribution networks in Sudan. The current structure accounts for the channel and customer needs required for the different parts of the business. The historical backbone of

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[23] See: https://www.bloomberg.com/profiles/companies/6057410Z:US-sayga-investment-co-ltd

DAL Food has been the development of the B2B channel, servicing bakeries, pastry producers and shops through a network of agents and some selected direct deliveries. For fast moving consumer goods (FMCG) products, a combination of direct delivery (including cold chain), third party agents, and wholesalers is leveraged to ensure that DAL Group packaged products have the broadest distribution and most prominent merchandising across the entire country and arrive in perfect condition for optimal shelf life and reliable quality.

Therefore, this section corroborates the first hypothesis concerning the existence of innovation (product and process innovation) in two large size (food) industrial firms in Sudan (KSC and DAL Group).

## 4 Characteristics of the sectoral systems of innovation related to industrial firms in Sudan (Analysis based on a Firms Survey)

This section uses primary data based on the Firms Survey (March 2017) which were collected from two large size firms (food and chemical) and two medium size firms (metal and textile) working in the manufacturing industries in Sudan.[24] The results in this section investigate the size and intensity of innovation (product and process innovation), assess the innovation capacity, evaluate the innovation strategies, the R&D strategies, and the human resources (training) strategies, and investigate the main factors hindering and those contributing towards the promotion of innovation in industrial firms in Sudan. This section examines the first hypothesis concerning the existence of innovation in industrial firms in Sudan. It investigates the second hypothesis that the degree, size and intensity of innovation is determined by firm size. It examines the third hypothesis regarding the limited

[24] At the early preparation stage and the initial contact for conducting the Firms Survey (2017), the two large-size (food) industrial firms in Sudan (KSC and DAL Group) apologized from responding to the Firms Survey (2017). Due to lack of response from them, they were not included in the form of primary data in the Firms Survey (2017), that includes other two large size firms working on chemical and food industries in Sudan. In this paper, the detailed profiles of the two large-sized firms and the two medium-sized firms were not included in the Firms Survey (2017), mainly due to lack of information. It is hoped to provide more comprehensive analysis of these firms in future research when adequate information is available from these selected firms. The distribution of firms by geographical location is equally distributed between Khartoum (50%) and Khartoum North (50%); the chemical and metal industrial firms locate in Khartoum, while the textile and food industrial firms locate in Khartoum North. The inclusion of large, medium, chemical and metal industrial firms as covered in the Firms Survey (2017) is based on a random selection.

size and intensity of innovation (product and process innovation), the limited innovation capacity, and the limited innovation strategies, R&D strategies, and human resources (training) strategies. It investigates the fourth hypothesis that the inadequate availability of human resources and the inadequate availability of financial resources are the major constraints for innovation, for the development of local technologies, and for the local adaptation with regard of foreign imported technologies in the industrial manufacturing firms in Sudan.

In the Firms Survey 2010 the questionnaire on 'Technological Change and Skill Development' was circulated amongst 100 of the food, textile, chemical and metal small, medium and large size enterprises in Sudan; the total number of respondent firms was 87 with a total response rate was 87%. The Firms Survey 2017 was distributed amongst four firms: two large size firms (chemical and food) and two medium size firms (metal and textile), all of which were working in the manufacturing industries in Sudan. The Firms Surveys 2010 and 2017 use the same methodology of collecting the data through survey questionnaires that aim at collecting micro-level qualitative and quantitative data, and cover the small, medium and large size firms engaged in the food, textile, chemical and metal industries in Sudan. The Firms Survey 2010 covered small, medium and large size firms located in three industrial areas in Khartoum city (Khartoum, Khartoum North, and Omdurman), whereas the Firms Survey 2017 covered medium and large size firms located in two industrial areas in Khartoum city (Khartoum and Khartoum North). Another difference is that the number of firms was reduced to only four firms included in the Firms Survey (2017), compared to 100 firms covered in the Firms Survey 2010. The reduction of the number of firms is partly due to the limited time available for conducting the study and partly due to the practical difficulty concerning a reliable response from the industrial manufacturing firms in Sudan.[25, 26] It would be useful to provide detailed profiles of the firms which are included in the Firms Survey (2017), in terms of the spectrum of activities (products and services), the location of the firms, and the size of employment. Some information on the four firms is given below. The profile of the chemical firm implies that it is a large size firm in terms of employment size (hiring 140 persons in 2016), that it locates in Khartoum, and that the spectrum of activities is specialized in pharmaceutical (medical) products. The profile of the food firm implies that it is a large

[25] In the Firms Survey 2017 the results concerning all firms is calculated as the average of the large and medium size firms.

[26] It would be good to provide more information on the large and medium size firms, and about their role in chemical, food, textile and metal industries sectors, on the specifics of the innovation categories, and it would be helpful to give examples for these innovations, and the meaning of the innovations in these four firms for the sectoral innovation systems in food, chemical, textile and metal industries, but at this stage it was not possible to do that, mainly due to limitation of adequate information from the respondent large and medium size firms.

size firm in terms of employment size (hiring 125 persons in 2016), that it locates in Khartoum North, and that the spectrum of activities is specialized in food and beverage products. The profile of the metal firm implies that it is a medium size firm in terms of employment size (hiring 60 persons in 2016), that it locates in Khartoum, and that the spectrum of activities is specialized in metal and glass (aluminium, glass and metal) products. The profile of the textile firm implies that it is a medium size firm in terms of employment size (hiring 60 persons in 2016), that it locates in Khartoum North, and that the spectrum of activities is specialized in textile products.[27]

*Dependency on foreign technology*

The results based on the firms survey (2017) are consistent with the results of Nour (2013b) based on the earlier Firms Survey (2010), that firms show weak technology indicators and a dependence on imported technology. The results based on the new firms survey (2017) show that all the respondent firms indicate that the main reason for the dependence on foreign technology is the lack of local technology from local suppliers; this result is consistent with the results of Nour (2013b) based on the earlier Firms Survey (2010) which implies that the main reasons for the dependence on foreign technology are first, the lack of local technology from local suppliers, and second, the better quality and the better price of foreign technology.[28] The results based on the current Firms Survey (2017) imply that due to the high dependency on imported technologies, it is reasonable that a high degree of automation by using a sophisticated and advanced technology level is reported amongst the majority and nearly three quarter of the respondent firms (75%), while a simple technology level is reported only amongst nearly a quarter (25%) of all the respondent firms. The results based on the new firms survey (2017) are different from the results of Nour (2013b), which are based on the earlier Firms Survey (2010) which indicates that a high degree of automation by using sophisticated and advanced technology is relevant for only 54% of all the respondent firms (see

[27]It would be helpful to know more about the firms' integration into the value chain (how they are linked with suppliers and customers) and also about the size of the firms in terms of sales, but there are limitations with regard of adequate information from the responding large and medium size firms.

[28]The results of the Firms Survey (2017) imply that there are differences in terms of dependence on foreign technology amongst industrial firms in Sudan. There is a high dependency on imported technologies amongst the respondent four large and medium size firms, mainly due to the lack of local technology available from local suppliers, compared to the relatively lower dependence on imported technology reported by Kenana Sugar Company (KSC) and the DAL group, as these two large size firms have huge R&D capabilities and an own equipment production. There are equipment development departments in Kenana Sugar Company and in the DAL Group (see Section 3 above based on the websites of these two firms).

table 2 below).[29] The results based on the new firms survey (2017) imply that despite the high dependency on imported technologies, it is somewhat surprising that the level of technology used is below international standards amongst nearly half of the respondent firms (50%), while a high level of technology used is limited only to half (50%) of all the respondent firms (see table 2 below). Our results based on the Firms Survey (2017) are consistent with the results of Nour (2013b), which are based on the Firms Survey (2010) and show that, despite the high dependency on imported technologies, the level of technology used is below international standards amongst the majority of the respondent firms in the Firms Survey (2010) (53%), while using a high level of technology being equivalent to international standards is limited to 47% of the respondent firms in the Firms Survey (2010) (see the results of the Firms Survey (2010) as discussed in Nour 2013b). Moreover, the results based on the new Firms Survey (2017) are consistent with the results of Nour (2013b) which are based on the Firms Survey (2010), and which imply that the degree of automation/sophistication in the use of technologies is comparable to international standards and levels and is largely determined by firm size.[30]

*Weak technology indicators*

The results of the Firms Survey (2017) indicate weak R&D indicators; the observation of weak R&D indicators appears from the following: (a) the limited R&D activities/efforts as they are performed continuously or occasionally amongst only 25% of all the respondents firms; the limited prevailing research activities include for example the marketing research; (b) the limited R&D activities and expenditures particularly devoted/aimed at improving firm products and to produce a new product; (c) the low R&D expenditures in absolute terms and the low R&D expenditures as a percentage of total expenditures; and (d) the low number of both full time and part time R&D employees. For instance, a majority (75% and 75%) of the responding firms have no or only a low number (1–3) of full time research employees and/or part time research employees, respectively.

[29] The deviations concerning sophistication of technology between the Firms Survey 2010 and the Firms Survey 201) refers to the level of advanced technology used among the 87 responding large, medium and small size firms in the Firms Survey 2010, compared to the 4 responding large and medium size firms in the Firms Survey 2017.

[30] In this paper and in the Firms Survey (2017) the level of production technology refers to the level of either advanced or basic or simple technology, as used by the firms to complete the firm's production, while, the degree of automation refers to the extent of mechanization which is used by the firms.

**Table 2: Technology indicators and Dependence on Foreign Technologies**

| | **All firms Number** | **Large Size Share** | **Medium Size Share** | **All firms Share** |
|---|---|---|---|---|
| **Level of production technology** | | | | |
| Advanced production technology. | 3 | 50% | 100% | 75% |
| Basic/simple production technology. | 1 | 50% | n.a. | 25% |
| **Degree of automation/Level of technology used** | | | | |
| Equivalent to the International Standard. | 2 | 75% | 75% | 75% |
| Lower than the International Standard. | 2 | 25% | 25% | 25% |
| **Technological and innovative capacity** | | | | |
| (a) capacity to develop new products/processes | 3 | 100% | 50% | 75% |
| (b) capacity to develop local technologies | 4 | n. a. | n. a. | n. a. |
| (c) capacity to adapt foreign imported technologies | 4 | 100% | 100% | 100% |
| **Dependency on foreign technology** | | | | |
| Purchase of equipment, machines and techniques from abroad: because they are not available from a local supplier | 4 | 100% | 100% | 100% |

**Source:** Own calculation based on the Firms Survey (2017), **Note:** n. a. means not available

The results based on the Firms Survey (2017) are consistent with the results of Nour (2013b) based on the earlier Firms Survey (2010), which indicate limited R&D activities/efforts performed, low R&D expenditures in absolute terms and low R&D expenditures as a percentage of total expenditures, and low numbers of both full time and part time R&D employees. The findings of Nour (2013b) as based on the earlier Firms Survey (2010) indicate that the contribution of research units in adapting the imported technologies is constrained by a shortage of skilled and qualified workers, amongst 74%, 68%, 80%, 75%, 75%, 81%, 67%, and 70% of All firms, chemical, food, metal, textile, large, medium and small firms, respectively (see Nour 2013b). In addition, Nour (2013b) finds that the contribution of research units in adapting the imported technologies is constrained by a shortage of finance amongst 78%, 71%, 83%, 83%, 75%, 82%, 82% and 65% of All firms, chemical, food, metal, textile, large, medium and small firms, respectively.

Moreover, the results of Nour (2013b) based on the follow-up interviews with the officials and firms' managers revealed that R&D activities are constrained by several factors, such as high costs and low public and private spending, lack of information systems, and the absence of an R&D culture due to inadequate awareness and concern. In addition, Nour (2013b) indicated the limited cooperation between industrial firms in terms of R&D, a situation that relates for example to the limited cooperation in the exchange of information. Exchange of information is practised within specific limits, probably because of the intense competition between industrial firms. Nour (2013b) finds that additional constraints relate to the poor coordination between the institutions engaging in R&D activities, either due to the absence of explicit government policy or the ineffective role of a central body (e.g. the government) to coordinate and promote R&D efforts and to motivate collaborative research efforts between the industrial firms and universities. In addition to the weak networking systems, R&D efforts, in particular, are limited across firms because of weak contacts and forms of collaboration with universities; this is probably attributable to the fact that the university sector is lacking resources and/or concern and interest to conduct jointly applied research with industrial firms. Moreover, Nour (2013b) finds that the main gap to encourage the development of R&D and to build of local technology is related to the fact that research is not a fundamental goal for the firm. The primary goal is profit, and this in a short-term view, as research is not seen as a long-term driving force of profit. In addition, the lack of an entrepreneurial perspective and the dominance of a commercial perspective need to be mentioned as causes of the weak technology indicators. Also, the lack of government policies and support, the lack of efficient organisational management, and the lack of relevant qualified workers need to be mentioned as responsible factors for the problems mentioned above. Nour (2013b) finds also that – regarding the issue of import dependency from the firms' perspective - the development of local technologies in Sudan is hindered by the acute shortage of local raw materials. The results based on the recent Firms Survey (2017) are consistent with the findings from Nour (2013b) which show weak technology output indicators as measured by patent applications. For instance, in the year 2016 none of the respondent firms have applied for a patent; the low degree of patenting may be attributable to the low R&D efforts. In addition, a lack of R&D efforts may hinder collaborative innovative activities across firms.[31]

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[31] The results of the Firms Survey (2017) reveal the discrepancy in terms of technology input indicators amongst industrial firms in Sudan, being the result of the low research, development and innovation capacities amongst the respondent four large and medium size firms, while some few large firms have relatively high research, development and innovation capacities as reported by the Kenana Sugar Company and the DAL Group (see Section 3 above based on the websites of these two firms).

*The limited Incidence of Innovations and the Constraints for Innovation*
The limited incidence of innovations appears from the incidence of product and process innovations. There is a slight incidence with regard of production of new combinations of old output amongst only a quarter (25%) of the respondent firms, while there is incidence of new processes, new organisational methods, new methods of production, the production of more output with low cost, the production of the same output with low cost, and to open a new market amongst half (50%) of the respondent firms.[32] The majority (75%) of all firms indicate the incidence of new products, the improvement of product quality, the improvement of training within firms, and the improvement of communication within the firms; less firms report about innovations on the other seven categories.[33] It is found that the degree of innovation is determined by the firm size (see table 3).

It is also found that the inadequate availability of human resources (human skills and highly skilled workers) and the inadequate availability of financial resources (lack of adequate finance for covering the high costs of building technologies) are the major constraints for innovations, for the development of local technologies, and for adaptations of foreign imported technologies in the respondent industrial manufacturing firms in Sudan. The inadequate availability of financial resources (lack of adequate finance for covering the high costs of building technologies) is obviously considered as more important than the inadequate availability of human resources (skills and highly skilled workers), when looking at the major constraints for innovations, for the development of local technologies, and for adaptations of foreign imported technologies (see table 4).[34]

[32]The terms "new product" and "new process" refer to new products and processes intended even just for local firms or for local markets and not necessarily for the international market.

[33] As reported by 50%, 50%, 50%, 50%, 50%, 50% and 25% of all respondent firms respectively.

[34]There is obviously an observed contradiction between the results discussed in section 3, emphasizing the huge role of human development and research, development and innovation strategies, and the results discussed in section 4, which imply much less relevance of such activities as based on the questionnaire interviews and the Firms Survey (2017). The contradiction is explained as being based on the results of the Firms Survey (2017) for the four large and medium size firms (see section 4 above), while some few other large size firms have relatively strong research, development and innovation capacities, such as the Kenana Sugar Company and the DAL Group (see Section 3 above based on the websites of these two firms).

**Table 3: The Incidence of innovations (product and process innovations) within firms**

| | All Firms Number | Large Firms Share | Medium Firms Share | All Firms Share |
|---|---|---|---|---|
| Produce a new product | 3 | 100% | 50% | 75% |
| Produce a new process | 2 | 50% | 50% | 50% |
| Produce a new combination of old output | 1 | 0% | 50% | 25% |
| Produce a new method of production | 2 | 50% | 50% | 50% |
| Produce a new organizational method | 2 | 50% | 50% | 50% |
| Produce more output with lower cost | 2 | 50% | 50% | 50% |
| Produce the same output with lower cost | 2 | 100% | 0% | 50% |
| Open a new market | 2 | 50% | 50% | 50% |
| Improve the quality of the firm's product | 3 | 100% | 50% | 75% |
| Improve the training within the firm | 3 | 100% | 50% | 75% |
| Improve the communication within the firm | 3 | 100% | 50% | 75% |

**Source:** Own calculation based on the Firms Survey (2017), **Note:** In Table 3, the category, "Produce a new combination of old output" means that firms use the old output produced by the firms to produce new products (varieties). However, the firms provided an inadequate information from the respondent large and medium size firms.

The importance and relevance of the sectoral system of innovation for the large and medium size firms appears from the importance of innovation for enhancing the quality of production and the competitiveness of the large and medium size firms in the local market in Sudan. It is important for the large and medium size (chemical, food, metal and textile) firms to enhance human and financial resources (by improving investment in research and development) to promote the sectoral innovation systems. Through both, joint research and development projects and sharing and transferring knowledge, other firms in the sectors of food and sugar potentially could benefit from the innovations in the two large firms, Kenana Sugar Company and DAL Group.

**Table 4: Constraints for innovations, development of local technologies, and adaptations of foreign imported technologies**

| | All Firms Number | Large Firms Share | Medium Firms Share | All Firms Share |
|---|---|---|---|---|
| **a. Constraints for innovations** | | | | |
| Inadequate availability of human resources (skills and highly skilled workers) | 4 | 100% | 100% | 100% |
| Inadequate availability of financial resources (lack of adequate finance for covering the high costs of building technologies) | 4 | 100% | 100% | 100% |
| **b. Constraints for the development of local technologies** | | | | |
| Inadequate availability of human resources (skills and highly skilled workers) | 4 | 50% | 100% | 75% |
| Inadequate availability of financial resources (lack of adequate finance for covering the high costs of building technologies) | 4 | 50% | 50% | 50% |
| **c. Constraints for the adaptation of imported technologies** | | | | |
| Inadequate availability of human resources (skills and highly skilled workers) | 4 | 50% | 100% | 75% |
| Inadequate availability of financial resources (lack of adequate fiancé for covering the high costs of building technologies) | 4 | 50% | 50% | 50% |

**Source:** Own calculation based on the Firms Survey (2017)

*The limited provision of training and human resources development strategies*

Our results based on the Firms Survey (2017) illustrate that the low provision of training appears from the following: (1) The lack of an in-house training unit, as for instance none of the respondent firms has an in-house training unit; (2) The complete absence of public financial support, as for instance none of the respondent firms received any government subsidies to support training provision; (3) The selective training provision, as in the year 2016 the priority for training among the respondent firms was mostly given to the production engineering staff and the management staff[35]; and as for few firms the limited provision of training is also extended to include the provision of training for university students; (4) The limited type of training as most of the training provision is focused on forms of on-the-job training, and as on-the-job training and off-the-job training combined are preferred by 100% and 50% of the respondent firms, respectively; the other types of training, such as off-the-job training within the firm (training centre) and off-the-job training outside the firm (in specialist training centres inside the country and outside the country) are very limited[36]; (5) The limited sources of information about training opportunities, as most of the information about training opportunities is provided by the chambers of commerce and private trainers (local and foreign companies).[37] While none of the respondent firms obtained information about training opportunities from government and semi-government units, other firms working in the same sector got information from public educational institutions/universities and from other sources, as, for example, firms were self-searching for training possibilities from private Sudanese universities, from public and private institutions, and from actors of foreign expertise. But, the majority and nearly three quarters (75%) of the respondent firms reported that investing in training will be pursued in the near future, to train existing employees, to send trainers and mentors abroad to acquire skills, to send workers abroad to acquire skills and to bring back new foreign skills, to attract scientists and engineers from the Diaspora, and to encourage learning on the job.[38] This is followed by nearly half (50%) of the respondent firms which indicate using ICT to upgrade skill levels and to support long distance learning in the near future.[39] Nearly half (50%) of the respondent firms reported that using ICT to upgrade skill levels will be pursued now; this is followed by nearly a quarter (25%) of the respondent firms which indicate that encouraging learning on-the-job and supporting long distance learning will be pursued now (see table 5). [40]

[35] As reported by 50%, 50%, 50% and 50% of the respondent firms respectively.
[36] As indicated by 38%, 38% and 25% of the respondent firms, respectively.
[37] As reported by 100% and 50% of the respondent firms, respectively.
[38] As reported by 75% of the respondent firms, respectively.
[39] As indicated by 50% of the respondent firms, respectively.
[40] As reported by 50% and 25% of the respondent firms, respectively.

**Table 5: Human resources development: Provision of training and skill development activities**

| Issues | Importance | | | | To be Pursued now | | | | To be Pursued in near future | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Firms** | **All firms** | **Large** | **Medium** | **All firms** | **All firms** | **Large** | **Medium** | **All firms** | **All firms** | **Large** | **Medium** | **Al firms** |
| **Skill development activities** | | | | | | | | | | | | |
| Investing in training to train existing employees | 4 | 75% | 75% | 75% | 4 | n.a. | n.a. | n.a. | 3 | 100% | 50% | 75% |
| Sending trainers and mentors abroad to acquire skills | 3 | 50% | 63% | 56% | 4 | n.a. | n.a. | n.a. | 3 | 100% | 50% | 75% |
| Sending workers abroad to acquire skills | 3 | 38% | 100% | 69% | 4 | n.a. | n.a. | n.a. | 3 | 100% | 50% | 75% |
| Bringing back/ / attracting new foreign skills, scientists and engineers | 3 | 50% | 50% | 50% | 4 | n.a. | n.a. | n.a. | 3 | 100% | 50% | 75% |
| Using ICT to upgrade skill levels | 4 | 100% | 100% | 100% | 2 | 100% | n.a. | 50% | n.a. | n.a. | 100% | 50% |
| Encouraging learning on the job. | 4 | 100% | 100% | 100% | 1 | 50% | n.a. | 25% | 3 | 50% | 100% | 75% |
| Supporting long distance learning | 4 | 75% | 75% | 75% | 1 | 50% | n.a. | 25% | 2 | 50% | 50% | 50% |

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| **Provision of a regular training to the following types of employees** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Firms** | **All firms** | **Large** | **Medium** | **All firms** | | | | | | | | |
| Production workers | 4 | n.a. | n.a. | n.a. | | | | | | | | |
| Service workers | 4 | n.a. | n.a. | n.a. | | | | | | | | |
| Production engineering staffs | 2 | 50% | 50% | 50% | | | | | | | | |
| Management staffs | 2 | 50% | 50% | 50% | | | | | | | | |
| **Important categories of training** | | | | | | | | | | | | |
| **Firms** | **All firms** | **Large** | **Medium** | **All firms** | | | | | | | | |
| On– the job | 4 | 100% | 100% | 100% | | | | | | | | |
| On – the - job and Off– the - job combined | 3 | 50% | 50% | 50% | | | | | | | | |
| Off – the - job within the firm [training centre] | 2 | 75% | n.a. | 38% | | | | | | | | |
| Off– the - job outside the firm [specialist training centre inside the Sudan] | 3 | 50% | 25% | 38% | | | | | | | | |
| Off– the - job outside the firm outside Sudan/abroad | 2 | 50% | n.a. | 25% | | | | | | | | |

**Source:** Own calculation based on the Firms Survey (2017)
**Note:** n.a. = not available

Therefore, the results in this section corroborate the first hypothesis concerning the existence of innovation in industrial firms in Sudan. The findings also support the second hypothesis that the degree, the size, and the intensity of innovation is determined by the firm size. The results confirm the third hypothesis regarding the limited size and intensity of innovations (product and process innovation), the limited innovation capacity, and the limited character of innovation strategies, and R&D strategies, and human resources (training) strategies. The findings also support the fourth hypothesis that the inadequate availability of human resources and the inadequate availability of financial resources are the major constraints for innovations, for the development of local technologies, and for adaptations of foreign imported technologies in the industrial manufacturing firms of Sudan. There is observation of a limited cooperation between private firms, industry, universities, and the public sector for promoting innovation, R&D and human resources development (training).

## 5 Conclusions and Policy Recommendations

This paper examines the existence of innovation in industrial firms in Sudan as a case study of innovation in Africa. The paper uses a combination of primary and secondary data, and uses descriptive, comparative and analytical approaches drawing on the frameworks of innovation theories, the national innovation systems and the sectoral innovation systems as presented in the international literature.

Section 1 presents an introduction and briefly provides the background about the general socio-economic characteristics of the Sudan economy, and shows the aims, the methodology and the structure of the study.

Section 2 presents the conceptual framework and a literature review; this section examines the conceptual framework of "the sectoral innovation systems" as discussed in the international literature.

Section 3 uses secondary data obtained from online information on the websites of the Kenana Sugar Company (KSC) and the DAL Group of Industries to explain the common characteristics of the two large-size food manufacturing industries in Sudan. It is explained that the large size firms in Sudan, such as the Kenana Sugar Company (KSC) and the DAL Group of Industries share several common characteristics. For instance, they are characterized by a large size business and by long-standing establishments that operate across many business units and sectors and produce diversified products with well recognized trademarks in the domestic market of Sudan. Also, they are characterized by the adoption of an explicit policy to enhance Training and Research & Development (R&D). They are characterized by an increasing awareness about the need to contribute to economic and social development, to human resources development, to education and training, to the environment, and to sustainable development.

Section 4 uses primary data based on the Firms Survey (March 2017) which were collected from two large size firms and two medium size firms working in the manufacturing industries in Sudan, to explain the characteristics, the incidence, and the constraints of innovations in large and medium size manufacturing industrial firms working in Sudan. The study aims to investigate the size and the intensity of innovations (product and process innovations), to assess the innovation capacity, to evaluate the role of innovation strategies, R&D strategies, and human resources (training) strategies, and to look at the main factors hindering and those contributing the promotion of innovations in the selected large and medium size firms working in the manufacturing industries of Sudan. The results corroborate the first hypothesis concerning the existence of innovation in industrial firms in Sudan. The findings also support the second hypothesis that the degree, the size, and the intensity of innovation is determined by the firm size. The results of the study also confirm the third hypothesis regarding the limited size and intensity of innovation (product and process innovation), the limited innovation capacity, and the limited role of innovation strategies, R&D strategies, and human resources (training) strategies. Also, the findings support the fourth hypothesis that the inadequate availability of human resources and the inadequate availability of financial resources are the major constraints for innovations, for the development of local technologies, and for the adaptations of foreign imported technologies in the industrial manufacturing firms of Sudan. Observed is also the limited cooperation between private firms, industry, universities, and the public sector for promoting innovation, R&D, and human resources development (training).

Based on these results this section 5 concludes and presents some recommendations which refer to the provision of adequate human and financial resources (by improving the provision of training to upgrade the skill levels, by improving the provision of more incentives to encourage employment of high skill personnel, and by improving the allocation of more financial resources to strengthen research and development and the cooperation with universities) as the main factors contributing towards the promotion of innovations and of an innovation capacity in industrial firms of Sudan.

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# Knowledge Spillovers from Foreign Direct Investment to Domestic Firms in Sudan

**Mohammed Elhaj Mustafa Ali**[1]

## 1 Introduction

The contributions of foreign direct investment (FDI) in achieving economic development in recipient countries, especially the developing ones, are well documented in economic literature. Especially, the interest about this issue has been revived in recent years, mainly due to the emergence of integration between economies through globalization and the recognition that FDI by multinational corporations (MNCs) plays a substantial role in facilitating domestic businesses. FDI has a potential to stimulate domestic firms through several channels, including strengthening backward and forward linkages between MNCs and these firms, diffusing up-to-date technologies, accumulating foreign exchange stocks, as well as connecting domestic firms with foreign markets (Aitken and Harrison, 1999; and Aitken et al., 1997). These are the direct benefits that have been anticipated to spring from FDI. However, FDI presence could also contribute indirectly in promoting domestic firms. That is, there is a branch of benefits that can be transmitted indirectly to these firms. These benefits are demonstrated in the so-called knowledge spillovers that are disseminated among workers, business persons and consumers in recipient economies. Specifically, knowledge spillovers include equipping workers and other economic actors with modern managerial skills, introducing new marketing techniques, and transferring modern business practices from the home countries of the MNCs to other countries (Blomström and Kokko, 1998). These knowledge spillovers are defined as the positive externalities that may result from FDI, and these may have a potential to increase the domestic factors productivity (Caves, 1974; Blomstrom, 1986; and Spencer, 2008). Especially, knowledge spillovers from FDI are expected to contribute positively in augmenting the productivity of local workers and employees in a manner that instigates growth in domestic firms. However, numerous studies have indicated that the ability of firms to internalize FDI knowledge spillovers is conditioned by the existence

[1] Assistant Professor of Economics, Department of Economics, University of Kassala, Sudan, Corresponding author: Email: mohdaj1976@gmail.com
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of many factors. These include the characteristics of MNCs hosted (signifying the potentiality for spillovers), the characteristics of domestic firms (indicating the absorptive capabilities), the channels through which the spillovers are transmitted (see: Paus and Gallagher, 2008), as well as differences in host countries' factors that may exercise a great role in forming the characteristics of foreign and domestic firms (Castellani and Zanfei, 2003; Lipsey and Sjöholm, 2005; and Gallagher, 2005).

Sudan as a developing country needs FDI not only to provide its economy with physical capital; but also needs them to supplement its human resource base with modern knowledge and experiences, to initiate sustainable economic development. It is worth mentioning that the country is very rich in terms of natural resources, that, if they were fully exploited, would qualify it to exit the trap of underdevelopment. The deficiency in the availability of skilled human resources represents one of the impediments that obstruct placing the country's economy on the path of economic development. Put differently, the shortage in skilled labour curbs the evolution of domestic firms and so inhibits economic development. In this regard, it is well known that the key factors in preparing a highly skilled labour force can be accomplished by establishing a modern educational system. However, given the accelerated nature of innovations in science and technologies, the outcomes of this system will not function well unless combined with modern knowledge and practices which are already existing in developed countries. As outlined above, one of the channels to disseminate such knowledge and practices to domestic workers, and thus to domestic firms, can be obtained by hosting larger amount of FDI. Recently, and after exploiting oil in commercial quantities, many MNCs entered the country as investors (UNCTAD, 2014). This progress in the reception of FDI is anticipated to play a pivotal role in diffusing modern knowledge spillovers among labour force and, therefore, to boost growth in domestic firms. Yet, no indicator can be picked up to advocate that the knowledge spillovers from FDI have promoted growth in Sudanese domestic firms by means of its contribution to labour productivity. This is because the country's economy keeps on growing at sluggish rates that fail to mitigate the chronic poverty experienced by large segments of the Sudanese population. This conclusion can be defended by the declining rates of economic growth witnessed after the secession of the South Sudan and the sharp reduction of the oil revenues earned. In other words, the bright economic performance, which implicitly indicates growth in domestic firms observed in the first decade of the 2000s, seems to be attributed to the oil price development rather than to productivity gains owing to the FDI inflows. However, concluding that FDI has no beneficial spillovers on the Sudan economy, as demonstrated by the growth in domestic firms, is considered untrustworthy without executing an empirical investigation. Accordingly, this inconclusive evidence, combined with controversies in the theoretical and empirical literature, makes the question about the role of FDI knowledge spillovers in fostering Sudanese domestic firms as being a most important one that needs to be answered. Precisely, this study attempts to examine the role of FDI knowledge spillovers in elevating growth in these firms by means of its contribution to labour productivity. The investigation will be run by applying Autoregressive Distributed Lag (ARDL) co-integration procedures to the time series data pertaining to Sudan, covering the period from 1980 to 2014.

In our opinion, this study should contribute to the existing literature on FDI in general, and to the evidence on the impact of FDI spillovers on the Sudanese domestic firms in particular. First, Sudan has a long history in hosting FDI. However, till this date there is no evidence to provide policymakers with a precise judgment about the relation between FDI knowledge spillovers and the performance of domestic firms. Second, in a country like Sudan, FDI knowledge can be considered as one of the pillars to achieve the desired economic transformation. This is because the country is well-endowed with natural resources, and their exploitation depends largely on the availability of well-developed human resources. Hence, disseminating FDI knowledge spillovers can help significantly in the development of human resources to the extent that natural resources can be better exploited.

The rest of this study proceeds as follows: In Section 2, the related literature is reviewed and assessed. Section 3 gives a brief overview of the FDI presence in Sudan by emphasizing its relationship with the performance of domestic firms. In addition, this section exhibits the adaptability of the country's business environment to FDI operations. Section 4 discusses the methodology and the data for the empirical analysis. Section 5 introduces the empirical results, and finally, Section 6 presents the conclusions and some policy implications.

## 2 Literature review

The importance of FDI knowledge spillovers in stiumlating growth in domestic firms via labor productvity effects continues to capture the attention of both economists and policymakers. In general, the existing literature differentiates between two types of potential spillovers that probably arise from FDI. The first type is manifested in the competitive disciplinary effects which are embodied in either the effective usage of the existing technologies and resources or in the adaptation of new foreign technologies (Hamida, 2013). The second type of spillovers is represented by the knowledge spillovers that result from transmitting know-how into domestic firms, demonstrating new technologies, and conducting training packages for workers who lately become recruited by domestic firms.

Considering the second type of FDI's effects, a large body of literature confirms the role of knowledge spillovers in stimulating growth in domestic firms. Theoretically, several mechanisms have been identified as channels through which these spillovers can be disseminated into domestic firms, including backward and forward linkages, labour mobility, imitation, demonstration effects, and export spillovers. For instance, FDI may create backward and forward linkages with domestic firms, permitting knowledge spillovers to boost growth in these firms beyond the levels maintained before its entry (Van Loo, 1977; Lall, 1980; Feldstein, 1995; Chen et al., 1995; Rodriguez-Clare, 1996, Markusen and Venables, 1999; Aitken and Harrison, 1999; Blomström et al., 1999; Agosin and Machado, 2005; Lin and Saggi, 2004; and Faeth, 2006). Also, labour mobility has been identified as a key channel to transfer via FDI knowledge spillovers to domestic firms. Precisely, Glass and Saggi (2002) and Fosfuri et al. (2001) viewed workers moving across sectors, including sectors dominated by foreign enterprises, as a superior channel for the desirable knowledge spillovers. The authors argued that the physical movement of workers, who have previously been recruited by foreign firms, would intensify the knowledge spillovers since those workers have been exposed to modern business practices and technologies. However, it has been documented that foreign firms often tend to restrict workers' mobility by paying higher wages, exceeding those paid by domestic firms (Aitken et al., 1996). Therefore, the transmission of knowledge spillovers into domestic firms may be delayed.

The literature also suggests that knowledge spillovers may occur when foreign MNCs upraise domestic firms' export capabilities. Compared to local firms, MNCs possess more information about global markets and conduct sophisticated managerial techniques in exports operations. These knowledge stocks can be easily copied by domestic firms and, thus, become qualified to export more goods and services (Haddad and Harrison, 1993; Aitken et al., 1997; Aitken and Harrison, 1999; Barrios and Strobl, 2002; Greenaway et al., 2004; and Banga, 2003). Exposing to such experiences and practices in export sectors would trigger the growth in domestic firms. In the same way, knowledge spillovers may take place when domestic firms imitate modern knowledge (i.e. are adopting new production and management methods) being offered by MNCs, and use it to execute businesses' matters (Das, 1987; Wang and Blomström, 1992; Djankov and Hoekman, 2000; Fosfuri et al., 2001; Görg and Strobl, 2005). Likewise, spillovers can also occur through competition between foreign enterprises and domestic firms (Wang and Blomström, 1992; and Glass and Saggi, 2002). However, these spillovers would be beneficial if and only if the presence of foreign businesses (i.e. the competitors) stimulates local firms to use modem technologies or at least to employ the ones already used in most efficient manners. Otherwise, the presence of MNCs may crowd out the infant industries by reducing their limited markets and/ or by taking over the skilled workers from domestic firms through paying higher wages.

However, regardless of the channels through which FDI knowledge spillovers could be conveyed to domestic firms, the existing literature emphasizes the existence of some prerequisites to comprehend the potential benefits of these spillovers.

Complying with this argument, a great number of scholars considered the absorptive capacity in host economies as an important factor in intensifying the benefits arising from FDI spillovers. A considerable number of studies has also accentuated the role which could be played by the type of FDI in determining the existence as well as the magnitudes of knowledge spillovers tracked to domestic firms. This strand of the literature underestimates the ability of FDI in the form of mergers and acquisitions (M&A) in producing knowledge spillovers to boost productivities and growth in domestic firms. In contrast, it has been argued that FDI in the form of Greenfield investments and in the form of Joint ventures are very impactful in generating signficant knowledge spillovers and, therefore, contribute to the evolution of new developments in domestic firms. Agreeing with this argument, the literature asserts that the knowledge spillovers occur if, and only if, MNCs make new investments in downstream or upstream production which would not take place in their absence (Caves, 1971; Jansen, 1995; De Mello, 1999; Apergis et al., 2006; and Sala and Trivin, 2014).

Furthermore, the locational proximity between foreign and local firms symbolizes another key element that determines the transmission of knowledge spillovers into domestic firms. Many authors have considered spatial proximity between MNCs and domestic firms as one of the crucial factors in explaining the amount as well as the geographical scope of knowledge spillovers (Audretsch and Feldman, 1994; Audretsch, 1998; and Crespo et al., 2009). Moreover, some scholars recognized that knowledge spillovers can be diffused more efficiently the greater the technological gap between FDI's parent and host country (Wang and Blomström, 1992; and Glass and Saggi, 2002). In contrast, Blomström, Globerman, and Kokko (1999) claim that the existence of a small technological gap between foreign and local firms increases the likelihood of the occurrence of knowledge spillovers. Additionally, some studies argue that the spillovers of FDI are industry-specific, meaning that the impact that FDI could have on domestic firms might differ across sectors and industries. Specifically, these studies confirm that foreign firms operating in the manufacturing sector tend to employ more sophisticated technologies than those investing in primary sectors. Accordingly, FDI in the manufacturing sector is likely to generate higher productivity gains for domestic firms pushing them to grow faster (Nunnenkamp, 2002; and Criscuolo and Narula, 2008). Supporting the same argument, some studies present the view that FDI in primary sectors have less potentiality to generate knowledge spillovers compared to those operating in manufacturing sectors (Sayek et al., 2003; and UNCTAD, 2001).

So, it can be concluded that there is unanimous support for the role of FDI knowledge spillovers in boosting growth in local firms via its contribution to labour productivity. Nevertheless, the literature submits that FDI knowledge spillovers are not assured; rather they are governed by some conditional factors. These factors, as detailed above, include the host country's absorptive capacity, the type of FDI hosted, the extent of technological gap between foreign and domestic firms, the type of the sectors in which MNCs are transplanted, and the geographical proximity. Hence, the puzzle about the occurrence and the effectiveness of knowledge spillovers becomes dependent on the presence (absence) of these conditions. Yet, these conditions are differing across regions, countries, and even firms. In other words, these conditions are determining the magnitude of knowledge spillovers being disseminated to Sudanese domestic firms through labour productivity. The above mentioned stylized facts suggest the importance of co-movements between the evolution in Sudanese domestic firms and the FDI presence. However, this picture remains incomplete and is so far lacking the empirical verification. Thus, the extent to which knowledge spillovers affect labour productivity in Sudanese domestic firms is considered an empirical issue on which this study attempts to shed some lights. Thus, an advanced econometric technique, represented by the Autoregressive-Distributed Lag (ARDL) approach, is instigated to determine whether FDI's knowledge spillovers lead to growth in domestic firms via their contributions to labour productivity.

## 3 The performance of domestic investment and FDI in Sudan

Having a look at the interactions between FDI and Sudanese domestic firms would help in understanding the relationship between FDI knowledge spillovers and the performance of these firms. However, due to unavailability of the accurate data on domestic firms in terms of numbers and magnitudes of capital, it would be suitable to use gross domestic capital formation[2] and gross fixed capital formation[3] as proxies for these firms. Table 3.1 summaries the averages of FDI stock (FDIS), gross capital formation (GKF), gross fixed capital formation (GFKF), and private gross fixed capital formation[4] (PGFKF) as percentages of GDP in Sudan during 1980-

[2] Gross capital formation (formerly gross domestic investment) consists of outlays on additions to the fixed assets of the economy plus net changes in the level of inventories. Fixed assets include land improvements (fences, ditches, drains, and so on); plant, machinery, and equipment purchases; and the construction of roads, railways, and the like, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings (The World Bank, 2015).

[3] Gross fixed capital formation (formerly gross domestic fixed investment) includes land improvements (fences, ditches, drains, and so on); plant, machinery, and equipment purchases; and the construction of roads, railways, and the like, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings. According to the 1993 SNA, net acquisitions of valuables are also considered capital formation (The World Bank, 2015).

[4] Private investment covers gross outlays by the private sector (including private non-profit agencies) on additions to its fixed domestic assets (The World Bank, 2015).

2014. In addition, in the same table 3.1, both annual average growth rates of GKF and GFKF are displayed in the columns six and seven, respectively.

As can be understood from the table 3.1, the ratios of FDI stock (FDIS), gross capital formation (GKF), gross fixed capital formation (GFKF), and private gross fixed capital formation (PGFKF) as percentages of GDP at the beginning of the 1980s were negligible, reflecting the sluggish performance characterizing the economy during that period. At that time, the country was exposed to several upheavals that imposed negative consequences on its economic performance. For instance, after the relative peace enjoyed by the country following the signature of Addis Ababa Agreement in 1972, that period witnessed the implementation of Islamic Sharia laws which stoked the second version of the civil war in the south. By waging that war, the country had adopted a war's economy policy due to which all resources, including human resources, had been mobilized for military purposes. Moreover, the economy had been affected deleteriously by the spread of drought and famine that hit the country in 1984.

These events led to undesirable effects on both, domestic and foreign firms which were working in Sudan. Especially, their destructive effects were manifested in the negative growth of gross capital formation during that period. Specifically, gross domestic capital formation recorded an annual average of -0.83% during the period 1980-1984, indicating a great decline in the performance of domestic firms. During the same period, the patterns of FDI stock (% of GDP) did not diverge from that of domestic capital formation. It decreased from an annual average of 0.94% to 0.82% during 1986-1989 and then further to 0.62%, demonstrating that the country was not fitted for hosting foreign investors.

Consistent with the questions posed by this study it can be said that the absence of FDI during that period has contributed in limiting the growth of domestic firms. Alternatively stated, the deterioration in the performance of these firms can be, in part, interpreted based on the missed benefits that could be trickled to them from FDI. This can be indicated by the impressive deterioration in the infant firms emerged in Sudan at the ends of the 1970s. Thus, in addition to its direct losses, as represented by physical capital, there were other indirect losses embodied in productivity improvements that could result from FDI spillovers. The opportunity cost can be calculated based on the losses in the superior knowledge and experiences that could be gained from FDI and that could possibly subsidise labour productivity. This matter is clearly evident in Table 3.1 which shows the volatility of capital formation in the 1980s and early 1990s, the periods that were characterized by low FDI inflows.

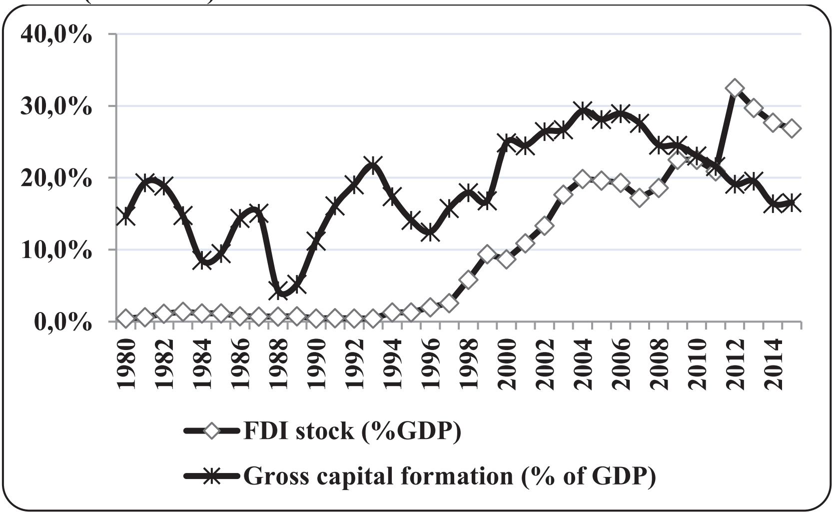
**Table 3.1: FDI's and the performance in domestic capital formation in Sudan (1980-2015)**

| (1) Year | (2) FDIS (%GDP) | (3) GKF (%GDP) | (4) GFKF (%GDP) | (5) PGFKF (%GDP) | (6) GKF (annual % growth) | (7) GFKF (annual % growth) |
|---|---|---|---|---|---|---|
| 1980-1984 | 0.94 | 15.2 | 14.4 | 9.32 | -0.83 | 18.4 |
| 1985-1989 | 0.82 | 9.69 | 10.3 | 4.99 | 10.3 | -5.94 |
| 1990-1994 | 0.62 | 17.1 | 11.8 | 9.10 | 2.76 | 1.77 |
| 1995-1999 | 4.21 | 15.4 | 9.42 | 8.73 | 36.1 | 26.7 |
| 2000-2004 | 15.3 | 26.4 | 20.2 | 16.5 | 19.7 | 13.4 |
| 2005-2009 | 19.6 | 26.7 | 22.7 | 17.2 | 6.37 | 8.37 |
| 2010-2015 | 26.7 | 19.4 | 17.7 | 15.7 | -3.3 | -2.9 |

**Sources**: The World Bank, World Bank Indicators (2014); and United Nations Conference on Trade and Development (UNCTAD), UNCTADSTAT, (2014)

However, due to the adoption of privatization policies in 1990s, FDIS has increased to an annual average of 4.21% during 1995-1999, and has climbed further to double digits average annual ratios of 15.3%, 19.6%, and 32.4% during 2000-2004, 2005-2009, and 2010-2014, respectively. In the same way, excluding the period which followed the secession of South Sudan, the gross capital formation (GKF), the gross fixed capital formation (GFKF), and the gross fixed capital formation by the private sector (PGFKF) as percentages of GDP have shown similar improvements to those which were observed in FDIS. This tight co-movement between capital formation indicators and FDI stock indicators may convey the positive effects of FDI knowledge spillovers in stimulating growth in domestic firms (see figure 3.1).

**Figure 3.1: Gross capital formation (% of GDP) and FDI stock (%GDP) in Sudan (1980-2015)**

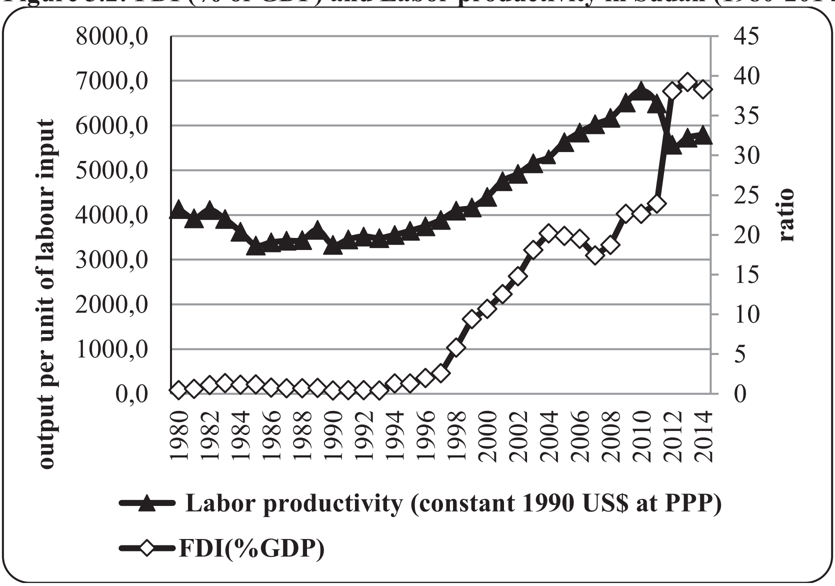



**Source**: World Bank Development Indicators (2017) and UNCTAD, http://unctad-stat.unctad.org/wds/TableViewer/tableView.aspx

To make the picture on the potentiality of FDI knowledge spillovers in boosting growth of domestic firms clearer, Figure 3.1 illustrates the pathway of the FDI stock and of gross domestic capital formation (% of GDP) in Sudan throughout 1980 - 2015. As sketched in the figure 3.1, the gross capital formation (% of GDP) was relatively unsteady over the 1980s, masking the volatility of domestic investment in response to the economic downturn, experienced by the economy during that period. Expectedly, FDI replicated the route of gross domestic capital formation, signifying the likely mutual dependence between foreign and domestic investments. In the second half of the 1990s, however, the FDI stock (% of GDP) rose dramatically compared to the 1980s and the early 1990s, establishing its mark as a key contributor to domestic firms' promotion.

In general, it can be inferred that domestic firms were positively influenced by FDI presence. Such a complementary relationship may indicate the effective role of FDI, through its knowledge spillovers effects, in boosting the number of firms run by native investors. In the same way, the role of these spillovers in supplementing domestic firms can be further supported by the co-movement between FDI's stock and factor productivity. This can be clearly indicated by figure 3.2 which shows the existence of a co-movement between per worker productivity and FDI stock in Sudan. However, as documented by previous literature, foreign firms may exercise some types of measures to block domestic firms, especially the competitors, from gaining these benefits. Nonetheless, the figure 3.2 demonstrates the opposite. This was clearly evident particularly after the second half of the 1990s and till the year 2011. Specifically, the observed co-movement between FDI and per worker productivity may vindicate that foreign firms do not put restrictions to prevent domestic businesses from reaping the benefits of knowledge spillovers. However, these co-movements just give an indication that FDI may have positive impacts on domestic firms, and that prospering domestic firms may lead to more FDI.

**Figure 3.2: FDI (% of GDP) and Labor productivity in Sudan (1980-2014)**




**Source:** UNCTAD Statistics on FDI (2016), and statistics from ILO 2016 (http://www.ilo.org/global/statistics-and-databases/research-and-databases/kilm/lang--en/index.htm)

The potentiality for these positive outcomes can be justified based on many reasons. First, most of the foreign firms in Sudan are concentrated in the petroleum sector so that they are beyond the concerns of local firms. Therefore, due to the absence of local competition, the foreign firms' worries from transferring knowledge to domestic firms - through imitation and labour turnovers - will be minimized. Second, since most of the foreign firms are vertically related to domestic ones (i.e. these firms act as suppliers to foreign firms), the first may encourage the latter to adopt modern business practices. This is so because adopting such an action would help foreign firms to reduce the cost of inputs bought from local suppliers. Third, the gap between the stock of knowledge and business practices preserved by foreign firms and the one possessed by domestic firms is expected to be very great. Accordingly, based on the argument by Wang and Blomström (1992), the connections between labour in MNCs and that in domestic firms would generate multiple benefits pushing domestic firms to expand. In other words, domestic firms with a little capital can depend on FDI knowledge spillovers to expand their businesses without a need for significant increases in profitability. Although there are counterarguments, the context of these three arguments gives room for such expectations.

The most prominent examples for the role of FDI knowledge spillovers in promoting Sudanese domestic firms can be observed in the three sectors dominating the economy, namely industry, services, and agriculture. For example, in the industrial sector, the influence of these spillovers can best be traced in cement industry. It is well known that the cement industry in Sudan dates back to 1947 when Atbara Portland Cement Company was established as a joint-venture investment shared between native and foreign investors. Nevertheless, the production of cement remained less than the country's demand. However, after allowing foreigners to invest in this area, the production of cement has gone up dramatically. According to reports by the Sudanese Ministry of Industry, foreign investments in cement amounted to $ 1,615 million in 2016, which is relatively high inflow when compared to total inward FDI. Five fully or partially foreign owned new cement plants have been built. Atbara Cement Limited Company[5] itself has been sold to the African Development and Investment Company (owned by three Arab businessmen, namely Suleiman Al-Rajhi, Saleh Kamel and Ibrahim Mandarin). However, in 2003 the company became owned solely by Al-Rajhi (Global Cement, 2017).[6] Due to this transformation in the ownership, the production of the company increased from 1,000 to 5,700 metric tons per day, reflecting the influence of foreign capitalization and management in facilitating growth in this company. The success of the Atbara Cement Company stimulated the establishment of new companies, including Al Shamal Cement Factory Limited[7] and Berber Cement Company Limited[8] (established in 2005). The ownership of Berber Cement Company Limited has been shared by Arab and Sudanese investors. The company has a capacity to produce 4,800 metric tons per day and grants 340 jobs. In 2005, Jordanian Mass Group Holding has started the construction of Al Shamal Cement Company which became operating in 2008 with 1.50 million metric tons per year.

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[5] See: http://atbaracement.sd/en/

[6] See on new developments: http://www.globalcement.com/news/itemlist/tag/Sudan and http://www.globalcement.com/

[7] See: http://www.industryabout.com/country-territories-3/470-sudan/cement-industry/2644-al-shamal-atbara-cement-plant

[8] See: https://www.zawya.com/mena/en/company/Berber_Cement_Co_Ltd-1006991/

Driven by the waves of FDI in cement industry, in 2008 Al Salam Cement Production Company Limited[9] was founded by a native investor with a capacity to produce 6,000 metric tons per day and reaching a number of 300 employees. In 2010, both, the ASEC Cement Company of Egypt[10] and the Sudanese National Social Insurance Fund[11], have established Al Takamol Cement Company Limited (ASEC)[12] with a capacity of 1.6 million metric tons per year and with a cost of reaching $252 million. It is worth to mention that all these five cement plants are placed in the River Nile State. This proximity is expected to intensify the transfer of knowledge and the experiences between foreign-owned and native-owned factories, particularly through labour mobility and exchange of management knowledge.

The FDI knowledge spillovers in the services sector are very apparent in the hotels sector. In the last two decades, many new hotels have been established in Khartoum. For example, the Al Salam Rotana five stars hotel[13] is fully owned by foreign investors. The Corinthia Hotel Khartoum[14] was founded in 2008 as a foreign-owned firm (owned by the Libyan government) at a cost of Euro 81 million. The expansion in the hotel sector's foreign ownership motivated native investors to enter the industry. This observation can be advocated by the emergence of new hotels and guest houses in Khartoum during the last two decades. For example, it is possible to mention the following hotels and guest houses: Kanon Hotel Suites, Paradise Hotel, Soluxe Hotel, Horizon Hotel, Rosa Park Hotel, 5M Hotel, City Flats Hotel, Prince Hotel, Abbasher Hotel, German Guesthouse Khartoum, and Albahrain Hotel. So, the foreign experiences and skills arising from the existence of FDI in the hotel industry gave birth to this large expansion.

In the same way, FDI in agriculture may spark the current expansion in domestic firms in the agricultural sector. According to Tanyeri-Abur and Hag Elamin (2010), FDI in agriculture accounted for 88 projects during the period from 2000 to 2008. These projects were distributed between crops (22 projects), mixed farming (33 projects), poultry (13 projects), and others (13 projects). Despite of the fluctuating and seasonal nature of this sector, one can be able to conclude that the presence of such huge numbers of projects may possibly assist growth in domestic agricultural firms. This can be indicated by the accelerated growth in the value added generated by agriculture in relation to the GDP. The reports by the World Bank show that the value added by the sector to the GDP has grown by 25.27%

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[9] See: http://listings.findthecompany.com/l/274768662/Al-Salam-Cement-Production-Co-Ltd-in-Khartoum-Sudan
[10] See: http://asecement.com/
[11] See: http://www.nsif.gov.sd/
[12] See: http://asecement.com/contact.aspx
[13] See: https://www.hrs.de/hotels/de/sudan/khartoum/al-salam-rotana-401362.html
[14] See: https://www.corinthia.com/en/hotels/khartoum

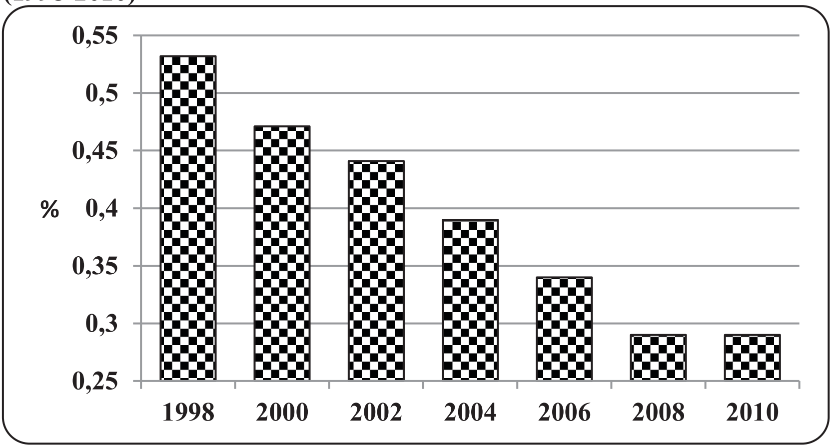
during the period 2000-2009, indicating again the potentiality of positive knowledge spillovers (The World Bank, 2016). However, concluding that FDI has knowledge spillovers into Sudanese domestic firms, based on the above descriptive facts, provides only an indecisive conclusion. Therefore, the econometric techniques can be called up to challenge this conclusion.

## 3.1 The Absorptive Capacity of Domestic Firms in Sudan

Many studies emphasize the role of the absorptive capacity preserved by domestic firms in maximizing the absorption of fresh knowledge brought by foreign companies (Cohen and Levinthal, 1989; Nelson and Phelps, 1966; Dunning, 1993; Coe et al., 1995; Borensztein. et al., 1998; Nelson and Pack, 1999; Zahra and George, 2002). In view of that, the capacity of Sudanese firms to absorb knowledge spillovers emanating from FDI is likely to depend on the levels of development in internal knowledge infrastructures and the relationship with the rest of the world. These might include research and development (R&D) in the firm and in the host country, education at all levels, and the culture that emerges from the durability of connections enacted with other countries. Especially important is the role of R&D (see figure 3.3.).

Picking up R&D and training, one can notice that Sudan is extremely poor in these aspects of infrastructures. This is the case because the country devotes small portions of its GDP to develop these crucial areas of development. Figure 3.3 shows expenditures on research and development as a percentage of GDP in Sudan during 1998 to 2010. As can be seen in the figure 3.3, these expenditures remained below a one percent level. Consequently, the current R&D outcomes are expected to exercise no role in raising the absorptive capacity of domestic firms to the level that makes them able to internalize the benefits disseminated by FDI. In terms of training programmes, the situation is not much better: only 9.5% of Sudanese local firms have offered formal training programmes for their employees (The World Bank, 2014). Like the negative impact of the very low R&D expenditures, the absence of the training programmes is likely to obstruct taking the full advantages of FDI knowledge spillovers.

**Figure 3.3: Research and Development Expenditure (% of GDP) in Sudan (1998-2010)**




**Source**: Adopted from Trading Economics data (http://www.tradingeconomics.com/sudan/research-and-development-expenditure-percent-of-gdp-wb-data.html).

Picking up R&D and training, one can notice that Sudan is extremely poor in these aspects of infrastructures. This is the case because the country devotes small portions of its GDP to develop these crucial areas of development. Figure 3.3 shows expenditures on research and development as a percentage of GDP in Sudan during 1998 to 2010. As can be seen in the figure 3.3, these expenditures remained below a one percent level. Consequently, the current R&D outcomes are expected to exercise no role in raising the absorptive capacity of domestic firms to the level that makes them able to internalize the benefits disseminated by FDI. In terms of training programmes, the situation is not much better: only 9.5% of Sudanese local firms have offered formal training programmes for their employees (The World Bank, 2014). Like the negative impact of the very low R&D expenditures, the absence of the training programmes is likely to obstruct taking the full advantages of FDI knowledge spillovers.

Likewise, the records of the country on the educational front, which represents one of the facilitators of FDI knowledge spillovers, do not diverge from that of R&D and training. About 90.3 % of Sudan's population aged 15 and over were unschooled in 1950. However, this percentage dropped significantly, particularly during the 1980s. Recently, in 2014, the portion of the unschooled population has diminished to, approximately, 52%, indicating significant improvements in educational attainments. The progress in education has been reflected in great increases in the average years of total schooling, which increased steadily during the period from 1950 to 2014. However, evaluating the performance in education only with regard of quantitative criteria may turn out to be misleading. The type of education and its quality should be always taken into consideration. In this regard, the country still lags behind in terms of vocational and professional schooling. The total number of students who joined vocational programmes in public and private secondary education institutions was only 26,126 (The World Bank, 2017). Thus, the failure to afford such educational programmes would also disturb the transmission of knowledge from FDI to local firms. Breaking down, Sudan's huge young labour force may represent one of the channels through which these FDI spillovers may possibly trickle to local firms. However, the deficiency in retaining reasonable levels of professional educational stocks may undermine the capabilities of workers to digest the up-to-date knowledge brought in by FDI.

On the whole, it can be concluded that Sudan's absorptive capacity, as represented by education and R&D, does not qualify local firms to utilize the full advantages of knowledge diffused by FDI. This conclusion has two explanations. First, the partial absence of R&D along with the poor performance in educational attainment would hinder FDI reception and, consequently, will diminish the opportunities to acquire higher knowledge spillovers. Second, even if larger amounts of FDIs are being received, the existence of a fragile absorptive capacity resulting from deficiencies in R&D and education would lower the exploitation of potential spillovers arising from FDI presence. Finally, the limited levels of R&D and education will affect negatively the domestic firms' expansion paths. That is to say, the absence of R&D, coupled by inadequate education, will discourage the growth of domestic firms and, thus, will decrease the overall externalities which are generated by knowledge spillovers that may possibly result from hosting FDI.

## 3.2 The Sectoral Distribution of FDI in Sudan

The distribution of MNCs' activities among different sectors in an economy might impact the diffusion of FDI knowledge spillovers to domestic firms (see table 3.2 on the case of Sudan). This is so because each sector possesses its own characteristics that may provide distinctive sources of spillovers from hosted FDI (Yin et al., 2014). For instance, manufacturing and industrial sectors are anticipated to be good channels for transferring the ingredients of FDI knowledge spillovers to the rest of the economic sectors. Moreover, the absorption of the FDI knowledge spillovers can also be affected by the technological and managerial gaps between domestic and foreign firms. Accordingly, given the fact that most of the Sudanese firms hire relatively unskilled workers and implement traditional technologies, initiating contacts with foreign firms would inspire them to switch to modern technologies.

**Table 3.2: The sectoral distribution of FDI in Sudan (2003-2016)**

| Year | Manufacturing sector | | Services sector | | Agricultural sector | |
|---|---|---|---|---|---|---|
| | Number of projects | Capital (US$ Million) | Number of projects | Capital (US$ Million) | Number of projects | Capital (US$ Million) |
| 2003 | 91 | 349 | 72 | 276 | 22 | 372 |
| 2004 | 114 | 350 | 85 | 1,189 | 7 | 3 |
| 2005 | 133 | 907 | 193 | 2,077 | 8 | 15 |
| 2006 | 184 | 1,668 | 147 | 1,114 | 17 | 198 |
| 2007 | 139 | 3,036 | 113 | 1,602 | 7 | 311 |
| 2008 | 83 | 8,264 | 150 | 3,951 | 9 | 175 |
| 2009 | 98 | 845 | 59 | 1,918 | 9 | 122 |
| 2010 | 95 | 457 | 85 | 2,483 | 13 | 9,785 |
| 2011 | 9 | 194 | 14 | 4,210 | 6 | 106 |
| 2012 | 10 | 76 | 12 | 118 | 10 | 197 |
| 2013 | 30 | 800 | 91 | 8,879 | 22 | 741 |
| 2014 | 71 | 2,308 | 20 | 826 | 14 | 434 |
| 2015 | 44 | 60 | 45 | 111 | 18 | 45 |
| 2016 | 48 | 288 | 61 | 610 | 58 | 486 |
| **Total** | **1,149** | **19,602** | **1,147** | **29,364** | **220** | **12,990** |

**Source***:* Ministry of Investment, Sudan; the report on the approved FDI per sector (2000-2016)

Table 3.2 exhibits FDI hosted by manufacturing, services and agricultural sectors in Sudan during the period 2003-2016. As the table 3.2 shows, in 2003, the numbers of foreign projects in Sudan were only 91 in manufacturing, 72 in services, and 22 in agriculture. Nevertheless, if the total amount of capital invested is taken into account, foreign projects in agriculture came before manufacturing. At the middle of the 2000s, however, the situation has changed. The manufacturing and services sectors took the lead as FDI recipients. Specifically, throughout the period 2003-2016, the number of FDI projects executed in the manufacturing sector captured roughly around 46% of the total number of projects implemented (1,149 projects) followed by services (1,147 projects), a sector which accounted for 45%, and agriculture with a share of 9% (220 projects). Yet, the manufacturing sector was surpassed by the services sector in terms of amount of foreign capital received. Specifically, the services and manufacturing sectors capture, respectively, 47% and 31% of the total foreign capital hosted during the period under consideration.

The message from the concentration of FDI in manufacturing and services sectors and its probable role in stimulating the expansion of domestic firms is straight forward. The argument is that by reallocating FDI away from agriculture and towards manufacturing, as manufacturing has a greater potential for circulating knowledge spillovers, would promote growth in these firms. However, although the manufacturing sector appeared to be leading in hosting foreign companies in Sudan, it can be argued that these companies were mostly driven by oil. This can be indicated by the huge surge of MNCs that initiated businesses in Sudan after the advent of oil at the end of the 1990's. A slight breakdown in data on the sectoral composition of FDI confirms this view. As reports by the Ministry of Investment (MoI) in Sudan show, throughout 2000-2010, the best performer in FDI reception turned out to be the mining and oil sector which constitute around 73.92% of the total FDI stock hosted by the economy. Such sectoral composition of FDI stocks, which tends to concentrate heavily in oil-oriented industries, is expected to delay the dissemination of FDI knowledge spillovers among domestic firms. This argument has many justifications. First, oil-based investments, by its nature, are incapable to generate the desirable positive spillovers effects. Indeed, such a type of FDI has a tendency to be located in peripheral areas, making knowledge spillovers arising from learning by doing, agglomeration effects, and demonstration effects to become weaker. Additionally, oil represents an exhaustible resource, which depletes in a few years or a few decades. Therefore, its contribution in sustaining FDI knowledge spillovers might be conditioned by the extent to which oil revenues are employed in creating a diversified GDP.

## 3.3 FDI in Sudan by country of origin

Since the colonial era, Sudan has hosted a huge number of foreign enterprises. As reported by Sudan's Directory, in 1925 the numbers of projects registered were 259, of which only one project was owned by a Sudanese national (Tom, 1988). The Gezira scheme which was established in 1923 was one of the FDI projects that were financed by foreigners. In addition, Sudan inherited huge foreign investments in the banking sector, including banks such as Barclays Bank, Egyptian Ahli Bank, National and Grindlay's Bank (Ottoman Bank), Misr Bank (Egypt), Credit Lyonnais (France), Arab Bank, and the Ethiopian Commercial Bank. In addition, the country hosted some of the major oil companies, such as Mobil, Shell, Total and AGIP (Tom, 1988). However, the number of foreign enterprises decreased sharply in the successive years, reflecting the early stages of political unrest that seized the country in the period after independence.

Figure 3.4 shows the total amount of foreign registered capital in Sudan according to the origin countries during 2003-2015. As the figure 3.4 illustrates, China captured the lion share of the FDI hosted by the country. The Chinese FDI amounted to, approximately, one third of total foreign capital registered in the country (28.80%) during the period 2003-2015. The second top investor was Germany, contributing around 17% of total foreign investments. Qatar with a share of 10.80% came in the third rank, followed by Malaysia (10.70%), U.A.E. (7.30%), India (6.20%), Egypt (5.70%), Indonesia (5.50%), Lebanon (2.40%), and Saudi Arabia (with 1.20%), demonstrating improved contributions from Arab countries to the total FDI stock of the country during 2003-2015[15].

Table 3.3 breaks down data on the top investing countries by presenting the top 10 companies investing in Sudan between January 2003 and May 2015. During this period, China National Petroleum Corporation (CNPC)[16] was the largest foreign investing company at, nearly, US$ 2,687 million. However, although the company possesses three projects, it provides the Sudanese labour market with a negligible number of jobs (only 440 jobs), reflecting the tendency of these companies to recruit native Chinese. Conversely, the Indian Oil and Natural Gas Corporation (ONGC)[17], which was ranked the ninth foreign investing company in Sudan, provides the Sudanese labour market with 740 jobs. The German Fuchs Petrolub[18] was the second largest foreign investing company in Sudan, providing US$ 1,641 Million, followed by Petronas (Malaysian)[19] with a total capital reaching US$ 1,033. The Qatari Barwa Real Estate[20] is recorded as the fourth company in terms of foreign capital invested in Sudan. Its two projects in Sudan create 893 jobs. This indicates that such a type of companies has more ability to create job opportunities when compared to the three oil-oriented foreign companies which created together only 1,122 jobs.

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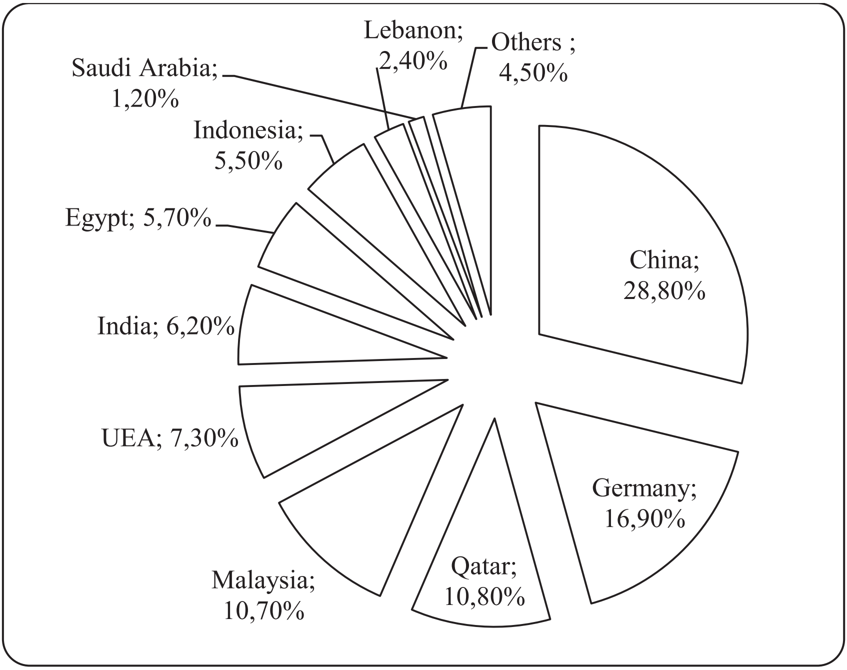
[15] It is worth mentioning that the growing FDI inflows from Arab countries mirror the recovery in Sudan-Arab relationships which were exposed to severe damage due to the political attitudes adopted by the country when Iraq invaded Kuwait in August 1989.

[16] See: http://www.cnpc.com.cn/en/
[17] See: http://www.ongcindia.com/wps/wcm/connect/ongcindia/home/
[18] See: https://www.fuchs.com/gruppe/
[19] See: http://www.petronas.com.my/Pages/default.aspx
[20] See: http://www.barwa.com.qa/en/

**Figure 3.4: Top countries investing in Sudan between January 2003 and May 2015**




**Source**: adopted from FDI Intelligence from The Financial Times (http://dhaman.net/wp-content/uploads/2016/02/Sudan.pdf)

The conclusion is that the non-oil foreign investments in Sudan, although they differ in the number of projects and the volume of capital invested, have contributed significantly in creating job opportunities. Undoubtedly, this is anticipated to exercise great influence on the transmission of knowledge spillovers to domestic firms and, therefore, to their vertical and horizontal expansion paths.

Summing up, the distribution of foreign investments hosted by Sudan according to the country of origin reflects the fact that most of them were driven by natural resources, mainly oil. This is totally different from what occurred in Asian countries (like Malaysia, China, Thailand, and Indonesia) and in Latin American countries (like Brazil, Mexico, Argentina, and Chile) in the 1980s and 1990s. In these countries, the conducive environment (i.e. the availability of skilled labour and the easiness of doing business) represented the key motive behind FDI inflows. Hence, with respect to knowledge spillovers and its role in nurturing domestic firms, Sudan's experience with FDI is expected to generate different outcomes than those experienced by Asian and Latin American countries. Alternatively stated, since foreign companies hosted by Sudan offer fewer jobs, the knowledge spillovers are expected to be lesser than the ones enjoyed by the other countries. Also, the country from which FDI has been originated is expected to have a great influence in deciding on the effectiveness of knowledge spillovers circulated into the rest of the sectors and, thus, imposes a great effect in improving the efficiency of domestic firms. For instance, Chinese and other Asian FDI, which are mostly dominated by oil and oil-based industries, are likely to have lesser knowledge spillovers compared to those firms originated from Western Europe and U.S.A. The small contribution by such types of FDI can be justified based on many reasons. First, most of the Asian FDI, especially the Chinese, is from countries which are endowed with a large labour force. This fact drives firms with this FDI to be accompanied by a great number of workers with the effect of restricting the share that could be occupied by native workforces. Second, even if native workers find ways to be recruited by these firms' FDI, the dissimilarity in languages of instructions and the cultural background would impede the dissemination of knowledge spillovers between foreign and native firms.

Another argument is centred on the role of the proximity in distributing knowledge spillovers into domestic firms. Oil-oriented investments, the major investing companies in Sudan, by its nature are scattered far away from domestic firms. Lacking proximity between foreign and domestic firms could place some limitations on the transmission of knowledge spillovers and, consequently, would discourage growth in native businesses (Menghinello et al., 2010). Nevertheless, oil-based companies can lead to some positive knowledge spillovers since most of them tend to operate in export industries and, therefore, they do not crowd out but rather crowd-in local companies (for providing services of various types). The occurrence of such a crowding in-relationship may facilitate exchanging knowledge and experiences supporting the growth of domestic firms. However, it is difficult to quantify these repercussions.

**Table 3.3: The top 10 companies investing in Sudan between January 2003 and May 2015**

| Rank | Company | No. of Projects | No. of Jobs offered | Volume (Million $) |
|---|---|---|---|---|
| 1 | China National Petroleum (CNPC) | 3 | 440 | 2,687 |
| 2 | Fuchs Petrolub | 1 | 146 | 1,641 |
| 3 | Petronas | 2 | 536 | 1,033 |
| 4 | Barwa Real Estate | 2 | 893 | 893 |
| 5 | Medco Energi Internasional | 1 | 214 | 537 |
| 6 | Arab Swiss Engineering Company (ASEC) | 2 | 1462 | 523 |
| 7 | Bharat Heavy Electricals (BHEL) | 1 | 38 | 392 |
| 8 | Bin Omeir Holding | 1 | 1,720 | 300 |
| 9 | Oil and Natural Gas Corporation (ONGC) | 1 | 740 | 200 |
| 10 | Investcom Holding | 1 | 89 | 150 |
| | Other Companies | 48 | 6,475 | 1342 |
| **Total** | | **63** | **12,753** | **9,698** |

**Source**: adopted from FDI Intelligence from The Financial Times (http://dhaman.net/wp-content/uploads/2016/02/Sudan.pdf)

## 3.4 Business Environment in Sudan

It is well established that the performance of Sudan in terms of FDI seems to be not satisfactory and, therefore, fails to generate significant benefits for domestic firms. This occurs although the country has made major economic reforms since 1992 onwards. In particular, these reforms include the implementation of economic liberalization which gives a green light for welcoming foreign investments. Moreover, on the regulatory front, the successive Sudanese governments had enacted a number of laws to encourage FDI. These packages were embodied in the Investment Encouragement Acts which were undertaken in 1956, 1958, 1972, 1973, 1974, 1976, and 1980. Lately, these reforms included the Acts of 1999, 2000, and 2005. Specifically, the Investment Encouragement Act of 1999 offered foreign investors a very rich package of concessions to establish businesses in Sudan. Going further in welcoming foreign investors, after one year, this Act was evaluated and modified in the 2000 Act. The new amendments gave foreign investors further encouraging incentives, including the permission to run businesses in sectors which were traditionally managed by the government, such as healthcare services provision, information technologies, and education. To give the legislation more reinforcement, the 2008's Presidential Decree and the Investment Act of 2013 strictly prohibited the expropriation of foreign investors.[21]

Currently, there are many obstacles hindering the country's performance in FDI's reception and utilization. In the global business environment, Sudan can be regarded as one of the countries being most costly in production for running businesses. This is so because the country's business environment is inhospitable for foreign investors. According to the World Bank and International Finance Corporation's Doing Business Reports, Sudan ranks 154th, 154th, 135rd, 143th, 149th, 160th and 159 out of 183 economies (see table 3.4) which are covered in the survey conducted for measuring the easiness of doing business for the years 2010, 2011, 2012, 2013, 2014, 2015, and 2016, respectively. Likewise, as can be read from the table 3.4, Sudan was a weak performer among the world's nations when it comes to indicators such as starting a business (with ranks 118, 121, 126, 122, 131, 139, and 146 for the years 2010, 2011, 2012, 2013, 2014, 2015 and 2016, respectively), and closing a business (rank 183 for the years 2011 and 2012, respectively). Moreover, Sudan stands, respectively, at rank 155 in 2014 and in 2015, and at rank 162 in the ranking of 183 economies on the ease of trading across borders. Similarly, on the global ranking for enforcing contracts, Sudan stands at ranks 154, 163 and 142 for the years 2014, 2015 and 2016, respectively.

No matter how much macroeconomic transformation reform is done, potential foreign investors are expected to be delayed by the massive amount of red tapes that faces them when they run business transactions. Complicated bureaucratic procedures concerning FDI have been common in Sudan, thus, frustrating foreign investor's job in setting up and operating new businesses. This conclusion can be indicated by the information given in table 3.5. As the table 3.5 shows, Sudan is behind other countries in terms of facilitating foreign investors' tasks. Compared to countries reported, Sudan occupies lower ranks in the easiness of doing business indicators. For instance, compared to countries such as Saudi Arabia (at 49th rank), Rwanda (at 46th rank), Kenya (at 136th rank), and Malaysia (at 18th rank), the country has ranks 160 and 159 in easing doing business in 2015 and 2016, respectively (table 3.5). Moreover, the gap between the best performer (Singapore) in terms of easiness of doing business and Sudan is very large, indicating that the country needs to do radical changes in its economic, social and political settings to improve its business environment. Moreover, the spread of corruption in government departments represents one of the challenging hindrances that deteriorate FDI flows. According to the Transparency International organization's report on the corruption perceptions index, Sudan ranks among the most corrupt countries in the world

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[21] See on the recent UNCTAD Investment Policy Review: http://unctad.org/en/pages/PublicationWebflyer.aspx?publicationid=1156

with an index score of 11, 11 and 12 out of 100 (clean from corruption) for the years 2013, 2014 and 2015, respectively.[22]

**Table 3.4: Rank of Sudan in doing business indicators for different years**

| **Indicator** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Ease of doing business** | **160** | **143** | **147** | **154** | **154** | **135** | **143** | **149** | **160** | **159** |
| Starting a business | 82 | 95 | 107 | 118 | 121 | 126 | 122 | 131 | 139 | 146 |
| Dealing with construction permits | 92 | 131 | 135 | 139 | 139 | 130 | 156 | 167 | 160 | 146 |
| Registering property | 29 | 32 | 35 | 37 | 40 | 41 | 37 | 41 | 46 | 89 |
| Getting credit | 143 | 135 | 131 | 135 | 138 | 166 | 167 | 170 | 165 | 167 |
| Protecting minority investors | 142 | 141 | 150 | 154 | 154 | 155 | 158 | 157 | 174 | 166 |
| Paying taxes | 93 | 60 | 67 | 103 | 94 | 103 | 101 | 108 | 139 | 140 |
| Trading across borders | 165 | 143 | 139 | 142 | 143 | 151 | 153 | 155 | 162 | 184 |
| Enforcing contracts | 158 | 143 | 143 | 146 | 146 | 148 | 151 | 154 | 163 | 142 |

**Source**: World Bank Group (Ease of Doing Busienss Reports for different years)

[22] See on the Transparency International's Corruption Perceptions Index: https://www.transparency.org/

**Table 3.5: Rank of Sudan in ease of doing business indicators compared to some other countries**

| Indicator | Sudan 2014 | Sudan 2015 | Sudan 2016 | South Africa 2015 | Egypt 2015 | Ethiopia 2015 | Lebanon 2015 | Kenya 2015 | Malaysia 2015 | Saudi Arabia 2015 | Rwanda 2015 | Best performer globally (Singapore) 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ease of doing business** | **149** | **160** | **159** | **43** | **112** | **132** | **104** | **136** | **18** | **49** | **46** | **1** |
| Starting a business | 131 | 139 | 146 | 61 | 73 | 168 | 119 | 143 | 13 | 109 | 112 | 6 |
| Dealing with construction permits | 167 | 160 | 146 | 32 | 142 | 28 | 164 | 95 | 28 | 21 | 34 | 2 |
| Registering property | 41 | 46 | 89 | 97 | 106 | 154 | 106 | 136 | 75 | 20 | 15 | 24 |
| Getting credit | 170 | 165 | 167 | 52 | 71 | 165 | 116 | 116 | 23 | 71 | 4 | 17 |
| Protecting Minority Investors | 157 | 174 | 166 | 17 | 135 | 154 | 106 | 122 | 5 | 62 | 117 | 3 |
| Paying Taxes | 108 | 139 | 140 | 19 | 149 | 112 | 40 | 102 | 32 | 3 | 27 | 5 |
| Trading across borders | 155 | 162 | 184 | 100 | 99 | 168 | 97 | 153 | 11 | 92 | 164 | 1 |
| Enforcing contracts | 154 | 163 | 142 | 46 | 152 | 50 | 110 | 137 | 29 | 108 | 62 | 1 |

**Source**: The World Bank Group (Ease of Doing Reports 2014, 2015, and 2016)

The low rankings of Sudan in terms of doing business, coupled with widespread corruption, mirror the numerous challenges that the country faces at the current stage of development. The country is in a stage in which the economy needs more injections from physical capital and, more importantly, modern knowledge and sophisticated business practices

## 4 Research Methodology

As concluded above, the occurrence of FDI knowledge spillovers is conditioned by the existence of varieties of factors that differ from country to country and from region to region. For that reason, the current study attempts to examine the role of FDI knowledge spillovers in boosting growth of Sudanese domestic firms via their contributions to the labour productivity. The specification of the model, variables, method of analysis, and data are presented in this section.

### 4.1 Model specification

This study, based on the lead of a Caves-type model (Caves, 1974), and studies by Aschauer (1989) and Gera et al. (1999), formulates an empirical model to examine the impact of FDI knowledge spillovers on labour productivity in Sudan, which is taken as a function of physical capital intensity, educational attainment, total employment, workers' health, stock of FDI, and trade openness. The model to capture this purpose can be represented by the following equation:

$$LP(t) = EMP(t)^{\varphi_1} \, KL(t)^{\varphi_2} \, FDI(t)^{\varphi_3} \, OPEN(t)^{\varphi_4} \, EDU(t)^{\varphi_5} H(t)^{\varphi_6}(t) e^{\varphi_0'} \quad (4.1)$$

Where $LP$ is the labor productivity which is measured by the value of GDP per worker engaged in production[23]; $EMP$ is the number of labour force employed, $KL$ is the physical capital intensity which is normally measured by the capital labour ratio indicating an average level of physical capital needed per worker employed, $FDI$ is the stock of foreign direct investment, $OPEN$ is trade openness which is measured by the sum of exports and imports divided by GDP, $EDU$ is the human capital development measured by average years of schooling, and $H$ is workers' health status which is measured by the life expectancy at birth. By adding the constant, logarithms and error term to equation 4.1 yields:

[23] Wooster and Diebel (2010) state that the productivity, which mostly appears on the right-hand side, can be measured according to three approaches, including sector output (Aitken and Harrison, 1999), or labour productivity (Blomstrom and Sjoholm, 1999), or total factor productivity as proposed by Chaung and Lin (1999).

$$ln\,LP_t = \beta_0 + \beta_1 lnEMP_t + \beta_2 lnKL_t + \beta_3 lnFDI_t + \beta_4 lnOPEN_t + \beta_5 \ln EDU_t + \beta_6 lnH_t + \varepsilon_t \quad (4.2)$$

The error term is denoted by $\varepsilon_t$ and it is supposed to be normally distributed. The coefficients $\beta_1, \beta_2, \beta_3,\ \beta_4, \beta_5$and $\beta_6$ measure the percentage changes in labour productivity in response to a one percentage change in $EMP, KL, FDI, OPEN, EDU,$ and $H$ variables.

The parameter of interest is the estimated coefficient of the real FDI stock variable, $\beta_3$, which gathers the contribution of FDI knowledge spillovers to the productivity of labour working in Sudanese domestic firms. The testable hypothesis is that the growth in domestic firms is higher the higher the contribution of FDI knowledge spillovers to enhance labour productivity. Hence, a positive coefficient on $lnFDI_t$ can be suggested. Moreover, the theoretical claim that the productivity of labour is dependent on the capital per worker represents the main reason to include the physical capital intensity variable in the model. In addition, total employment is another key explanatory variable in determining labour productivity. According to the law of diminishing marginal productivity, increases in the number of labour employed entail decreases in labour productivity. The sign of the coefficient accompanied with this variable is, therefore, expected to be negative.

To capture the influence of human development on labour productivity, both the average years of schooling and the life expectancy are included as independent variables. It has been hypothesized that the greater the educational attainment, the higher the labour productivity. The Barro and Lee conjecture is that increases in average years of schooling induce significant increases in labour productivity (Barro and Lee, 1996). Hence, in the above model, the relationship between labour productivity and both education and workers' health status is expected to be positive. Nevertheless, there is no catch-all measurement for workers' health and, therefore, proxies such as healthiness are frequently used. Thus, the life expectancy at birth ($H_t$) has been included in the model as a proxy for workers' healthiness and has been justified based on the human capital argument which emphasizes the role of good health in raising labour productivity.

Lastly, labour productivity is also expected to be affected by the degree of trade openness. Specifically, trade openness can affect labour productivity by increasing technology transfers from abroad, expanding market discipline, and granting additional market channels for local products. Consequently, the expected sign of the coefficient on $lnOPEN_t$ is expected to carry a positive sign.

## 4.2 The econometric methodology

The autoregressive distributed lag (ARDL) procedure to co-integration will be used to estimate the model developed in the previous sub-section. As advocated by Pesaran et al. (2001), the ARDL co-integration procedure has many econometric merits compared to other multivariate co-integration techniques such as Johansen and Juselius[24] and Engle-Granger[25] two-step methods. For instance, ARDL is applicable irrespective of whether the variables are integrated of I(0) or I(1). Additionally, the ARDL bound test technique is relatively more efficient in the small sample data size and, thus, eliminates the possibility of a spurious relationship resulting from non-stationary data while preserving the long run information (Pesaran et al., 2001).

The procedure to estimate the ARDL involves four steps. First, performing stationary tests to determine the co-integration order of the variables and to ensure that no variable is integrated at order that exceeds I (1). Second, as proposed by Pesaran et al. (2001), in the next step, the bounds test based on F-statistics will be executed to inspect the presence of the long-run relationship among variables. Third, if the variables in each equation reveal the existence of co-integration, the estimation of the coefficients of the long and short-run relationships will be carried out. Based on the assumption made by Pesaran et. al. (2001), the study proceeds to estimate the short run and long run parameters by constructing an Unrestricted Error Correction Model (UECM). Specifically, the error correction version of the ARDL model for equation 4.2 can be expressed as:

$$\begin{aligned}\Delta lnLP_t = \beta_0 &+ \sum_{i=1}^{n} \beta_{1i}\, \Delta lnLP_{t-i} + \sum_{i=0}^{n} \beta_{2i}\, \Delta lnEMP_{t-i} + \sum_{i=0}^{n} \beta_{3i}\, \Delta lnKL_{t-i} \\ &+ \sum_{i=0}^{n} \beta_{4i}\, \Delta lnFDI_{t-i} \sum_{i=0}^{n} \beta_{5i}\, \Delta lnOPEN_{t-i} + \sum_{i=0}^{n} \beta_{6i}\, \Delta lnEDU_{t-i} \\ &+ \sum_{i=0}^{n} \beta_{7i}\, \Delta lnH_{t-i} + \lambda_1\, lnLP_{t-1} + \lambda_2\, lnEMP_{t-1} \\ &+ \lambda_3\, lnKL_{t-1} + \lambda_4\, lnFDI_{t-1} + \lambda_5\, lnOPEN_{t-1} + \lambda_6\, lnEDU_{t-1} \\ &+ \lambda_7\, lnH_{t-1} + \varepsilon_t \qquad (4.3)\end{aligned}$$

Where $\Delta$ represents the first difference operator, $t$ is time trend, $n$ is the optimal lag length. The parameters $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$ and $\beta_7$ represent the short run error correction dynamics, while $\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6$ and $\lambda_7$ represent the long run relationships. The null hypothesis of no co-integration in the long-run relationship - when $lnLP_t$ is treated as dependent variable ($H_0 : \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = \lambda_6 = \lambda_7 = 0$) - is tested against the alternative hypothesis ($H_1 : \lambda_1 \neq$

[24] See: https://ideas.repec.org/c/dge/qmrbcd/16.html

[25] See: https://en.wikipedia.org/wiki/Cointegration

$\lambda_2 \neq \lambda_3 \neq \lambda_4 \neq \lambda_5 \neq \lambda_6 \neq \lambda_7 = 0$ ) by an F-test. Then the computed F-statistic values, which are generated from the estimation of the above equation, will be evaluated with the critical values of Pesaran et al. (2001). Specifically, if the computed F-statistic is found to be greater than the upper bound value, then it can be concluded that the concerned variables have a long-run level relationship. On the contrary, if the computed F-statistic is smaller than the lower bound value, then the null hypothesis cannot be rejected and we conclude that there is no long-run relationship between labour productivity and the predictors' variables including the FDI knowledge spillovers. Yet, if the computed F-statistic falls between the lower and upper bound values, the results are inconclusive.

Once the long-run relationship between concerned variables is ascertained, the final stage of the ARDL technique involves estimating the coefficients of the long run relationships and interpreting their values. Therefore, the vector error correction model will be estimated to detect the causality direction between labour force productivity and the FDI knowledge spillovers. The vector error correction of ARDL which belong to the variables in equation 4.2 can be constructed as follows:

$$\begin{aligned}\Delta lnLP_t = \alpha_0 &+ \sum_{i=1}^{n} \alpha_{1i}\, \Delta lnLP_{t-i} + \sum_{i=1}^{n} \alpha_{2i}\, \Delta lnEMP_{t-i} + \sum_{i=1}^{n} \alpha_{3i}\, \Delta lnKL_{t-i} \\ &+ \sum_{i=1}^{n} \alpha_{4i}\, \Delta lnFDI_{t-i} \sum_{i=1}^{n} \alpha_{5i}\, \Delta lnOPEN_{t-i} + \sum_{i=1}^{n} \alpha_{6i}\, \Delta lnEDU_{t-i} \\ &+ \sum_{i=0}^{n} \alpha_{7i}\, \Delta lnH_{t-i} + \delta_1\, ecm_{t-1} \\ &+ \mu_t \end{aligned} \qquad (4.4)$$

Where $n$ represents the optimal lag length, $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \alpha_6, \alpha_7$ are the short-run dynamic coefficients of the model, $ecm_{t-1}$ represents the error correction term, $\mu_t$ is the serially uncorrelated errors term, and $\delta_1$, which is expected to have a negative coefficient, is the speed of adjustment toward the long-run equilibrium.

### 4.3 The Data

This study employs 35 annual observations covering the period from 1980 to 2014 to investigate the role of FDI's knowledge spillovers in boosting growth in Sudanese domestic firms by means of their support to labour productivity. The data on the variables relating to gross domestic capital formation and life expectancy at birth are sourced from the World Development Indicators (The World Bank, 2015), reported by World Bank. Similarly, the data on total employment and the stock of foreign direct investments (FDI) are obtained from United Nations Conference on Trade and Development (UNCTAD) statistics (http://unctadstat.unctad.org). Finally, the data on labour productivity (measured by per worker output) and on educational attainment (measured by average years of schooling) are brought from International Labour Organization (ILO) statistics (http://www.ilo.org/global/statistics-and-databases/research-and-databases/kilm/lang--en/index.htm), and from the Barro and Lee database (http://www.barrolee.com/data/dataexp.htm), respectively. The data reported include labour productivity ($LP$), total employment ($EMP$), trade openness ($OPEN$), physical capital intensity ($KL$), real FDI stock ($FDI$), human development ($EDU$), and worker's health status ($H$). The physical capital intensity is computed by dividing real gross domestic capital by the number of workers employed. All monetary variables have been converted to real values.

## 5 The Empirical Results

### 5.1 Testing the order of integration

Both the Augmented Dickey-Fuller (ADF)[26] and the Phillips and Perron (PP)[27] unit root tests are applied to the logarithms of the seven time series included in the model under investigation ($lnLP_t, lnEMP_t, lnEDU_t, lnOPEN_t, lnFDI_t, lnKL_t, and\ \ lnH_t$), with and without constant and time trend. Table 5.1 reports the results related to the Augmented Dickey-Fuller (ADF) and Phillip and Perron (PP) unit roots tests. Overall, the tests show that the null hypothesis, the series in levels contain unit roots, with constant but without trend, cannot be rejected with exception of total labor employed ($lnEMP_t$), real FDI stock ($lnFDI_t$), and workers' health ($lnH_t$) series.

[26] See: https://en.wikipedia.org/wiki/Augmented_Dickey%E2%80%93Fuller_test
[27] See: https://en.wikipedia.org/wiki/Phillips%E2%80%93Perron_test

**Table 5.1: Summary of ADF and PP unit roots tests for variables at both level and first difference**

| Variables | ADF test Statistic | | PP test Statistic | |
|---|---|---|---|---|
| | With constant but without trend | With constant and trend | With constant but without trend | With constant and trend |
| LnLP | -0.1412 | -2.2938 | -0.3646 | -2.3038 |
| LnEMP | -0.5438 | -4.0302** | -0.5162 | -2.1520 |
| LnEDU | -2.1773 | -1.7344 | -14.026*** | -3.1958 |
| LnOPEN | -1.6438 | -1.6716 | -1.6169 | -1.7887 |
| LnFDI | -3.0237** | -2.7601 | -1.6321 | -1.1998 |
| LnKLR | -1.4467 | -2.9923 | -1.4762 | -0.9645 |
| LnH | -2.6801* | -3.8968** | 4.7950*** | -2.1073 |
| ΔLnLP | -4.8018*** | -4.7829*** | -4.8094*** | -4.7940*** |
| ΔLnEMP | -0.5439 | -4.0301** | -0.5162 | -2.1520 |
| ΔLnEDU | -1.9271 | -2.2873 | -2.1098 | -2.3157 |
| ΔLnOPEN | -7.2912*** | -7.1818*** | -7.1164*** | -7.0249*** |
| ΔLnFDI | -2.7182 | -3.0406 | -2.7279* | -2.9915 |
| ΔLnKLR | -1.8039 | -1.9368 | -3.2354** | -3.5815** |
| ΔLnH | -1.4844 | -1.2661 | -1.5775 | 2.5998 |

**Note**: Δ denotes first difference operator. ***, **, and * denote the rejection of null hypothesis of unit root at the 1%, 5% and 10% significance levels, respectively.

Similarly, apart from average years of schooling and workers' health series, the test results for stationarity with constant and trend fail to reject the null hypothesis for unit roots. However, after differencing the data once, the test statistics reject the null hypothsis for the series that were found to be non-stationary at levels. Specifically, the results of the ADF and PP tests suggest that some varaibles are I(1) at log level while others are I(0) at first differences. Thus, the inclusiveness in the presence of unit roots legitimates the use of the ARDL approach to estimate the empirical model without giving attention for whether the underlying varaibles are I(1) or I(0) .

## 5.2 Co-integration test results

After verifying that all variables are integrated of an order that does not exceed one, the data series are further tested by using the ARDL bounds test procedure to co-integration (see table 5.2). However, before testing for cointegration, it is necessary to determine the appropriate lag length to be used in the test. Five lag selection criteria have been used for this purpose. The five tests, namely, the Sequential Modified Likelihood Ratio test statistic (LR), the Final prediction error

(FBE), the Akaike information criterion (AIC), the Schwarz information criterion (SC), and the Hannan-Quinn information criterion (HQ), suggest for setting the lag length at 1.

**Table 5.2: Bounds tests for cointegration**

| Critical value | Lower Bound | Upper Bound | Decision |
|---|---|---|---|
| 10% | 2.12 | 3.23*** | Cointegration |
| 5% | 2.45 | 3.61** | Cointegration |
| 2.5% | 2.75 | 3.99*** | Cointegration |
| 1% | 3.15 | 4.43 | Inconclusive |
| *Calculated F-Statistic: (LOG(LP) LOG(EMP) LOG(EDU) LOG(OPEN) LOG(FDI) LOG(KL) LOG(H))* | | | 4.42 |

***, **, and * indicate statistical significance at 1%, 5% and 10% levels, respectively.

The results of the ARDL bounds test for co integration between real labour productivity and its determining factors, among them is FDI knowledge spillovers, are reported in table 5.2. From these results, it can be read that the computed F-statistic (F-statistic = 4.42) is higher than the upper-bound critical values (3.23, 3.61 and 3.99) at the 10%, 5%, and 2.5% significance levels, respectively. This implies that the null hypothesis of no co-integration (i.e. no long-run relationship) between real labour productivity and its regressors is rejected at the 10%, 5%, and 2.5% significance levels. In other words, the results indicate that there is a long-run relationship among the variables incorporated in equation 4.3 when real labour productivity is normalized, and that the right-hand side variables can be treated as the long run factors in explaining growth in real labour productivity. Thus, the study goes forward to estimate the short-run and long-run relationships in ARDL framework.

## 5.3 Estimating the long-run coefficients

After having established that there is a long run co-integrating relationship between labour productivity, total employment, physical capital intensity, FDI knowledge spillovers, and human development variables (educational attainment and workers' health), in the next step, equation 4.3 will be estimated using the ARDL (1, 1, 0, 0, 0, 1, 0) specification and selected as based on the Akaike Information Criterion (AIC). The estimation results are reported in table 5.3, along with the commonly used diagnostic tests. The results indicate that the coefficients of FDI knowledge spillovers ($lnFDI_t$), total employment ($lnEMP_t$), education ($lnEDU_t$), physical capital intensity ($lnKL_t$), trade openness ($lnOPEN_t$) and workers' health status ($lnH_t$) are all associated with the correct signs and significant.

The influence of FDI knowledge spillovers is of primary concern. Interestingly, the coefficient of FDI knowledge spillovers is positive and significant in the long run. However, this coefficient is marginally significant. Such a result can be interpreted as being a consequence of the fact that Sudan does not possess the sufficient prerequisites that are necessary for maximizing FDI knowledge spillovers. The estimated coefficient suggests that a one per cent increase in FDI knowledge spillovers is associated with an increase in real labour productivity growth rate by almost 0.08 per cent. This confirms that FDI knowledge spillovers in Sudan play a substantial role in escalating labour productivity and, accordingly, promote growth in domestic firms. This outcome also complements our earlier stylized facts on the observed association between FDI presence on the one hand and growth in labour productivity and gross domestic capital formation on the other. This outcome is also compatible with findings by Barrell and Pain (1997), Sjoholm (1999), and Ramirez (2000) who confirm the role of FDI in raising labour productivity in host countries.

As expected, the estimated coefficient of the total employment variable is found to be negative and statistically significant at the ten percent level of significance, suggesting that the growth in employment contributes negatively towards real labour productivity. In particular, an increase in total employment by 1% would lead to a 1.42% reduction in per worker productivity. Based on the law of diminishing marginal utility one could be attempted to argue that, other things being equal, increases in the number of labour would shrink total output and, consequently, diminish per worker productivity. The human development variables are found to be significant at the 10% level or better. The average years of schooling ($lnEDU_t$) was intended to convey the absorptive capacity of the labour force. As expected, the variable's coefficient bears a positive and significant sign indicating that higher educational attainment fosters labour productivity in Sudan. The results imply that an increase in the average years of schooling by one percent increases total labour productivity by 0.50 percent. Similarly, the significant positive relationship in front of the life expectancy at birth variable implies that workers' health status has an edge effect among the rest of factors affecting labour productivity and, thus, growth of Sudanese firms. This could be the case because healthy workers are usually possessing higher absorptive capacity what makes them capable to digest educational and knowledge inputs. In contrast, the coefficient of physical capital intensity is negative and statistically insignificant, thus, contradicting a priori expectations. Theoretically, adding more capital units in the production function increases other factors productivities. However, there are a couple of explanations that could be offered to account for this contradiction. One explanation is that the level of capital intensity in Sudanese firms is still less than the thresholds may possibly allow generating productivity gains for labour. In other words, the huge numbers of labour working in these domestic businesses make the negligible increases in capital intensity unable to realize a significant and positive impact on per worker productivity. Another potential explanation is that the occurrence of such a negative relationship is a manifestation of the usage of underdeveloped technologies in many of the Sudanese domestic firms.

**Table 5.3: Estimates of the long run coefficients - ARDL (1, 1, 0, 0, 0, 1, 0)**

| **Dependent variable** | **Labour productivity** | | | |
|---|---|---|---|---|
| Variable | Coefficient | Standard Error | t-ratio | P-value |
| LnEMP | -1.423** | 0.653 | -2.178 | 0.039 |
| LnEDU | 0.495** | 0.216 | 2.299 | 0.031 |
| LnOPEN | 0.077 | 0.055 | 1.392 | 0.177 |
| LnFDI | 0.056* | 0.031 | 1.815 | 0.082 |
| LnKL | -0.017 | 0.016 | -1.023 | 0.317 |
| LnH | 8.373*** | 2.450 | 3.417 | 0.002 |
| Constant | -3.844 | 3.574 | -1.076 | 0.293 |
| $R^2$ | 0.98 | Mean dependent variable | | 8.395 |
| Adjusted $R^2$ | 0.97 | S.D. dependent variable | | 0.237 |
| S.E. of regression | 0.0342 | Akaike info criterion | | -3.668 |
| Sum squared resid. | 0.0282 | Schwarz criterion | | -3.219 |
| Log likelihood | 72.365 | Hannan-Quinn criterion | | -3.515 |
| F-statistic | 174*** | Durbin-Watson statistic | | 1.686 |
| Prob (F-statistic) | 0.000 | | | |

**Note**: ***, **, and * indicate significance at the 1, 5 and 10 percent levels, respectively

In terms of the relative magnitudes of the variables' coefficients, the results show that improving human capital indicators, compared to FDI knowledge spillovers, were more effective in boosting labour productivity. The interpretation of such findings is straightforward. Firstly, in the context of a developing country like Sudan, improvements in healthiness and education can lead to significant increases in labour productivity, stimulating domestic firms to develop. Second, the moderate achievement in human development in Sudan is anticipated to limit workers' capacities to internalize knowledge spillovers brought in by FDI. Concisely, in order to generate a significant enhancement in labour productivity, human development must exceed a certain threshold that allows the efficient utilization of FDI knowledge spillovers. Third, as discussed earlier, since the business environment in Sudan is not hospitable for MNCs' operations, the small size of FDI hosted by the country would lower the magnitudes of these knowledge spillovers on labour productivity.

## 5.4 Results on Short-run Dynamics

Table 5.4 reports the results for equation 4.2 when estimated as a short-run dynamic. As apparent from the table 5.4, most of the explanatory variables are significant at the 5 percent level or better and carry the expected signs. This reveals several interesting outcomes regarding the influence of FDI knowledge spillovers on Sudanese firms. The short-run coefficients of FDI knowledge spillovers ($lnFDI_t$), total employment ($lnEMP_t$), education ($lnEDU_t$), physical capital intensity ($lnKL_t$), trade openness ($lnOPEN_t$) and worker's health ($lnH_t$) are positive, but two variables (i. e., physical capital intensity and trade openness) fail to satisfy the significance conditions even at conventional levels. The crucial variable, FDI knowledge spillovers, has a positive effect on labour productivity with a coefficient of 0.039 in the short run, half of the one obtained in the long run (0.077). This implies that a one percent increase in knowledge spillovers, as measured by FDI stock, will be associated by, approximately, a 0.04 increase in labour productivity. The fact that FDI's presence has a positive and significant effect in both the short and the long run reinforces the existence of the hypothesized contributions of FDI of knowledge spillovers in boosting growth of domestic firms in Sudan. However, different from the long run outcome, the short run coefficient of employment turns out to be positive indicating that higher employment levels are associated with short run increases in labour productivity. This outcome can be propounded by the argument of the law of diminishing marginal productivity which states that the increases in a production input, before exceeding a certain limit, would generate increases in total product.

Interestingly, the coefficients associated with the human development variables are positive and statistically significant in the short run. In particular, the coefficient on the workers' healthiness is roughly 5.84. It is the largest among all predictor variables reaffirming the decisive contribution of healthiness to labour productivity. Analogues to the long run results, the coefficient in front of capital intensity carries the correct sign but it does not show any level of significance. In accordance with the long-run results, the findings also show that the coefficient of trade openness is found to be positive, however, it lacks the significance. Such a result may advocate the neutrality of trade openness in upgrading labour productivity in Sudan. Finally, as displayed in Table 5.4, the error correction term ($ecm_{t-1}$), which measures the short run deviation of real labour productivity from its long run equilibrium, is negative and statistically significant. This entails that the explanatory variables are jointly exercising short run effects on real per worker productivity. Specifically, the error correction term's coefficient (the speed of adjustment) is -0.69, demonstrating a rapid convergence to the long run equilibrium.

**Table 5.4: Estimates of the error correction representation**

| **Dependent variable** | **Labour productivity** | | | |
|---|---|---|---|---|
| Variable | Coefficient | Standard Error | t-ratio | P-value |
| DLnEMP | 0.817* | 0.449 | 1.817 | 0.081 |
| DLnEDU | 0.346** | 0.130 | 2.658 | 0.013 |
| DLnOPEN | 0.054 | 0.043 | 1.239 | 0.227 |
| DLnFDI | 0.039* | 0.021 | 1.849 | 0.076 |
| DLnKL | 0.018 | 0.019 | 0.923 | 0.365 |
| DLnH | 5.841*** | 1.786 | 3.269 | 0.003 |
| ecm(-1) | -0.698*** | 0.149 | -4.663 | 0.000 |

**Note**: ***, **, and * indicate significance at the 1, 5 and 10 percent levels, respectively

## 5.5 Results of Diagnostic Tests

Summing up, the estimated model indicates a good fit to the data since the estimated value of Adjusted $R^2$ shows that 97% of the variations in total labour productivity are explained by variables incorporated in the model. The computed F-statistic is highly significant (174.0113), inferring that the null hypothesis that all regressors have zero coefficients is rejected. More importantly, the diagnostic tests show no problem suggesting that the model is well specified and has satisfactory diagnostics. Table 5.5 reports the results for a set of diagnostic tests performed on the residuals in the model estimated.

As shown in the table 5.5, the results show that the residuals are normally distributed since Jarque-Bera statistic[28] does not reject the null hypothesis of normality (JB statistic = 0.133028, with a p-value of 0.9357). Also, the diagnostic tests demonstrate no evidence for serial correlation, since the Lagrange-Multiplier F-test (LM)[29] shows p-values of 0.3506 and 0.2574 for the first and the second orders, respectively. The model is also free from heteroskedasticity given that the results of Breusch-Pagan-Godfrey[30], ARCH[31], Harvey[32] and White[33] have strongly

[28] See: https://en.wikipedia.org/wiki/Jarque–Bera_test
[29] See: https://en.wikipedia.org/wiki/Lagrange_multiplier
[30] See: https://en.wikipedia.org/wiki/Breusch%E2%80%93Godfrey_test and: https://en.wikipedia.org/wiki/Breusch%E2%80%93Pagan_test
[31] See on ARCH (Autoregressive Conditional heteroskedasticity): https://en.wikipedia.org/wiki/Autoregressive_conditional_heteroskedasticity
[32] See: http://econpapers.repec.org/article/ecmemetrp/v_3a44_3ay_3a1976_3ai_3a3_3ap_3a461-65.htm
[33] See: https://en.wikipedia.org/wiki/White_test

rejected the null hypothesis of homoscedasticity. Additionally, the model convincingly passes the Ramsey Reset stability test[34] at the 1% level of significance since the estimated F statistic value is 1.15 with p-value of 0.2950.

**Table 5.5: The residuals diagnostic tests**

| Diagnostic test | Estimated Value | Probability |
|---|---|---|
| Normality Test (Jarque-Bera) | 0.133028 | [0.9357] |
| Breusch-Godfrey Serial Correlation LM Test | [1]:F(01,23) = 0.907943 | [0.3506] |
| | Chi-square (1) = 1.291206 | [0.2558] |
| | [2]:F(02,22) = 1.444411 | [0.2574] |
| | Chi-square (2) = 3.946348 | [0.1390] |
| ARCH heteroskedasticity test | [1]:F(01,31) = 0.768501 | [0.3874] |
| | Chi-square (1) =0.79829 | [0.3716] |
| | [2]:F(02,29) = 0.216179 | [0.8069] |
| | Chi-square (2) = 0.47007 | [0.7905] |
| | [3]:F(03,27) = 1.306956 | [0.2925] |
| | Chi-square (3) = 3.93090 | [0.2690] |
| Breusch-Pagan-Godfrey heteroskedasticity test | [1]:F(09,24) = 0.795088 | [0.6240] |
| | Chi-square (9) = 7.809044 | [0.5535] |
| White Heteroskedasticity test (with no cross terms) | F(09,24) = 0.845402 | [0.5833] |
| | Chi-square (9) =8.18425 | [0.5157] |
| Residuals stability test (Ramsey RESET Test) | [1]:F(01,23) = 1.148488 | [0.2950] |
| | [2]:F(02,22) = 0.970734 | [0.3944] |

[34] See: https://de.wikipedia.org/wiki/RESET_Test

Based on the good performance of the model and the quality of diagnostic tests, it can be said that FDI knowledge spillovers have positive effects on domestic firms in Sudan by means of their contribution to labour productivity.

## 6 The Implications of Empirical Results

According to the results reported in previous subsections, the contribution of FDI in elevating growth in Sudanese domestic firms, via labour productivity, is found to be positive but it is negligible. Many obstacles are thought to stand behind this unsatisfactory performance. These may include the characteristics of domestic firms themselves, the type of FDI hosted, the low level of human development, and the fragile infrastructural setting in which both foreign and domestic firms operate. Picking one factor, domestic firms in Sudan are far behind in the usage of sophisticated technologies and in applying managerial practices in businesses. According to a report by the World Bank, only 7% of Sudanese firms have obtained internationally-recognized quality certification, and only 9.5% of them offer training programmes for their permanent employees. The most noticeable indication of underdevelopment engulfing these firms is the fact that the share of the industrial sector in GDP is not expanding; it is contributing only an annual average share which is not exceeding 20% of the total value added to the country's GDP during the last five decades (World Bank, 2017). Most of the goods produced by this sector come from light industries, such as soft drinks, sweets, and soap, sectors in which sophisticated technologies are not used. In addition, labour employed in these sectors remains with low skills and is too often incompetent to digest new technologies and business practices including the ones brought by FDI. This fact pushes foreign investors to import inputs from abroad leaving no room for potential forward and backward linkages with domestic firms. Accordingly, the majority of the FDI projects operate without creating connections with domestic businesses. Undoubtedly, the absence of such connections hinders the process of transferring knowledge from foreign firms to domestic firms and, consequently, frustrates the growth of domestic firms.

The weakness in human development can be also counted as one of the factors that impede the full utilization of potential FDI spillover effects in extending growth of Sudanese domestic firms. The above positive results on human development variables confirm the significant effects of FDI in increasing labour productivity. However, the poor impact of FDI on labour productivity may indicate that the existing level of human development does not allow the circulation and use of FDI knowledge spillovers. It is well recognized that the existing educational system in Sudan fails to equip enrolees with knowledge and skills needed by foreign firms. The shortage in preparing highly skilled labour leads foreign firms to contract workers from abroad. In the end, the failure to equip labour with the suitable tools and the requested knowledge decreases the benefits that could arise from FDI, leading to real growth losses for Sudanese domestic firms.

Equivalently, the poor infrastructural development in Sudan may also minimize the effectiveness of FDI's knowledge spillovers in augmenting growth of domestic firms. That is, the poor infrastructure, such as unpaved roads, shortages in waters supply, deficient health care services, as well as the severe lack in the provisions of public utilities, places adverse effects on the transmission of FDI knowledge spillovers. Poor infrastructure disturbs labour mobility by making the domestic sector with its firms operating in isolation from each other and, consequently, weakens the transfer of FDI knowledge spillovers. Additionally, the existence of a fragile infrastructure discourages hosting larger amounts of FDI, and in the best cases it encourages companies with less sophisticated technologies and managerial skills. In either case, the poor infrastructure adversely affects the process of transferring FDI knowledge spillovers to local workers and, thus, delays acquiring the benefits that could possibly boost growth of domestic firms.

Similarly, the impact of the type of FDI hosted should not be ignored when diagnosing the modest contribution of FDI knowledge spillovers to the growth of domestic firms. As shown above, the majority of FDI which is targeting Sudan is attracted by the country's richness in natural resources, particularly oil. Such a type of FDI, which mostly operates in isolation from domestic firms, prevents domestic workers from acquiring knowledge spillover effects. It is also worth mentioning that most of the oil fields of Sudan are in South Kordofan State (i.e. the Heglig area), which is an area far away from the country's major cities, such as El Obeid, Wad Madni, Atbara, Port Sudan and Khartoum. The concentration of oil-oriented FDI outside of these business focal points would exert negative consequences on the transmission of FDI knowledge spillovers, or at least would neutralize its role in nurturing growth of domestic firms. In addition, hosting larger amounts of resource-seeking FDI will hamper the establishment of huge industrial and businesses areas and, thus, will minimize the circulation of FDI spillover effects via the agglomeration effects.

With all these obstacles in mind, policymakers in Sudan need to adopt a package of policies to increase the benefits of FDI knowledge spillover effects on Sudanese domestic firms. These policies may include:

*First***,** policymakers need to coin policies that aim at promoting growth in the industrial sector. This is because the dynamic nature of this sector, coupled with the feasible backward and forward linkages with other sectors, would optimize the productivity's benefits arising from FDI, and thus, would further growth of domestic firms. The suggested policies may include encouraging growth in industrial sector via granting tax concessions and the provision of free public utilities to domestic investors who intend to invest in industries that possess multiple backward and forward linkages. Such concessions need to be bound strictly by measurable successes.

*Second,* encouraging FDI to locate in the where domestic firms also are located. Specifically, foreign companies should be driven to locate projects in the country's key industrial and business areas in Khartoum, Omdurman, and Khartoum North. Furthermore, extra hospitable packages of incentives should be given to foreign investors who situate their investments in regional cities in areas such as El Obeid, Kassala, Gadarif, Gezira, Darfur, Kordofan, White Nile, River Nile, and Northern states. This will help greatly in maximizing the transmission of knowledge spillovers from foreign companies to domestic ones by easing and facilitating labour mobility. Moreover, given the technological gap between industries located in regional cities and FDI, transplanting more foreign projects to cities in regions/states could contribute to benefits of domestic firms from FDI's knowledge spillovers. Again, the packages of incentives need to be carefully targeted and monitored.

*Third***,** policymakers should encourage innovations among Sudanese domestic firms via creating a highly competent and disciplined accreditation body. Establishing such organization will enact competition and, thus, motivate domestic firms to implement modern technologies in their production processes. Furthermore, enacting such an accreditation body will motivate domestic firms to be more innovative and, thus, to be familiarized with the new knowledge introduced by FDI. As an end outcome, FDI knowledge spillovers will be fully exploited allowing for more growth of domestic firms. Although there are various accreditation/certification bodies (such as the Sudanese Standards and Metrology Organization) and specialized firms (involved in training and advising on accreditation and certification) already acting in Sudan, more transparency and control is needed.

*Fourth,* the existing infrastructure in Sudan is fragile and inadequate to support both foreign and domestic businesses. Hence, policymakers should work on developing a modern infrastructure to make FDI knowledge spillovers more effective in promoting growth of domestic firms. New road networks, water supply plants, sewerage services, and electricity supplies need to be developed. Particularly, as being a cheaper mean of transportation, Sudanese Railways need to be rehabilitated. Also, ICT infrastructure needs to be developed, extended and updated. A long-term infrastructure development plan is requested. All this would encourage foreign firms to invest in the country, giving birth to more extensive FDI knowledge spillovers and, thus, accelerating growth of domestic firms.

*Fifth,* educational attainment plays a crucial role in elevating the growth of the Sudanese domestic firms via boosting labour productivity. Yet, the relatively weak contribution of FDI knowledge spillover effects in boosting per worker productivity may be attributed, among other factors, to the extremely underdeveloped educational systems in the country. Thus, to make these effects impactful on domestic firms, the existing educational systems in Sudan need to be reformed. Especially the vocational education system and the higher education system need an overhaul, mainly by restoring the whole systems and institutions, but also by establishing new colleges and centres being able to provide the students with the developmentally demanded qualifications and specializations, such as in the applied sciences, in engineering sciences, and in computer-based specializations. Taking such steps would decrease the gap between the knowledge and the skills that the students are equipped with and the demand of both foreign and domestic businesses for specific skills and qualifications. Such an overhaul of the educational systems would enlarge the opportunities to benefit from the FDI spillover effects.

*Sixth*, policymakers should work on attaching technical and applied colleges and centres to related businesses and industries to facilitate conducting training programmes for the students who may lately become employed in these industries and businesses. The whole vocational training system needs a reappraisal and a revitalization in Sudan, not only in the capital city but also in the regional cities. Also for this system close connections of the training institutions to the domestic firms and the transfer of modern technologies and learning aids are a prerequisite to attract also foreign firms.

## 7 Conclusions and Policy Implications

This study examines the impact of FDI knowledge spillovers on growth in domestic firms in Sudan by means of their contributions to total labour productivity. The empirical investigation is based on time series data sets which are spanned over the period 1980-2014. The autoregressive distributed lag (ARDL) approach to cointegration has been employed to overcome the econometric problems that could emerge from the stationarity characteristics of the data used. On the whole, the results based on the ARDL bound testing procedure demonstrate the existence of a stable long-run relationship between total labour productivity and its determinants. With the exception of physical intensity and trade openness variables, the empirical results show that most of the variables' coefficients are statistically significant, accompanied with correct signs, and are of interpretable magnitudes. In particular, the results indicate that FDI knowledge spillovers exercise a considerable influence in boosting labour productivity and, consistently, promote growth in Sudanese domestic firms. Most importantly, the findings on human development variables indicate the pivotal role of worker's health and education in deciding growth in domestic firms by improving total labour productivity.

Based on these findings, policymakers in Sudan might find it beneficial to encourage the integration between domestic and foreign firms to exhaust the possibilities of knowledge spillovers. This goal can be accomplished by taking up two policy actions. First, FDI knowledge spillovers can be encouraged by stimulating MNCs that use sophisticated technologies, have tendencies to create backward and forward linkages with domestic firms, and enjoy strong connections with foreign markets. Looked at differently, these desirable spillover effects can be reinforced by promoting the category of domestic firms that have a wide range of connections with FDI. The existence of such an integration would help in providing FDI with intermediate goods instead of importing them from abroad and, therefore, would motivate FDI inflows. Second, another policy option could also be implemented. In particular, this option calls on the government to design specific policies to attract the types of MNCs that contribute directly to strengthen domestic firms and, at the same time, have the potentiality to stimulate FDI inflows. Third, as confirmed by previous literature, the expansion in domestic firms through spillovers from FDI-productivity enhancing effects are not automatic, rather they are conditioned by the existence of a set of factors including enhanced absorptive capacities, higher levels of infrastructural development, and a friendly business environment. Fourth, to make these policy actions implementable, the existing Investment Acts need to be reconsidered. Especially, the encouragement packages proposed by these Acts, such as tax holiday and free access to public utilities, should be given to the type of FDI with higher potentials for knowledge spillovers. Finally, the findings of the study confirm the crucial role of education in accelerating total labour productivity in Sudan. Therefore, policy makers should intervene by modernizing the educational system to equip native workers with the skills and capabilities that make them able to absorb knowledge associated with FDI.

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# Unit 3: Science, Technology and Innovation (STI) Polices for Agricultural Transformation in Nigeria

# Science, Technology and Innovation (STI) Polices for Agricultural Transformation in Nigeria – An Introduction

**Reuben A Alabi[1] and Karl Wohlmuth[2]**

## 1 The Issues

### 1.1 Unfavourable food production and importation trends in Nigeria request urgent and determined policy action

Agriculture in the past was the biggest sector in Nigeria, and still accounts for 23 percent of GDP. About 85 per cent of Nigeria's total land area is agricultural land (covering 78.5 million hectares) out of which 39.5 million hectares are arable. Of the arable land, only 60 per cent has so far been cultivated. Less than 13 per cent of the country's agricultural land are irrigated (Eluhaiwe, 2010). Regarding the prevalent natural resources, there is no reason why Nigeria should be a net importer of large quantities of food. However, Nigeria's total food and agricultural imports are growing and are estimated to be at more than $10 billion in 2015 (USDA/United States Department of Agriculture, 2016). Wheat, rice, frozen fish, dairy products, wine, vegetable oil, intermediate and consumer-oriented products are the products with the largest imports. By continent, Nigeria imported goods mostly from Asia (44.6 percent), the European Union (33.6 percent), the Americas (14.1), Africa (6.5 percent), and from other countries (1.2 percent). By country, Nigeria's most significant suppliers include China (23 percent), the United States (10 percent), India (8 percent), Belgium (6 percent), the Netherlands (6 percent), and other countries across the world (FAO/FAOSTAT, 2017).

Nigeria imports about $1 billion worth of wheat annually[3]. Its estimated annual demand for milled rice is 5.2 million tonnes, while the average national production is 3.3 million tonnes. The supply and demand gap of 1.9 million tonnes is bridged only by importing rice (JICA/Japan International Cooperation Agency,

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[1] Reuben A. Alabi is Full Professor of Agricultural Economics at the Department of Agricultural Economics, Ambrose Alli University, Ekpoma, Edo State, Nigeria, and Guest Professor at IWIM (Institute for World Economics and International Management), University of Bremen.

[2] Karl Wohlmuth is Professor Emeritus at the University of Bremen, Bremen, Germany, and Chief Editor of the African Development Perspectives Yearbook since 1989.

[3] The country remains a growth market for wheat imports because of its huge population. Demand for wheat flour, which is utilized for producing bread, noodles, pasta and biscuits (cookies), has also continued to increase.

2013). Nigeria's dairy market is estimated at 440,000 tonnes. However, local dairy processors rely on combining and reconstituting milk powder which is imported mostly from the European Union (Netherlands, Denmark, etc.)[4]. Frozen sea food is the cheapest form of animal protein in Nigeria, and consumption has been increasing. The country is a potential market for approximately 2.5 million tonnes of fish valued at about $3 billion. The Netherlands, China, Chile, etc. are also the major suppliers of frozen seafood to Nigeria. U.S. fish exports to Nigeria alone reached about $14 million in 2015 (USDA, 2016)[5].

The country's consumption of wheat remained high, at more than 4 million tonnes in 2015. Local wheat production is insignificant as Nigeria produced only 70,000 tonnes of wheat in 2014. In 2013, Nigeria had imported 4.4 million tonnes of wheat at a cost of $1.6 billion (FAO/FAOSTAT, 2017). The huge market gap is filled by wheat imports. It is believed that up to 600,000 hectares of land are suited to wheat production in Nigeria, with only 10 percent currently cropped on a regular basis. Insurgency activities have adversely impacted on Nigeria's wheat production[6]. The Nigerian government targets 2017 for rice self-sufficiency. But Nigeria's rice production target is very far from reality, due mainly to a lack of infrastructure, poor policy implementation, as well as an increasing state of insecurity caused by Boko Haram in the major rice-producing region in Northern Nigeria. Domestic sea food catches and aquaculture production are underdeveloped, and the country relies on large volumes of imports to meet the local demand for fish.

Generally, the current situation in regard of the domestic production of agricultural products is unfavourable, due to increasing production/processing costs, non-competitiveness of the processing industry, and the failure to incorporate more advanced technologies. Trade and economic policies have been put in place to address the problem of low agricultural production and to reduce the imports of agricultural products in which the country has a production potential. For instance, to reduce wheat imports, to stimulate local wheat production and cassava production, and to conserve foreign exchange, the Government in 2012 introduced a policy compelling cassava flour inclusion in wheat flour and has also imposed an import tax (levy) of 15 percent on wheat grain (which has increased the effective

[4] However, squeezed consumer incomes, resulting from Nigeria's declining oil revenues, is retarding market growth. U.S. export of dairy products to Nigeria had continued to rise since 2011.

[5] Nigeria began the implementation of an import quota regime for fish in 2014. The aim was to stimulate the country to become self-sufficient in fish production over the next four years, through a 25 percent annual fish import cut. An annual baseline fish import figure has been set at 700,000 tonnes for 2014, which reduces the allowable quantity of imported fish to 500,000 tonnes for the year.

[6] Nigeria's wheat milling capacity is estimated at about 8 tonnes, with 21 milling operations stretched across the country.

duty from 5 percent to 20 percent). Another important policy introduced by the Nigerian government to stem the tide of excessive food imports was the introduction of a 20 percent levy in addition to the 10 percent duty (leading to a 30 percent total duty) for imported husked brown and semi-milled or wholly milled rice for investors with a rice-milling capacity and a verifiable backward integration programme in Nigeria[7]. Rice importers without local production programmes/projects were classified as "pure rice traders". They pay a 60 percent levy in addition to the 10 percent duty rate for the same type of rice (totalling a 70 percent import duty). Two different tariffs (30 percent and 70 percent) apply to two categories of importers (importers with backward integration and those without who are only rice traders). The higher tariffs were designed to dramatically increase the cost of imported rice and to direct Nigerian consumers to lower-cost local rice. However, domestic rice costs about 20-30 percent more than imported parboiled rice (USDA, 2016). Despite of the sizeable food imports, the Food and Agriculture Organization (FAO, 2014) states that in 2012 about 9.4 million Nigerians or about 6 per cent of the population were undernourished and that the poverty level in 2010 was estimated at 69 per cent (NBS/National Bureau of Statistics, 2012). All these points to the fact that trade policies are not enough to stem the tide of excessive food imports in Nigeria. The agricultural production system itself is weak in Nigeria.

### 1.2 STI inputs are needed for accelerating agricultural production and providing for food security in Nigeria

There is a need for appropriate science, technology and innovation (STI) policies that can increase the yield of the crops, reduce the pre- and post-harvest losses, and add value to the crops. For instance, FAO/FAOSTAT (2017) reveals that while the cassava yield in Nigeria stood at about 8 tonnes per hectare in 2014, the yield in Thailand and Ghana stood at about 22 and 19 tonnes per hectare respectively. This implies that Thailand and Ghana can produce more than 2 times of cassava output from a given one hectare of land compared with what Nigeria can produce from the same hectare of land. FAO/FAOSTAT (2017) also indicates that the average annual cassava yield in Nigeria (10.30 tonne per hectare) is not only lower than the World average (11.40 tonne per hectare), but that it is also growing at a slower pace (0.45%) compared with the World mean annual growth rate of 1.27%. The same lower yield trend is evident in the case of wheat, rice and yam as Nigeria produced 1.0, 2.2 and 8.3 tonnes per hectare of wheat, rice and yam in 2014 respectively, compared with a global average yield of 3.3, 4.6 and 8.7 tonnes per hectare of wheat, rice and yam in 2014 respectively (FAO/FAOSTAT, 2017).

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[7] The backward integration means that the importers have evidence that they have farms where rice can be grown and milled in Nigeria.

STI infrastructure that will increase the yield of the crops and will improve the soil through organic and inorganic fertilizer will help Nigeria in the direction of self-sufficiency in food production. However, STI are inputs to agricultural production and these inputs will have beneficial effects to agricultural production only if other important policies and services are also sustainably provided.

Significant reductions in food losses and waste would increase the amount of food available for human consumption and would as well enhance global food security (Oguntade, 2014). Moreover, yields lost at the farmer level constitute a loss of income and contribute to rural poverty, what is now emphasized by the Sustainable Development Goals/SDGs (SDG 1: zero poverty). The issue of food losses is therefore of crucial importance in the efforts to combat hunger (SDG 2: end hunger), to raise incomes and to improve food security in Nigeria. Agrochemical applications that can reduce crop losses, which are estimated at 11% for cassava, 10% for yam, 25% for rice, and 14% for maize, will assist in realizing food security in Nigeria (Oguntade, 2013, 2014). Oguntade (2013) estimated a mean per capita loss of 11.6 kg in the maize value chains in Nigeria. He indicated that the total sum of monetary losses in maize value chains amounts to around 120 billion Naira, which corresponds to approximately $333 million. Oguntade (2014) demonstrated that a total of 0.85 million tonnes of paddy, valued at 34 billion Naira ($95 million), was lost by the time of processing of paddy into milled rice in 2014. In addition, 0.06 million tonnes of milled rice, worth 6.8 billion Naira ($19 million), was lost during transportation and storage before the rice got into the hands of marketers (wholesalers and retailers). This added up to a net loss of 40.8 billion Naira ($114 million USD) in rice value chains in Nigeria in 2014.

Another area where STI inputs can help to improve the food security situation in Nigeria is the area of technology adoption. Inappropriate technology appears to be the dominant cause of low agricultural productivity, but also of food losses and waste in Nigeria (Oguntade, 2013)[8]. In the case of cassava, areas requiring attention are harvesting, peeling and storage of fresh cassava tubers, and raising efficiency in grating and milling. In the case of maize, areas where technology can be applied are in bagging, transportation, and storage. Appropriate technologies could be developed through collaborative research projects conducted by public and private actors, focussing, for example, on the development of a cassava peeling and harvesting machine. Appropriate packaging and transportation arrangements would have to be made for the transportation of semi-finished products to the starch factory. In the rice value chains, improved technology is needed in seed

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[8] Cassava farmers indicate that the most significant losses occur during harvest (4.95%), due to inappropriate harvesting technologies (machetes) and poor soil conditions (dry and stony).

multiplication and breeding; threshing and harvesting. Appropriate parboiling and milling technology is also needed to achieve a product of high quality.

Having appropriate STI inputs is not enough, because agricultural mechanisation in Nigeria is replete with examples of well-intended scientific advances that have had limited impact because they were not sustainably adopted by producers and consumers (Oparinde et al., 2016). For instance, numerous public-sector agencies were established in Nigeria in the 1970s and the 1980s to develop and to diffuse mechanized cassava processing machines. However, farmers have not adopted the machines developed by the government agencies because the machines are not as convenient and reliable as those developed by the small-scale private artisans (FAO, 2006). Important lessons for mechanization of food processing in Nigeria emerge from the analysis of the evolution of mechanized cassava processing methods. Mechanization of food processing must be ready for products that have a market demand such as gari. Since most villages in Nigeria do not have electricity and because petroleum fuel is scarce and expensive, mechanized machines should be small and easy to fabricate and to repair by village artisans, using local materials such as old engines and scrap metals. Machines that are manually driven are more suitable for remote villages, provided they can be fabricated and maintained by village artisans using local materials (FAO, 2006). Moreover, consumer marketing channels using print, television, and radio media can be used extensively to communicate the importance of the technology to consumers to create demand, and to investors to increase product supply. Radio and television Jingles can be developed and translated into major local languages for creating awareness on radio and television. Farmer to farmer information dissemination, field days, and radio jingles have been proved to help to increase awareness of agricultural technologies (Oparinde et al., 2016).

STI inputs will not only increase agricultural production and ensure food security, but they will also enhance export competitiveness and diversification of the economy[9]. The Nigerian government has a national agenda with the objective of becoming one of the top 20 economies in the world by the year 2020. This can be made possible by effective STI policies. However, the gross domestic expenditure on research and development (R&D) as a percentage of GDP was only 0.2

[9] STI plays vital roles in wealth creation and transformation in any society. Wealth can be distributed in the society only when it is first generated through the application of new technology for industrial development (Akinwale et al., 2012). These technological transformations can be linked to high-level R&D activities and to innovation. R&D, leading to the creation of new goods, new processes and new knowledge, is a major source of technical change (Guellec and van Pottelsberghe, 2001). R&D activities also entail the creation of new knowledge and the absorption of existing technology, which further leads to a reduction in the existing cost of production and an improvement in the quality of products.

(NEPAD/African Innovation Outlook, 2010).[10] This is far below the 1% target set for African countries to make them progress technologically (Kahn, 2008). It has been empirically proved that that expenditure on R&D has significant impact on economic growth (Akinwale et al., 2012). While increasing spending on R&D in Nigeria may be justified and necessary, it will not be sufficient to improve STI adoption and absorption when there are weak institutions, high corruption practices, low interactions between the academia and the industry, uncoordinated industrial clusters, among others. Akinwale et al. (2012) recommended that government must be committed to R&D and to innovation funding, developing strong institutions, enhancing the academia-industrial linkages as well as implementing a workable science, technology and innovation policy to bolster and to diversify the economy[11].

### 1.3 The role of a conducive business environment for stimulating agricultural production and for realizing food security in Nigeria

A conducive business environment is also required for firms in Nigeria to raise their global competitiveness and to take advantage of the knowledge opportunities. Nigeria has been slipping on the Knowledge Economy Index (KEI) largely due to the slow improvement in creating an enabling environment for business. The Doing Business 2018 ranking has seen Nigeria at the rank 145 out of 190 countries.[12] The rank of Nigeria in the Global Competitiveness Report 2017 is unfavourable.[13] This is a clear signal that a reversal is needed and will be essential if Nigeria is to aspire to move forward from its factor-driven stage of development into a knowledge-driven economy in the future.

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[10] See also on the level of R&D spending in Nigeria: https://knoema.com/atlas/Nigeria/topics/Research-and-Development/RandD-Expenditure/RandD-expenditure-as-a-share-of-GDP

[11] Government should also provide various fiscal incentives for the industrial firms in their various clusters to encourage them to engage in R&D and innovation activities, either through reverse engineering or inventing new technologies, as this will not only lead to economic growth but will also raise the global competitiveness of Nigeria.

[12] See also about the Doing Business 2018 rankings and scores for Nigeria: http://www.doingbusiness.org/data/exploreeconomies/nigeria

[13] The World Economic Forum's *Global Competitiveness Report 2017* ranks Nigeria 125th out of 137 economies. This places it below Senegal at the 119th place and well behind more dynamic African countries, such as Rwanda (rank 58), South Africa (rank 49), Kenya (rank 99) and Egypt (rank 116). Nigeria's ranking has remained low, it stood at 93rd in 2007, but at the 125th rank in 2017 (Schwab, 2017).

Access to finance for firms will also be essential to fulfil Nigeria's aspirations for the perspective 2020[14]. Business start-up and expansion will need support through the provision of tailored credit products by the financial sector. Business development services will also be a key to improving firms' access to formal finance. While the ratio of private credit to GDP is growing at an annualized rate of 72 percent (Isern et al., 2009), outreach of financial services to entrepreneurs, particularly for small and medium enterprises (SMEs), remains limited. Most credit from the banking sector flows into larger corporate entities or multinational companies, with some exceptions being made for smaller contractors which are operating in the oil and gas or the telecom sectors (Radwan and Pellegrini, 2010). Electricity is also perceived as a main bottleneck. According to Radwan and Pellegrini (2010), in Nigeria power outages result in losses equivalent to 10 percent of total sales. Almost all Nigerian firms (96 percent) experience power outages (Radwan and Pellegrini, 2010). On average, such outages last 196 hours per month, or about eight days. Faced with this situation, 86 percent of all firms have their own generators, which produce, on average, 61 percent of their electricity needs. Although they face the most significant outages, large firms have lower electricity-related indirect costs. This is explained by the fact that 97 percent have their own generators. Owning and maintaining a generator is an extremely costly affair. It is estimated that self-generated electricity in Nigeria costs between six and ten times more than that sourced from the grid. Airoboman et al. (2016) showed that if the power generated by the appropriate power utility is used, there will be a 30% reduction in the cost of generating power, thus leading to a corresponding reduction in the prices of goods by the industry. This makes all except the most essential and competitive businesses financially unviable and deters potential entrepreneurs from starting businesses. As these problems affect also agro-industries and agribusiness, the reaction on agricultural production is direct and negative. The food industry is extremely affected by this deficiency.

A more supportive business environment will help to attract Foreign Direct Investment (FDI) in sectors other than oil and gas or telecom, which have received the lion's share of FDI over the past five years. In this way, Nigeria will be better able to tap into the wealth of knowledge that multinational companies often bring.

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[14] Access to finance, and to a lesser extent the cost of finance, are perceived by Nigerian firms as the second most important constraint to doing business. Capital is a key input to any business. And an efficient financial system that can allocate financial resources quickly and cheaply to their most productive uses is an essential part of a growing knowledge economy. For Nigerian firms, both the Enterprise Survey data and other indicators suggest that finance imposes an important constraint on business expansion. Access to and the cost of finance do not impact all firms equally—the smaller the firm, the bigger the problem in terms of access to and the cost of finance (Radwan and Pellegrini, 2010). Domestic firms complain about access to finance twice as much (53 percent) as do foreign firms (25 percent), which often have access to external financing.

By fostering business linkages with local Small and Medium Enterprises (SMEs)[15], better production systems and superior technology could be passed on to local firms, thereby increasing their productivity and international competitiveness. Given the large untapped resources which Nigeria has— from fertile, uncultivated land to a large, young population, which can be both a production tool and a huge market—international investors' interest is likely to be very large, provided the conditions are in place for them to feel their money will get the expected returns[16]. A supportive regulatory environment must also be present for innovations to spread and to take root. In this context, a tricky trade-off exists between the need to foster the respect of intellectual property rights (IPRs), in order not to alienate potentially interested investors and innovators willing to set up an affiliate/a shop in the country, and that of tapping into knowledge and discoveries created elsewhere and applying reverse engineering techniques to foster innovation in Nigeria.

By leveraging its endowment of resources and its population's renowned entrepreneurial spirit and belief in the private sector, Nigeria can go a long way to foster an innovation culture[17]. The two major areas in which Nigeria is ranked among the lowest in the Global Competitiveness Index 2017 are in the areas of infrastructure and innovation. For example, out of a maximum number of 7, Nigeria scored 2.0 and 2.8 in infrastructural development and in innovation respectively, while Kenya scored 3.35 and 3.83 in infrastructural development and in

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[15] The adoption of innovation and know-how is needed at the SME level. SMEs do not often benefit from strong linkages with multinational corporations in the country or from the exchange of know-how and technologies with the outside world through export activities. In a vicious circle, their inability to tap into these sources of knowledge makes them less competitive in international markets and incapable of performing to the standards (in terms of quality, price, product specification, production time, etc.) required by foreign markets or large corporations which are present in Nigeria.

[16] A more conducive business environment, with well-defined, non-contradictory rules, would prove very helpful for the country to tap into the growing stock of global knowledge that foreign companies possess. This could be complemented with strategic alliances between such companies and the federal and state governments to attract international market players willing to transfer knowledge to local partners, for example by encouraging local content requirements (Radwan and Pellegrini, 2010).

[17] A country's innovation system is the set of institutions, procedures, and processes that determine how it can create, acquire, disseminate, and use knowledge and information. In practice, this is the network of universities, research centres, think tanks, firms, business associations, and, more generally, producers and users of knowledge in the country. This system can support or hinder the interaction between global and local sources of knowledge and the assimilation of the growing stock of global knowledge. Thus, an innovation culture for developing countries must be understood as the building of a technical culture and a system of incentives that support the adoption and, subsequently, the adaptation of existing (often foreign) technologies (Utz, 2006).

innovation respectively (Schwab, 2017). The Global Innovation Index (GII) 2014 surveyed 143 economies around the world, using 81 indicators to gauge both their innovation capabilities and the measurable results. Mauritius, which tops the African countries in the ranking, came at the 40th position, followed by South Africa at the 53rd position and Tunisia at the 78th position. Nigeria was placed only at the 110th position. The foregoing GII ranking has shown that in a global and dynamic world, the economies that remain flexible, adaptive, and innovative will reap the benefits of world trade. This is because the global competitiveness of any economy depends on its science, technology and innovation (STI) capabilities. In all ramifications of economic development, technology-dependent economies surpass economies dependent on their natural resources (Uchechukwu et al., 2016). Therefore, refocusing priorities and carefully choosing a menu of actions that foster knowledge, technology adoption, and adaptation would help the country target the key building blocks for the development of a solid knowledge economy, which would later entail the local production of new ideas[18]. The success of the East Asian economies has also followed this pattern of first moving to existing best practices and then attempting to develop new technologies. In absolute terms, Nigeria's innovation system is still less advanced than those of the chosen comparator countries, particularly South Africa. For instance, Nigeria ranked at the 113th position out of 137 countries based on innovation in the recent Global Competitiveness Index (GCI) compared with South Africa that ranked 64th (Schwab, 2017). There is a tremendous need of reforming the whole Nigerian production system towards innovation and technology absorption.

Nigeria needs to strengthen collaboration between universities and the private sector. On university-industry collaboration in R&D, Nigeria scored 2.5 out of a possible score of 7 and was ranked 133rd out of 137 countries in the World (Schwab, 2017). In this area, Nigeria was at par with Ghana in 2007, but Ghana progressed to the 65th position by scoring 3.5 out of a maximum score of 7 in 2017. India scored 4.4 and ranked 26th in 2017, based on university-industry collaboration in R&D. In India, for example, strong linkages exist among the private sector, tertiary education institutions, and research bodies, such as the Indian Institutes of

[18] Nigeria has a national strategy on science and technology that could be further revised to provide a sound framework for innovation in the country. Various business associations already connect members in a diverse and large country and these could become key vehicles for knowledge transfer. Such associations could also play a key role in the provision of training and business development services (BDS) to firms to foster the adoption of new production systems, and to support the creation of industrial clusters through public private partnerships (PPPs). By leveraging its prominent position in ECOWAS and the talents of millions of Nigerians in the Diaspora, Nigeria's innovation culture could receive a boost from the more fluid circulation of tools and ideas. Several studies have shown that developing countries reap far greater dividends by simply accessing and adopting existing technologies than inventing new ones (Perkins and Neumayer, 2006; UNDP, 2001).

Technology (IITs) and the Indian Institutes of Management (IIMs), which also have close ties with leading foreign universities and research institutes (Wijesinha, 2008). Such linkages have supported knowledge dissemination and transfer to the real sector of the economy.

### 1.4 Nigeria's vision 2020, the knowledge economy, and the process towards agricultural transformation

If Nigeria is to achieve its vision to become one of the top 20 economies by 2020 (Vision 2020), it must make innovation the centre of its development strategy when going forward. Much can be done to improve the innovation culture across Nigerian society. This can start by devoting adequate resources to encourage innovation. Government could boost the support to R&D by increasing funding to the significant number of underfunded Nigerian research institutions. Ideally, this would be achieved in tandem with a restructuring of these institutions to encourage partnerships with the private sector and to provide for additional fund-raising from remunerated activities. Many of the existing institutions are weakly linked to the private sector because of a lack of financial resources and of partnership agreements, which make them unable to achieve their potential in terms of contributing to the country's innovation system. Extracting a few key priorities from the new national strategy on science and technology could provide a sound framework for innovation in the country and could support the realization of the government's agenda of the diversification of the real economy and delivering higher agricultural production for food security. The policy on science and technology, which was revised in 2006 with the assistance from UNESCO, rightly puts emphasis on science as a fundamental part of any Nigerian child's education and on some key areas that the country should focus on, such as ICT[19], agriculture, and biotechnological research. It is important to start with manageable projects to avoid overstretching or wasting scarce resources. An agricultural transformation strategy for Nigeria needs great inputs from the national science & technology programme.

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[19] In today's knowledge-based world, information and communication technology (ICT) plays an increasingly central role in economic growth and productivity. Evidence has shown that an increase of 10 mobile phones per 100 people can boost GDP growth by 0.6 percent, and a 1 percent increase in the number of Internet users can increase total exports by 4.3 percent (National Media, 2007; Radwan and Pellegrini, 2010). Rapid advances in information infrastructure are dramatically affecting the acquisition, creation, dissemination, and the use of knowledge, which in turn affect economic and social activities, including how manufacturers, service providers, and governments are organized, and how they perform their functions. To develop a strong information infrastructure, it is necessary to mobilize the many stakeholders being involved in its deployment and use: the telecommunications networks, the strategic information systems, the policy and legal frameworks, and the skilled human resources needed to use and to develop the sector.

In-firm training is another way of spreading knowledge and know-how[20]. Only 26 percent of Nigerian firms provide training to their workers (Iarossi et al., 2009). These tend to be the largest ones, the exporting ones, and/or the foreign-owned firms. Nonetheless, Iarossi et al. (2008) find that, once firm size is controlled for, training does not have an independent effect on value added per worker. This is because the training provided in Nigerian firms is often theoretical or obsolete and does not equip workers with the necessary tools to positively impact the productivity of their firms. This may explain the reason why though Nigeria scored 3.8 out of the possible score of 7 and ranked 75$^{th}$ out of 137 on training but the workers' productivity is still low (Schwab, 2017). Not only is there a strong need to increase in-firm training, there is also the need to improve its quality and to ensure that applicable, practical know how is transferred. Obviously, these deficiencies in training matter also in food industries and in processing along the whole agricultural value chain.

The Diaspora could become a driving force behind Nigeria's knowledge economy efforts. It is calculated that more than 15 million Nigerians live outside of the country, and the Diaspora can also have a lead role in integrating ECOWAS and in pushing the innovation agenda[21]. Among them are accomplished physicians, scientists, businessmen, economists, writers, and artists. All of them, and particularly those in science and business, have a tremendous amount of know-how to offer. By transferring the practical knowledge of production systems (from supply chain management to knowledge management software, etc.), but also of international standards, regulations, and markets, they could foster innovation in their homeland to a considerable extent. In this effort, they would possess a comparative advantage that stems from their unique understanding of the local context, of cultural and business practices, and of specific constraints. In this way, they could facilitate the implementation of the "adopt-and-adapt" strategy as the basis of Ni-

[20] Firm-level productivity is the main driver behind competitiveness and economic growth. The World Bank's Investment Climate Assessment (ICA) has shown that most firms in Nigeria are poorly managed and few have adopted leading-edge technologies (World Bank, 2011).

[21] Stronger regional integration through ECOWAS could support the innovation effort and could produce positive cross-country spillovers. Nigeria is the "giant" of the ECOWAS community. As such it has extraordinary opportunities as well as responsibilities in pushing the innovation agenda forward in the sub-region. By leveraging on its economic and political influence, it could support regional initiatives aimed at productive exchanges of information and knowledge (e.g., from foreign language learning, which is still a barrier to integration in ECOWAS, to profitable trade exchanges of raw materials, exchanges of managerial know-how, and of other inputs). See on the potential of the Diaspora: https://www.vanguardngr.com/2017/03/15-million-nigerians-diaspora-dabiri-erewa/

geria's knowledge economy. Many from the Diaspora could also invest into agricultural transformation via business services, finance institutions, marketing agencies, and technology centres.

Industrial clusters can facilitate knowledge- and innovation-sharing. Clusters have the potential to improve firms' competitiveness by driving innovation, given the accumulation of a critical mass of players that can generate and disseminate sector-specific knowledge (Porter, 1990). In this context, the World Bank has been supporting the government of Nigeria through the identification of "growth poles" to encourage the formation of such clusters, along the lines of successful projects carried out in other countries. Various sectors were identified in four states of Nigeria (Cross River, Kaduna, Kano, and Lagos), with the purpose to boost non-oil production in key agriculture-related sectors along 14 value chains. The DFID-World Bank Growth and Employment in States (GEMS) programme was hugely financed. However, the implementation of the results of the study was weak or totally absent; despite of the fact that implementation constraints were part of the study.[22]

Some of the technological factors that affect the easy of doing business and the innovation process in Nigeria also affect both the upstream and the downstream segments of agriculture. They manifest itself in poor technology, poor quality of raw materials, and inadequate supply of modern inputs (Oni, 2013). The main constraints include low support from government, poor government policy, high level of poverty, low level of awareness, lack of adequate research, and increases in the prices of inputs. Poor government support and poor government policy prevent the emergence of innovations from agricultural research institutes through spreading inventions to the businesses, thereby curtailing the level of available technically feasible and efficient agricultural practices. Even when they are available, there seem to be communication gaps between farmers (end-users of research efforts) and the researchers (intending to develop new technologies for the farmers). Obviously, the extension service cannot close the gap. The existence of a unified agricultural extension system notwithstanding, there is still a poor coordination between researchers, extension agents and farmers. This situation is worsened by the low extension staff-farmer ratio, which hovers around 1 to 1000 (Oni, 2013). The poverty incidence among farmers, which is the highest in the economy, also contributes to the persistence of technical constraints in Nigeria (as these farmers are mostly involved in survival businesses). Thus, farmers are unable to take up new innovations aimed at boosting their productivity and, by extension, their output. The low level of productivity translates to a vicious cycle of

[22] See on this programme: http://www.nathaninc.com/projects-and-cases/nigeria-growth-pole-value-chain-study

poverty, thereby leading to low levels of production[23]. The technical constraint is further sustained by high input prices, which is a consequence of inflation in the economy as well as the dependence of the agricultural economy on foreign inputs.

Earlier attempts at improving agricultural production in Nigeria such as the Operation Feed the Nation programme (1976-1980)[24], the Green Revolution Programme[25], and other laudable interventions in the agricultural sector emphasized increases of production without commensurate efforts at post-harvest management and industrial utilization. Most of them handled the various aspects of the post-harvest system, such as processing, packaging, marketing, storage, distribution and transportation, in isolation from one another. There was no effort to make the system comprehensive and holistic in its management. Also, the industrial utilization of agricultural commodities is constrained in Nigeria by inadequate linkages of agriculture to the industrial sector. Each programme was followed by haphazard implementation what created more problems without achieving the anticipated goals. Although most of the programmes yielded seasonal increases in agricultural output, inefficient and ineffective post-harvest management and a generally low level of industrial utilizations have always resulted in substantial agricultural wastages, food losses, a reduction in available food, a restriction in its spread over the year, and a reduction in employment and rural income (Oni, 2007).

The difficulty confronting the local industrial utilization of agricultural commodities is how to initiate and to sustain the momentum for a diversification of the raw agricultural commodities into agro-industry production, by a transformation of the raw product into high-value added products to realize and to optimize a high growth potential that undoubtedly exists in agricultural commodities. This remained worrisome by the dilapidating state of rural infrastructures that hampered the creation of effective linkages from agriculture to industry. This undoubtedly makes investment unattractive to the private sector is and thus limiting agricultural development in the country. Excessive dependence on a narrow range of products as sources of income and foreign exchange earnings brings about various unfavourable consequences on the economy (Oni, 2005). Firstly, it exposes farmers unduly to the vagaries of climate, pests and diseases and to price fluctuations. Secondly, it leads to fluctuations in farm income and government revenue. Thirdly, it contributes to environmental degradation. Fourthly, it results in the failure to take advantage of complementarities (e.g. between livestock and crops) and thus has

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[23] Since agriculture in Nigeria is virtually un-mechanised, human labour accounts for about 90 per cent of all the farm operations. Under semi-mechanized systems, including animal traction use, human labour use is as high as 70 per cent of all the operations (NISER, 2001; Oni, 2013).

[24] See: https://www.britannica.com/topic/Operation-Feed-the-Nation

[25] See: http://nigerianwiki.com/Green_revolution_programme

negative effects on diet, food security, and welfare of Nigerians. In addition, adverse international terms of trade, facing the primary agricultural commodity sector, are a further constraint to the growth of the sector.

There is a clear need to diversify the production and the export base, both horizontally and vertically, from low value added to high value-added products. The high growth potentials and the opportunities available in diversifying agricultural commodities to agro-industry for the generation of high value-added products had been limited and thus underexploited in Nigeria due to the irregular supply of raw materials from the agricultural sector to the agro-industrial firms. Available evidence depicts that there are poor linkages of the agricultural sector to the industrial sector (Oni, 2013). This had aggravated the low domestic utilization of agricultural commodities by the agro-allied firms, which is being reflected by a general decline in the average capacity utilization rates by the firms. For instance, the average capacity utilization rates had declined from 54.3per cent to 19.0 percent in the cocoa confectionary industry (Oni, 2013). In the vegetable and grain milling industry, average capacity utilization rates had declined from 84.5 per cent to 45.8 per cent (Oni, 2013). The general decline in average capacity utilization rates in the agro-industry could partially be attributed to an inadequate and irregular supply of raw materials and to a combination of other factors like aging plants, deficient equipment, and poor performance of utilities (Oni, 2005). Value chain financing is another important constraint to mobilize agriculture and processing in Nigeria (UNIDO 2010).[26]

There is a need to improve production, processing, and trade through increased access to resources, such as land, technology (improved inputs), credit, and training in Nigeria's agriculture. Adoption of modern farming and husbandry practices, such as planting of improved seeds and seedlings, application of agricultural chemicals for pest and disease control, and use of tractors to reduce drudgery and to enhance yields, can be facilitated by assisting the farmers in sourcing improved technologies. Small-scale irrigation in all agro-ecological zones of the country should be promoted and strengthened in Nigeria. There is a need to strengthen agricultural research activities through increased and stable funding, proper coordination, strengthening of linkages among research centres and with extensions agents and farmers, as well as providing for adequate training of research and technical staff in specialized skills. Research systems must identify new mechanisms to find out why farmers do what they do, what their real research needs are, and what the research priorities are for the farming sector. Government should support capacity-building among small-scale farmers and facilitate linkages with large processors and manufacturers, using agricultural commodities to develop long-term contractual arrangements among them. Also, government

[26] See: https://www.unido.org/.../Nigeria_Finance_Diagnostics_final2_0....

should promote value-added agriculture to provide a stimulus for wealth creation and employment creation. There is a need for increased funding of the agricultural sector (and of the agricultural value chains) to improve the efficiency of the various institutional agencies for agricultural development. The functions of these agencies should be streamlined to ensure adequate funding for their core functions. Adoption of post-harvest processing technologies that minimize waste and control pollution of the environment should be encouraged. If efforts are put into ensuring effective implementation of the above recommendations, they will constitute quick wins in stimulating the flow of investment into the agricultural sector. This will pave the way for a diversification of the revenue sources, for increased income, for employment generation, and for poverty reduction in the country.

### 1.5 Ways Forward: Using more fully indigenous technologies and raising the acceptance of safe genetically modified and bio-fortified local food products

Nigeria is on the way to use more intensively indigenous technologies for agriculture development, and the country is also under way to use more intensively genetically modified crops technologies. This must not be a contradiction, as access to GM crops technologies can be an important element of strengthening the national innovation system of Nigeria, and especially the agricultural innovation system of the country. Using indigenous technologies means that technologies are used which are locally produced, which are using local materials and local expertise, which are reliable under harsh climate and soil conditions, which are easily to handle, to maintain and to repair, also by poor farmers and by unskilled workers, which are not demanding complex and/or imported inputs, etc. The list of criteria could be continued.

The issue of indigenous technologies is now again widely discussed, and it is related to the context of indigenous knowledge. Indigenous knowledge (IK) is considered as local knowledge which is unique to a given society or culture, and so is location-specific. IK is so important as it reflects the interaction of communities with their changing environments, so that those who are using IK need to adapt to the changing environment in the long run, leading to an accumulation of knowledge and experiences. The discussion about IK goes on since around 1980 at a broader scale but it is now again back on the agenda.[27] This return of the debate on IK has also to do with mitigation and adaptation to climate change, as it is assumed that coping with such threats requests the use of the accumulated IK. But it has also to do with the changes of the environment due to conflicts and socio-economic changes, as IK is destroyed on a large scale through civil wars, violent conflicts, population growth, labour and land scarcities, political instability, and

[27] See the synopsis of development of IK: http://www.ciesin.org/TG/AG/iksys.html

natural catastrophes. The link to GM crops technologies is obvious. In times of such threats to the accumulated IK the GM crops technologies may be useful to provide for seed varieties which are pest-resistant (such as GM cowpea), and seed varieties which can lead to bio-fortified food products (as yellow cassava). IK remains important, as the starting point for related agricultural researches.

Indigenous Agricultural Systems are the base for restructuring agricultural research systems. IK has an important role to preserve bio-diversity, and so indigenous knowledge (IK) about plant generic resources is an invaluable tool to search for new ways to conserve and to use the local resources to the benefit of local communities. Agricultural research systems need to consider the IK as a base for their researches, if they are directed to developing GM crops or just to reorganize the agricultural value chains of specific products. Indigenous Agroforestry Systems are also important as they are highly adaptable to specific agroecological conditions and meet many local needs (food, firewood, fodder, and lumber). The Indigenous Agricultural and Land Use Practices are based on generations of experience, on informal experiments, and on a deep understanding of their biophysical and socioeconomic environments.[28] Indigenous Farming Systems and Indigenous Food Production Systems are sophisticated and contribute to food security. Agricultural researches and food security strategies need to be built on this basis. Genetically Modified Crops in Africa can only be developed in the context of such a knowledge base. Food security strategies need to incorporate indigenous knowledge systems into the agricultural research systems, the extension services, the reorganization of the agricultural value chains, and the work of NGOs for sustainable agricultural development.[29]

The state of food insecurity in Africa requests also that new technologies are used to cope with the various causes. It is necessary to understand how food insecurity can be related to major issues of our times (overpopulation, pressure on resources, environmental degradation, deficiencies of food products in terms of micronutrients, lack of pest-resistance of crops, labour scarcity in rural areas, etc.), and that it is now more difficult to practice indigenous farming systems. Modifications are needed, so that the search for new technologies and adapted knowledge systems is a quite rational process. FAO et al. (2017) have given evidence that food insecurity is again on the increase in 2016, with diverse forms of undernutrition, with a serious lack of micronutrients, with increasing numbers of chronically undernourished people, and with multiple forms of malnutrition (affecting children ,women, and adults).The reversal of the trend towards a decline of hunger and malnutrition is caused by conflicts (civil wars, violence, political instability, displacement of people), but is occurring sometimes also in combination with droughts and floods. Data for children on low birthweight, underweight, wasting,

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[28] See the synopsis of development of IK: http://www.ciesin.org/TG/AG/iksys.html

[29] See the synopsis of development of IK: http://www.ciesin.org/TG/AG/iksys.html

stunting, and deficiencies in Vitamin A give a clear signal.[30] Such data request a reorientation of food security and agricultural research priorities and policies. The conflicts in Nigeria are associated with environmental degradation and lead to conditions of food insecurity, and to a destruction of indigenous knowledge (IK) by displacement of people, by environmental damages, by irregular production possibilities, and by a lack of regular inputs and the loss of traditional markets. A key message of FAO et al. (2017) is that conflict-sensitive approaches are needed to align actions for immediate humanitarian assistance, for long-term development, and for sustaining peace. This FAO report sends a clear message that more than business as usual is needed. Although the emphasis is on conflict-sensitive approaches, long-term development strategies require new agricultural research strategies. While IK is the base for agricultural development, also researches on GM crops and on bio-fortification of food crops will be part of a long-term development path.

Indigenous technologies have five characteristics (Jha 2008). They have a low capital intensity; they are sustainable because they are ecology-friendly, they are location- and site-specific; they are diffusing slowly over small and homogenous areas; and they have low rates of incremental innovations. So, on this basis there are limits of accelerating agricultural development in times of increasing food insecurity. In Nigeria, public research institutions are developing indigenous agricultural technologies along such criteria (see Ogunyemi/Adedokun, 2012). However, acceptability among small farmers for such simple technologies is limited. The reason is also that the contact from the research institutions to the farmers is not intensive enough and is not sustained over the whole project cycle. Integrating indigenous agricultural technologies with modern scientific knowledge is becoming an urgent necessity also for Africa (see Jasuja et al. 2012). Agricultural technologies with a higher rate of incremental innovation are requested. New agricultural technologies need to supplement/to complement the indigenous agricultural technologies also because of climate change. As climate change is affecting Africa more and more, indigenous mitigation and adaptation technologies (see the list of options in Sadiku/Sadiku 2011) can be used widely and complemented by modern mitigation and adaptation technologies, i.e. by IT-based technologies and bio-technology applications (see on the complementarity of indigenous and modern scientific agricultural technologies Sadiku/Sadiku 2011, and Enete et al. 2011). Indigenous Knowledge (IK) and Modern Scientific Knowledge (MSK) are not only in a complementary relationship but need a fundamental integration to support food security strategies and related research strategies.

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[30] See on the relevant definitions of malnutrition: https://www.unicef.org/infobycountry/stats_popup2.html

## 2 The Contributions

In this Unit 3 of Volume 20 of the African Development Perspectives Yearbook key issues of STI policies and inclusive growth in Nigeria are discussed – the role of developing and using indigenous agricultural technologies by taking the case of two Nigerian agricultural technology institutes, the role of introducing pest-resistant genetically modified (GM) cowpea in northern Nigeria with regard of acceptability through farmers and consumers, and the role of spreading innovations and new technologies in the cassava value chain with the aim of a fortification of the food products. These issues are now highly relevant, as food insecurity in Nigeria has increased, and as the wider use of indigenous technologies, the introduction of pest-resistant crops, and the fortification of local food products present possible solutions.

The first essay in the Unit 3 is by **O. I. Ogunyemi and A. S. Adedokun** and has the title **Indigenous agricultural technology in Nigeria: A Case Study of Nigerian Stored Products Research Institute (NSPRI) and the National Centre for Agricultural Mechanisation (NCAM).** This essay brings to the wider public that Africa, and specifically also Nigeria, has great technological competencies which could be used for agricultural development. These technological competencies have a long history and are therefore labelled indigenous agricultural technologies. This is demonstrated by looking at two research institutes which have a long-standing experience in designing and producing prototypes of agricultural technologies with the aim to disseminate the technologies to the farmers Nigeria-wide. Although Africa is considered as a technologically lagging continent, examples show that there is an indigenous production base for equipment which can be used in agriculture and in food industry. This equipment is produced by local technology institutes, funded by the Nigerian government, and the focus is on easy handling, easy servicing, low cost, use of local resources and raw materials, applicability under harsh climate conditions and adapted to the conditions of soil, being relevant for most important staple crops, being available nationwide, and being usable with relatively low qualified staff who can learn quickly to handle the equipment. If all these criteria can be met, such equipment would support tremendously agricultural and industrial development. Two major Nigerian institutes have a mandate for developing agricultural technologies in Nigeria. A review of their experiences and their prospects is done in the essay. These criteria are important as they reflect the competencies, the endowments, the scarcities, and the needs of the key economic sector, agriculture.

Although there exists the view that Africa is a net technology consumer, by importing significant amounts of technologies, Africa does have a considerable base for indigenous technologies, to be used for agriculture and for industry development. Efforts made by several countries in Africa give evidence of a technological catch-up with advanced and emerging countries, and the catching-up process is facilitated by looking carefully at the base of indigenous technologies. The new wave of STI policies in African countries which is observable now gives evidence of this trend. It is the purpose of this essay to draw attention to two of Africa's important indigenous technology providers for agriculture, and the two institutes are well placed in Nigeria with its huge agriculture base. Although Nigeria has seen a long period of deindustrialization with a shrinking manufacturing sector, because of the weight of the oil economy, public research was held at relatively high levels for industry and agriculture (especially in regard of research staff). This study therefore evaluates the activities of the Nigerian Stored Products Research Institute (NSPRI) and of the National Centre for Agricultural Mechanisation in Nigeria (NCAM). While the former centre is focussing on storing agricultural products, the latter is the only agricultural mechanisation centre in sub-Saharan Africa. The two organisations give evidence of how a country is advancing indigenous technology for agricultural development in Africa. But it is also important to understand why the technologies of these institutions are not more widely used by the farmers.

The study used both primary and secondary data which are mostly qualitative. The primary data were obtained through the key informant interview (KII) approach, directed to some senior staff of NSPRI and NCAM in Nigeria and through the observation of the technologies which were developed there. Thirty-five (35) expected end-users of the technologies, who were farmers, were also interviewed and supplied with questionnaires through convenience sampling. Out of the thirty-five (35) end-users who were interviewed and supplied with questionnaires, thirty-two (32) responses were successful for the analysis. The secondary data were accessed from the internet, journals and publications of the two organisations. The interviews were conducted with pre-drawn questions by the researchers through face-to-face discussions and telephone conversations. The questions asked were covering the mandate, the objectives, and the problems of the institutions, then about the indigenously developed technologies, their operations, applications, and the spread to the farmers. The pictures of some indigenously developed technologies were taken with a digital camera, with their uses and their applications being recorded as part of the data collected. The data were analysed with descriptive statistics which included content analysis.

The results show that the two organisations have fabricated home-grown agricultural machines, tools, equipment, and structures for small and medium scale farmers using indigenous technology with local material content. The application and the use of these technologies are still at the primary stage of development. Although NSPRI and NCAM have performed well in most, if not all, of their stated objectives, much is still left to be achieved as the organisations presently operate a bureaucratic style which affects their efficiency. The institutions are facing gross under funding as research and development (R&D) expenditure of the Nigerian government is inadequate compared to most middle-income countries. So, the study is also about technology institutions which are part of the public government machinery and have not enough linkages with private farmers and private small and medium businesses which could support the spread of the indigenous technologies.

The study concludes that the government institutions, such as the ministries of agriculture at Federal and State government levels and the Department of Agriculture at Local Government level, need to act more than now as coordinating agencies for bringing together various stakeholders (individual farmers, farmers' cooperatives, organised private sector actors, equipment leasing companies, R&D/STI institutes, and funding agencies) in the agricultural equipment sub-sector. Such a role is not yet performed by government institutions in Nigeria. Only such a stakeholder cooperation approach would lead to a successful spread and use of the new technologies by the farmers in the fields. Only such aa cooperation would lead to feedback impulses from the field and from distributors to the research institutes and then also to the funding government agencies. This approach would have the capacity to make the equipment fabricated and available in large quantity at affordable prices, since the R&D institution would have - with their partners in the production process - taken advantages of economies of scale.

After the Introduction the essay starts with an elaboration of the theoretical framework, the conceptual framework, and the methodology. Then the results of the findings are discussed, by focussing on the role of the two research institutions, on their location and the reach-out of their activities in Nigeria to the main stakeholders, and on the portfolio of indigenous technologies and the economic evaluation of the described technologies. Also, the role of the two research institutions in the frame of the national innovation system (NIS) of Nigeria is discussed, as well as the view of the farmers about the indigenous technologies supplied by the two institutions compared with alternatives (imported commercial technologies). The linkages between the farmers, the R&D institutions, and the equipment producers and traders are assessed, and the role of other public and private stakeholders in the value chain from research to production is considered. An important issue analysed is funding for researches and commercialisation; new proposals are made in the essay to reach a sustainable finance base for researches and the spread of the new technologies. Staff issues matter for both R&D institutions, as a performance-related management system is still lacking in these institutions. The prospects for better working conditions of the researchers are assessed, but these depend on a new institutional affiliation of the technology research institutes. So, the prospects are considered as generally unfavourable over the medium-term, but structural changes in regard of the mandate and the operation of the two institutions need to come forth over the long-term. Then, a more general analysis of the importance of promoting indigenous technologies is related to organizational problems of technology development institutions, to future-oriented STI plans and programmes, and to perspectives of agricultural sector and agricultural value chain developments.

Many important lessons follow from the study. Through a better funding strategy and a greater support from the national government, the international donors and other development partners, the fabricated equipment, tools, machines, and structures could be supplied less costly to the farmers. However, competition is important also for such suppliers of indigenous technologies, and the private sector firms should play a key role in the commercialization. Competing supplies of equipment and parts from other African countries, from emerging economies like China and India, and as well from the local informal sector need to be considered in regard of quality, servicing, usability, and price. International and local donor agencies could assist in funding research and development (R&D) of locally adaptable agricultural equipment, and they could help in the commercialisation of such products to allow for market penetration and an easy access by smallholder farmers and farmers' associations. Although there are already such activities of donor agencies in Africa and in Nigeria, these are not sustained and are not constructive enough to impact on the market. Extension linkages that are done at the level of farmers need to be extended and could lead to the most desired outcomes in terms of a use of such technologies. Nigeria and other African countries have national development plans which anchor on STI, but these plans are often vague and are not to the point of developing indigenous technologies by using local materials, local expertise and local contracting firms. The federalism of Nigeria could be embraced to engender technological competition among the states and among the local governments. The national STI policy should be implemented in such a way that these sub-national levels of government are also equipped with competencies and with adequate funding. Such a view of progressive STI policies would support agricultural development. These initiatives will make innovations to be evolving rapidly for improved market access and for a utilisation of the developed technologies by small farm holders and commercial farmers towards mass food production and food sufficiency.

The second essay presented to Unit 3 is by **Musa Isa Abubakar, Ben Ahmed, Zakari Abdulsalam, and Margaret Kofo Ajala** and has the title **Economic Impact Of Introducing Transgenic Pest-Resistant, Genetically Modified Cowpea in Northern Nigeria.** The essay is motivated by concerns of the authors regarding food security and nutrition in Northern Nigeria. *Nigeria is the largest cowpea producer in West Africa and in the world; and the country produces 3.13 million tonnes per annum on 4.5 million hectares. Nigeria is also the largest consumer of cowpea, with more than 400,000 metric tonnes in deficit. This huge deficit necessitates the need to increase cowpea production in the region. In the past decade, the deficit in cowpea supply has been a major issue in cowpea production in West Africa in general, and especially so in Nigeria. In Nigeria, there is concern* *that the deficit has increased between 2000 and 2013. Hence, there is an urgent need to increase cowpea production in the region, but* production in Nigeria *is also faced with many constraints and challenges, including insect pests, diseases, drought, poor soil, and, so far, resistance to the Maruca insect pest (an insect pest* affecting leguminous crops) *has been limited.* High on the policy agenda is therefore not only the need for production increases, but also the necessity of aiming at varieties with higher pest-resistance.

Cowpea has specific characteristics which make it a useful component of the local diet in Northern Nigeria. The cowpea is an annual herbaceous legume.[31] It is important, especially for semi-arid regions and for countries like Nigeria; cowpea is also useful due to its tolerance for sandy soil and low rainfall. It is therefore an important crop in regions across Africa, but also it is relevant in other regions of the world. Cowpea requires very few inputs, as the plants' root nodules are able to fix atmospheric nitrogen; so it is a valuable crop for resource-poor farmers and it is well-suited to inter-cropping with other crops. The whole plant is used as forage for animals, and with its use as cattle feed this likely is responsible for its name. All parts of the cowpea crop are used, as all parts are rich in nutrients and fibre.[32] In Africa the humans consume the young leaves, the immature pods, the immature seeds, and the mature dried seeds. The stems, leaves, and vines serve as animal feed and are often stored for use during the dry season. Fifty-two percent (52%) of Africa's production is used for food, 13% as animal feed, 10% for seeds, 9% for other uses, and 16% is wasted. So, cowpea is of great value for rural areas with crop production and livestock raising. But the specific problems in Nigeria are first, the huge cowpea deficit and second, how to increase the pest-resistance.

*Pest-resistant genetically modified (GM) cowpea varieties are a new technology which were developed by scientists in a laboratory in Australia, using biotechnology and genetic engineering techniques to confer resistance to an insect pest known as Maruca vitrata.* Nigeria has already passed the Biosafety bill into law in the year 2015 to regulate the use of GM cowpea, to ensure safety to the environment and to human health, and to allay the fear of the people on the socio-economic consequences of modern biotechnology, especially among the small-scale farming systems. The Federal Government of Nigeria (FGN) is considering if it is advisable and possible at all to introduce pest-resistant genetically modified (GM) cowpea in the year 2017 in Nigeria, to boost cowpea production, to contribute to food security, and to enhance yields. The intention is to satisfy the food needs of Nigeria's population and to increase the local cowpea consumption. But, before moving the new GM cowpea variety from regulatory approval to commer-

[31] See Wikipedia on Cowpea. Web Access: https://en.wikipedia.org/wiki/Cowpea

[32] See on cowpea production in Nigeria: https://agronigeria.com.ng/cowpea-production-in-nigeria/

cialization, it is important to understand how consumers evaluate the new technology. So, there is the need to conduct a careful economic impact analysis to predict the welfare impact and the consequences of introducing the new GM cowpea variety to avoid a technology backlash (with consequences for other GM crops and biotechnological researches done in Nigeria) as well as to provide guidance to policymakers (in making well-informed decisions towards solving this public policy problem). This essay uses a choice experiment to estimate the economic impact of introducing transgenic pest-resistant genetically modified (GM) cowpea in Northern Nigeria.[33] The method of choice experiments (CEs) is used here to estimate the net impact of pest-resistant GM cowpea on net social welfare, given price and income risks.

Of interest is therefore the acceptability of introducing genetically modified (GM) cowpea in Nigeria, to consumers and to farmers, but also to the broader public, as media have an important impact on the acceptability of GM cowpea and of other GM food products. Without secured acceptability the introduction of GM-based products may be a costly undertaking. Based on specific analytical methods like the choice experiments the expected net welfare benefit of introducing GM cowpea into the marketplace across Kaduna and Sokoto States, Northern Nigeria is estimated. The results revealed that the aggregate net welfare benefit of releasing GM cowpea in the marketplace to consumers was estimated to be about ₦ 242 billion (US $1.56 billion). This is a huge net benefit so that it is worthwhile to work hard on the strengthening of the acceptability, especially because of all the advantages which the crop has. The results further have shown that the expected net welfare benefit for both Kaduna and Sokoto States were estimated to be ₦ 10 and ₦ 45 billion respectively and were statistically significant at 5% levels. The study concluded that releasing transgenic pest-resistant GM cowpea in the marketplace would have a significant and highly positive net benefit on cowpea consumers' welfare in the study area. Because welfare measurement is of importance for the policymakers, it is recommended that before moving the new GM cowpea from regulatory approval to commercialization there is the need to ensure that the new GM cowpea variety promotes consumer welfare in the study area. Such an assessment needs to be done also in other study areas.

The authors proceed in the essay in seven steps to come to their conclusions and policy recommendations. After the Introduction the Stages of the Innovation

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[33] See on the term "transgenic" the following description from Wikipedia: A transgene is a gene or genetic material that has been transferred naturally, or by any of a number of genetic engineering techniques from one organism to another. And: *Transgenic* or genetically modified organisms, be they bacteria, viruses or fungi, serve all kinds of research purposes. Web Access: https://en.wikipedia.org/wiki/Transgene

Chain for the new GM Cowpea are presented, followed by an analysis of the Drivers and Obstacles Towards Introducing GM cowpea with a focus on the Farmers and the Consumers. In a next step a review of Related Studies is done, followed by Experimental Methods and Procedures and Results and Discussion, and then coming to Conclusions and Policy Recommendations. In so far, this is a model analysis which could be done also for other regions. Of great importance for the analysis and for the policymakers is the presentation of an innovation chain in the study, consisting of various stages: first, a basic research stage; second, a confined field testing (CFT) stage; and third, a biosafety regulation/commercialization stage. Also, the analyses of relevant drivers and of crucial obstacles is helpful. It is obvious that consumers and farmers are key drivers of the process, although the scientific community, regulatory bodies, public agencies, and international donors also play a significant role. The drivers need to be aware of the (net) benefits and they first need to assess the new technology.

The essay has estimated the economic impact of introducing pest-resistant transgenic genetically modified (GM) cowpea in Kaduna and Sokoto States, Northern Nigeria. The study has determined the net impact of welfare benefits and has provided information that will guide the policymakers in making well-informed decisions towards introducing the new GM cowpea in the study area. It was shown that releasing pest-resistant GM cowpea in the marketplace would have significant and positive net benefits on cowpea consumers in the study area, and it was also shown that there is still a very low consumer awareness of genetically modified (GM) cowpea in Nigeria. Awareness is therefore a crucial constraint on the side of the consumers. Furthermore, the cowpea attributes which were used in the design of the choice experiment are relevant in consumer purchasing and cooking decisions as well as in the valuation of the cowpea grain quality. Before moving the new GM cowpea from regulatory approval to commercialization, there is the need for the Federal Government of Nigeria (FGN) and of the regulatory authorities to ensure that introducing the new transgenic pest-resistant GM cowpea promotes consumer welfare in the study area. There is also the need for public enlightenment on the new GM cowpea to increase consumer awareness of pest-resistant GM cowpea before it is released in the local marketplace in the study area. To do this in an “objective and scientifically solid” process and in a “safety first” way is important for further advances of the GM technology in Nigeria. Finally, there is the need for crop breeders to improve those cowpea attributes that consumers give a relatively high level of importance. The most valued attributes, particularly large grain size and safety attributes, need to be given priority when introducing the new varieties of GM cowpea in the study area. The study is also contributing to the still hot debate on the role of GM technologies in Africa’s agricultural transformation.

In the third essay for Unit 3 of Volume 20 of the African Development Perspectives Yearbook the authors **Reuben Adeolu Alabi, Daniel Izevbuwa Osasogie and Onowu Endurance Omogor** present a study with the title **Cassava Production, Processing, Value Chain Integration, Fortification and Acceptability in Nigeria**. Nigeria is the largest producer of cassava in the world with a current output of about 55 million tonnes. In 2014, Nigeria devoted 7.10 million hectares of arable land to cultivate cassava. Cassava is a crop whose by-products have a wide array of uses. Cassava is the most important food crop in Nigeria not only by production quantity, but also because of its ability to reduce food insecurity in the country with implications on poverty reduction. It is tolerant to extreme stress conditions and is suitable to the present farming and food systems in Nigeria. However, Nigeria is losing its production competitiveness due to declines of production and productivity over time. Most of the cassava produced in Nigeria is not processed to high value products. This limits considerably the income generating ability of cassava. Lack of value addition along the value chain also limits cassava marketability and its exportation to international markets. Improvement of cassava processing and utilization techniques would greatly increase labour efficiency, income, and living standards of cassava farmers. Improvement of cassava along the value chain will enhance its shelf life, facilitate its transportation, increase marketing opportunities, and will help to improve human and livestock nutrition. The essay concludes by making recommendations on how to address problems confronting cassava productivity, value addition and its marketability in Nigeria. But also, cassava fortification and acceptance of fortified cassava products is an important issue discussed in this essay.

As the title of the essay shows, the problems associated with cassava production in Nigeria are related to the production system, especially the production technologies and the productivity conditions, to the various processing stages to add value to raw cassava, to the value chain integration, as the value chain needs an integration of the many stakeholders and producers involved, to the possibilities of bio-fortification to increase the nutritional value, and to the acceptability as fortified cassava has to be accepted by the consumers and as well by the producers. Most important, cassava is a crop being especially of great importance to the poor households. More than 30 percent of the Nigerians consume cassava more than four times a week; it was shown that the Nigerians derived an average of 257 kcal/capita/day from cassava which is more than the 241 kcal/capita/day they derived from yam between 2000 and 2013. As the cost of production is low, cassava has a high poverty reduction potential; the consumption of cassava by poor households in urban areas is double that of non-poor households, while in rural areas the consumption of cassava by poor households is triple that of non-poor households. It is therefore important to address the issue of fortification also from the point of view of poverty. Fortification can have a great poverty reduction potential if the nutritional value of the food is increased at moderate cost increases. Fortification is an option only if poor households can continue to afford the cassava. If costs increase by fortification, and so the price, the “crop of the poor” will not stay at the same level of demand. It is therefore necessary to investigate into the various fortification strategies. This is done in the essay.

All depends on family incomes. As family incomes increase, the consumption of cassava as dried root flour declines while consumption in convenient food forms such as gari increases. Dried cassava root flour is cheaper than gari because of the high cost of processing gari. Gari is a granulated and toasted cereal-like cassava food product which is convenient for consumption in urban environments because it is in a ready-to-eat form and it has an extended shelf-life. Medium and high-income families are found to consume gari because it is cheaper and more convenient to cook than grains. The future of cassava as a rural and urban food staple will however depend on cassava's ability to compete with wheat, rice, maize, sorghum, and other grains in terms of cost, convenience and availability in urban markets. Cassava can be produced with family labour, land, and a hoe and machete, making it an attractive and low-risk crop for poor farmers. Cassava has several other advantages over rice, maize, and other grains as a food staple in areas where there is a degraded resource base, uncertain rainfall, and weak market infrastructure. It is drought-tolerant; this attribute makes it the most suitable food crop during periods of drought and famine. Also, if the cassava food system is improved, it will enhance rural industrial development and raise incomes for producers, processors and traders. This is the developmental advantage of cassava. All this leads to the conclusion that cassava has a huge poverty reduction potential. Fortification should not reduce this potential, but should even wider it, by reaching also the urban poor, the poorest in rural areas, and the marginalized poor farmers. Acceptability may be a problem for just these groups of consumers, as it may be difficult to inform them by regular media. Although fortification has a great role in regard of agricultural innovations, many other innovations matter for a comprehensive cassava sector development.

The essay is composed of various analytical steps and policy considerations. After the Introduction (step 1) the essay gives an outline of cassava production and productivity trends (step 2), followed by an analysis of cassava development and improvement in Nigeria (step 3). Interesting is the case of Ghana, as Nigeria can learn from production and productivity trends in the country. Therefore, cassava quality improvement and advances in processing techniques seem to be most important for a competitive position of this crop. Nigeria has a long history of cassava breeding, like the TMS seed variety (a newly developed variety of cassava seed)[34],

[34] See on TMS varieties: http://seedtracker.org/cassava/index.php/product/tms-i30555/, and see the Cassava Seed Tracker: http://seedtracker.org/cassava/

but despite of advantages of such advanced varieties there are also perceived disadvantages, especially in terms of handling the cassava roots based on the new seed varieties. Also, technology development and policy measures have continued to improve the position of cassava, but the outcomes are not only favourable. Despite of improvements and policy support over time Nigeria is losing in competitiveness compared to other countries. More than STI is needed to change the situation; agricultural policy changes, export development policies, and agribusiness development policies are needed. A concerted approach is requested, beyond producing new seed varieties. Then, as a next step the processing of cassava in Nigeria is analysed in detail (step 4). It is found out that there is an enormous potential and need for innovative cassava processing. As Nigeria has diversified economic conditions and a huge market, the potentials are great to benefit from processing. The many actors and stakeholders in processing activities need to be affected by new production initiatives and policy measures.

Obviously, integrating the cassava value chain in Nigeria more fully (step 5) is an important way to develop competitiveness of this crop sector. It is obvious that there is a great need and potential for further integration of the value chain; the extent of the crop losses in the value chain is great, and there are also other weaknesses in the chain, such as with the organization of the smallholders who are producing cassava. There is lack of trust among the stakeholders of the value chain, and their coordination at various levels is difficult. Also, the next step (step 6) is not an easy issue to handle – the bio-fortification of the cassava crop. Frequently, consumers of cassava are at a greater risk of malnutrition - especially because of deficiencies in Vitamin A, iron, and zinc - than consumers of other diets, particularly those that are cereal-based. Therefore, bio-certification is important, and Bio-Cassava Plus (BC+) initiatives have a great and promising role. Bio-fortification is considered as a cost-effective approach to reducing Nigeria's micronutrient deficiencies and the corresponding health problems. Obviously, cassava bio-fortification is considered as a technically, economically and sustainably promising approach to control micronutrient deficiencies and to complement other intervention strategies. But, there are also many opponents to such programmes, arguing that Africa should not be a test place for GM technologies. Awareness creation in Africa is therefore not an easy undertaking. However, creating awareness and raising acceptability in rural areas are key factors to justify the high investments for BC+ programmes. A further step of the analysis (step 7) on the limits of agricultural innovations in cassava reveals that innovations in agriculture are complex and need to consider the cultural, motivational and educational background of the rural people in remote areas, what is too often neglected. And then the last step (step 8 on Conclusions and Policy Recommendations) reveals the long way to go to reach out to a large-scale application of innovations in Nigeria's cassava economy. Many more innovations than bio-fortification matter in Nigeria's agriculture development. An Agenda of Action is presented which relies heavily on policy measures at various government levels and on a close coordination with all the major stakeholders who are working with the cassava economy.

## 3 The Strategy

### 3.1 Developing and Applying Indigenous Technologies for Agricultural Transformation in Nigeria - The Role of Public Research & Development Institutes and of Local Farmers needs to be strengthened

Nigeria has now for decades emphasized the role of public research and development institutions in developing indigenous agricultural technology. The National Centre for Agricultural Mechanization (NCAM) in Nigeria is considered as a model institution in this regard as it is the only agricultural mechanization centre in sub-Saharan Africa. The Centre has now for many years fabricated homegrown agricultural machinery and equipment for use in small and medium-scale farming; this was done by referring to indigenous Nigerian agricultural technology, by aligning to the perceived demand of farmers and to the available local knowledge, and by producing with local material content (see Ogunyemi/Adedokun 2012, and the essay in this Unit 3 of volume 20). Observers of these institutions see a problem in the bureaucratic nature of NCAM and the other public research institutes, in the way of working as a government authority. NCAM is since decades mandated with the development of indigenous mechanization equipment and is equipped with public funds for research and prototype development. Lamented is the gross underfunding of the Centre, as funding is irregular and limited mostly to personnel expenses. A solution is seen by the staff of NCAM in a better funding through the government and through international donors.

However, the real problem of NCAM is that the institution has only weak linkages with the national innovation system (NIS) and with the agricultural innovation system (AIS) and sector innovation systems (SISs) along the specific agricultural value chains. To make such technologies available to a wider market of potential buyers in the farming community, it is necessary to link the public research centre with private sector entrepreneurs to get a steady supply of quality inputs, to procure cost-effective parts and raw materials, and to build a net of traders as intermediaries between NCAM and the farmers. But also, the relations to other pillars of the NIS are too weak and need to be created, especially to finance institutions which are mandated to grant credit to farmers for new machinery and equipment. Microfinance institutions, local agricultural development banks and NGO funding agencies are important in this context. Also, the relations with other agricultural research institutions are important, as indigenous technology development for agricultural transformation need to be based on agricultural research on a most comprehensive scale. Also, the relations to IT centres, to technological advisory centres, to commercial services centres, to training centres, and to biotechnology centres are highly relevant for agricultural transformation. New relations are needed for NCAM-type institutions also with regulatory authorities (authorization offices, patent offices, standardization agencies, quality assessment offices, etc.). NCAM and other public institutions never have sought these direct links with other pillars of the NIS, and the same deficiencies are observed in relation to the agricultural innovation system (AIS) and the Sector Innovation Systems (SISs). The over-dependence on public funding and on international finance support is not the way to make indigenous agricultural technologies spreading over the farming areas to the benefit of the smallholders. Also, deeper regional and international cooperation with similar institutes and initiatives in South Africa, Egypt, Ethiopia, Rwanda, and Kenya matter for NCAM and other indigenous technology institutes; international cooperation links may be useful with institutes in India and Bangladesh. As these countries also have experience in producing indigenous technologies, an exchange of experiences matters.

However, not only indigenous machinery and equipment matter. Also, indigenous technologies in regard of infrastructure development, construction, services provision, information gathering, training and market development are important. In times of climate change the indigenous efforts of farmers to cope with the effects of climate change are becoming even more important than in the past (see Sadiku/Sadiku 2011). Farmers need to know more about the most cost-effective and sustainable indigenous climate change adaptation practices in their region, as such strategies are always site- and location-specific (see on the case of Imo and Enugu southeast states of Nigeria the study by Enete et al. 2011). Farmers have accumulated experience of coping with climate change effects through indigenous mitigation and adaptation measures, as ways to ensure sustainable productivity levels (and even productivity increases) and to remain or become successful as producers in agricultural value chains. A great variety of coping strategies exists, but there is not much support in studying carefully and developing further such indigenous agricultural coping strategies.

Indigenous agricultural coping technologies relate to the traditional irrigation systems, to water harvesting and water storage methods, to soil moisture storage techniques, to traditional soil protection techniques (like digging compost-filled planting pits which hold water, and helping deep-rooted vegetables grow), to building up grass and rock barriers around crops to protect them from the soil erosion, to cultivate manure in septic tanks to use it as a fertilizer, to inter-cropping trees with food crops, and to many other measures for coping with the effects of climate change through indigenous technologies. Indigenous technologies therefore relate to irrigation, water harvesting and storage, cultivating manure, and soil protection. For all these indigenous technologies to be used not only equipment is needed, but also provision of services, extension support, supplies of scarce labour, and advice by researchers and technicians. This means that public research institutions like NCAM have also a role in providing advice and extension services, in developing markets for the products which they develop, in networking along the NIS and the AIS, and in doing foresight studies to be able to respond to the effects of climate change.[35]

Also, such institutes belonging to the agricultural research system, have also to study all the other problems which are affecting the farmers, like conflicts and violence, formal and informal taxation, lack of access to markets, procurement of inputs, information about weather and farming conditions, environmental degradation, risks of droughts and floods, and epidemics, etc. They also should be mandated to submit appropriate solutions to policymakers and farmers' associations. A new strategy means in this context that NCAM-type institutions will be open to new partners and networks, to new assessments and analyses, and to challenges and opportunities which are derived from real problems being articulated by the farmers. Creating markets for agricultural machinery, agricultural equipment, and agriculture-related-services is a huge task and can successfully be done only in cooperation with private business. The traditional coping strategies, such as traditional irrigation, inter-cropping, cultivating manure, etc., need support by professional advice, through reconstructed extension services, and they need continuously a strong R&D back-up. Agricultural transformation requests that a new role is found for such institutions along these coping strategies of the farmers. Agricultural development strategies and policies are the basis for the successful restructuring of these R&D institutions. In the case of Nigeria, the central government, the states' governments, and the local governments need to share interest, funding and action in such policies. These governments at the three governance levels give the frame for policy action. The sudden change of agricultural transformation plans and proposals by successive governments has over decades hindered the effective use of public research institutions and of extension services, as the orientation for the stakeholders in the sector was lost.

## 3.2 Introducing Genetically Modified (GM) Food Products in Nigeria – Responses of Farmers and Consumers need more recognition by Policymakers at all government levels

Food insecurity and malnutrition in Africa, also in Nigeria, have changed the position towards Genetically Modified (GM) crops and related technologies. For a

[35] Research (by Enete et al. 2011) reveals that cassava has a great role in southeast Nigeria because of the tolerance of the crop to climate change conditions. Also, the analyses of the various effects of climate change and of the effectiveness of the various coping strategies are of great interest for building a holistic strategy.

long time, there was a consensus that Africa should follow a careful position towards GM technologies, along the sceptical views in Europa. An argument in Nigeria for GM technologies is pest-resistance of seeds as losses due to plant diseases are huge in Nigeria's agriculture. Also, drought-tolerant seeds and Vitamin A fortified food play a role in the discussion. Agricultural research in Nigeria is therefore working hard on pest-resistant crops such as cowpea (see the essay in this volume), but also the acceptability issues play a role as GM crops need acceptance from the local consumers. More than discussing GM technologies as part of a strategy to realize food security, some proponents of GM technologies emphasize the need for a "second green revolution" for Africa. As many African countries have since the year 2000 shown interest in a collaboration with the GM industry, the number of field trials with GM crops has increased, but also GM food imports and GM seed smuggling have created problems for policymakers and for local agricultural administrations.

Many arguments are raised against GM crops and technologies[36]: GM crops contaminate non-GM crops; GM crops foster dependence on corporate seed supply chains; GM crops lead to an increasing dependence of African farmers on external supplies of seeds and costly chemicals; GM crops are patented; GM crops favour/lead to industrial agricultural systems, like large farms, monocropping practices, mechanization, and reliance on external inputs; GM crops threaten organic and sustainable farming systems. Most important is the issue of safety of GM technologies. Many more experts in Africa argue for more public awareness about the issue, so that the benefits and the risks of GM technologies can be better assessed.[37] It is argued that GM technologies can be a part of a solution in cases where traditional methods of farming have proved to be less efficient. It is also stated that the potential benefits of GM crops toward alleviating poverty and hunger, and toward improving agricultural productivity, health, food security and creating a friendly environment, cannot be overemphasised. But these experts also agree that the adoption of GM technology is at its initial stages in Africa and that a wider application is faced with several constraints, such as the lack of infrastructures, an inadequate human resource capacity, poor education (of farmers, government administrators, and consumers), weaknesses in regard of biosafety regulation, problems with intellectual property rights, and many others.

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[36] See on twelve critical points the early statement "Twelve Reasons for Africa to reject GM crops" from 25 July 2004: https://www.grain.org/article/entries/427-twelve-reasons-for-africa-to-reject-gm-crops

[37] See as examples the essays by A. A. Adenle: https://bmcresnotes.biomedcentral.com/articles/10.1186/1756-0500-4-388 and: https://www.researchgate.net/publication/51701420_Response_to_issues_on_GM_agriculture_in_Africa_Are_transgenic_crops_safe

Therefore, in list of recommendations experts argue for first, an increasing public support for agricultural R&D without precluding Genetically Modified Organisms (GMOs); second, developing cost-effective regulatory policies for GMOs, administered at regional levels if possible; third, promoting information exchange about experiences with GMOs; fourth, pursuing South-South cooperation on GMO trade and regulatory policies to prevent trade disruptions; and fifth, providing technology-neutral support from donors for R&D for food security, as well as capacity building to facilitate trade in GMOs.[38] But a much deeper strategic approach is requested from others. It is argued that it is unrealistic to expect effective biosafety systems to control GM crops in Africa, as state institutions are weak in protecting consumers, small producers and independent researchers and R&D institutions. It is also considered as unrealistic to expect from GM technologies a solution to the hunger problem in Africa, as the low purchasing power of the poor is the primary issue, and not the ways of maximizing output. GM crops will also not be able to resolve the problems associated with plant pests, as new forms of pests ("secondary pests") may come with GM technologies, leading to new resistance problems (and further rounds of dependence on GM technologies). GM crops may also lead to a destruction of biodiversity and may be a threat to human health.

Therefore, the solution is to invest more in indigenous and conventional agricultural research, directed to the root causes of poverty and food insecurity, to strengthen food processing, to improve rural infrastructure, to develop farmer-friendly credit schemes, to support low cost irrigation schemes, and to favour more rural training programmes and a better rangeland management.[39] But also consumer awareness matters, as the acceptability of conventional and GM food crops is an important objective of any consumer protection policy. The real solution is a better agricultural policy, embedded into a long-term development plan. On this basis a technology-neutral position of donors can be requested and implemented. Governments can favour indigenous, conventional and GM technologies in a coherent policy framework, which is also open to GM field trials and to GM crops acceptance surveys. But this means that public research and infrastructure funds should not be directed exclusively to one branch of agricultural technologies. Re-

[38] See the recommendations by K. A. Elliott and J. M. Keller: https://www.cgdev.org/publication/ft/can-gmos-play-role-new-green-revolution-africa

[39] See on further critical points about GM technologies: "Twelve Reasons for Africa to reject GM crops" from 25 July 2004: https://www.grain.org/article/entries/427-twelve-reasons-for-africa-to-reject-gm-crops

cent studies of independent institutions on the future of GM technologies for Africa come to such a balanced position: to be open to GM technologies, but not to disrupt indigenous and conventional technologies.[40]

A major study (by J. Falck-Zepeda et al., eds., 2013, pp. 219-226) summarises the effects of GM technologies in presenting five lessons for Africa. Concerning lesson one, there are generally positive economic effects of GM technologies in Africa, but GM technologies cannot be considered as a strategy to combat poverty (as rural poverty has many determining factors), and there are preconditions for the spread of GM technologies in the form of strong institutions (as they are found in South Africa). It is necessary to have ex ante simulations to assess prior to its introduction the potential benefits and risks of GM crops. Concerning lesson two, there is not enough public research done in Africa on the issues of biotechnology development, and the private sector is not at all involved in research and deployment. Concerning lesson three, the precautionary European model of regulating biotechnology may not be useful for Africa, as biosafety regulatory costs are then too high. The different conditions in Africa for GM technologies than in Europe need to be considered. Concerning lesson four, short term export risks because of the GM-adversity in Europa may be misleading and considered as too high, as the export prospects in the regional African markets are considerable and are obviously underestimated. Regional integration in Africa is especially important for GM technologies and the spread of GM crops. Also, regional African Conventional Agricultural Research (CAR), Indigenous Agricultural Research (IAR), and GM Agricultural Research (GMAR) may be important, to balance these three forms of practising agricultural research. Bt cowpea could lead to gains from trade and from common research in agriculture for all regional partners in West Africa, and so Nigeria as a lead actor in GM technologies could gain. Concerning lesson five, there is a low awareness about GM technologies, especially also among urban consumers. But, awareness campaigns have to offer objective information, by demonstrating the advantages of GM technologies versus conventional technologies and indigenous technologies.

Another study (by J. A. Chambers et al. 2014) is largely supporting the views presented above. But the authors argue convincingly that Africa needs to overcome the “status quo approach” on agriculture by new approaches, new methodologies, and new efficiencies for transforming Africa’s agriculture. The unique aspects of farming systems in Africa require, however, a deep discussion of stewardship, management and ownership to avoid an over-dependence on outside actors and to provide for a societal control of the agriculture sector, what is needed because of the instable government conditions in most of Africa. Regulatory problems are also emphasized (because of the weak institutions being responsible for

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[40] See: J. B. Falck-Zepeda et al. (eds.) 2013, J. A. Chambers et al. 2014, and M. R. Ahuja/ K. G. Ramawat (eds.) 2014

science & technology and for the promotion of agriculture) and delivery problems (as issues of controlling and organizing the seeds distribution are key in the current situation). A key constraint is the weak capacity for biotechnological applications in all possible forms, as public support for the agriculture sector is diminishing. Countries, in which public support for agricultural research is reduced, cannot really qualify for the development and use of GM technologies. Linked to this capacity gap is the gender gap as women have still an insignificant role in agricultural research and in developing and applying GM crops; also, in the related policymaking fields the role is limited.

But also, the financial capacity is too low, as current policies are not conducive to investment and as the local private sector is not involved in the GM crops agriculture business. So, there are various binding constraints which are hindering the development of GM technologies and a related transformation of agriculture. The regulatory capacity gap is a serious one, but also the capacity of the R&D, Tertiary Education and Science & Technology institutions is limited. The policy on intellectual property rights and the trade policy-focussed and regional integration-related aspects of controlling and developing GM technologies are weak. Gaps in these key areas (human and financial capacity, regulation, property rights, and trade and regional integration) are limiting seriously the application of GM technologies, but few successful country cases show that Africa can go along the new agricultural transformation path (South Africa is an example, and others are mentioned, like Burkina Faso, Egypt, Sudan). In nine recommendations the study outlines a long-term strategy to make Africa fit for GM technologies. An informative and concerned analysis on GM technologies in Africa (see chapter 2 in the study by M. R. Ahuja/ K. G. Ramawat, eds., 2014) emphasizes the impact of GM technologies on indigenous local seed systems; the impacts of GM technologies on traditional seed systems, such as seed selection, seed-breeding, seed-sharing and seed storage, are analysed. Also, the potential benefits of GM technologies are discussed in relation to key spheres of action (economy, health, and trade), Especially the importance for Nigeria's agricultural development may be huge, as various crops are positively affected (such as cassava, yam, banana, ginger, cowpea, and maize). But also, the conservation of medical plants and the human resource development effects through group training are potential advantages of GM applications in Nigeria. And, in Nigeria the R&D capacity is still there, although the institutional, operational and regulatory capacities are weak.

Despite of all these GM-related capacity gaps and the intense warnings for biosafety reasons, Nigeria is now a "door opener" for GM technologies in Africa.[41] Only four African nations (Burkina Faso, Egypt, Sudan, and South Africa) allow the cultivation of GM crops. And only South Africa grows GM food, as it allows

[41] See: https://geneticliteracyproject.org/2017/03/06/led-nigeria-africa-gradually-opening-door-genetically-modified-crop-cultivation/

the cultivation of GM corn and soybeans while the other countries, including South Africa, cultivate Bt cotton. The Academy of Sciences of many African countries, including Nigeria and Sudan, and the International Society of African Scientists (ISAS) have claimed that there are not more risks associated with GMO crops than with conventional or organic food products.[42] While large international corporations pressure for GM technologies in Africa, some development partners (donors) being active in African countries are opposing the spread of GMO technologies in Africa. This has also to do with export of African farm products to Europe. African countries were taking up the pressure from Europa for regulatory strictness but were neglecting the regional African markets and other advanced countries markets. Nigeria has not such export interests and is now emerging as a leader in African biotechnology development; so, the country has passed recently an influential biosafety bill. Confined field tests are being conducted for four GMO crops: insect resistant Bt cotton; Bt cowpea (a legume); iron, zinc, protein and vitamin A fortified and nitrogen-efficient sorghum; and salt-tolerant and water-efficient rice. Bio-fortified yellow cassava is under approval (see the essay in this volume on GM cowpea and fortified cassava). If these (confined) field trials prove successful, then the government hopes to commercialize these crops within two to three years.[43] As also South Africa is an important GM technology player for food crops, the situation of Africa is changing now quite rapidly. Bt corn and vitamin A and disease-resistant cassava are two other crops under governmental support in Nigeria. The National Biotechnology Development Agency (NABDA) of Nigeria has a strong position and is leading the pro-GM technology-campaigning. However, there is a major difference between Nigeria and South Africa. South Africa has developed and strong institutions to develop and to control the GM technology.

South Africa is the only country in Africa producing GMO food crops; the country has successfully done field tests of GMO drought and insect-resistant corn which was developed by the Water Efficient Maize for Africa (WEMA) project. The seeds are supplied royalty-free to small farmers in South Africa; commercialization was beginning in 2016. The growing need to increase food production in the face of rising population and the need to grow crops that are drought and insect-resistant and nutritionally enhanced is seen at governmental and expert level not only in Nigeria and South Africa.[44] Ethiopia, Kenya, Malawi, Swaziland and

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[42] See: https://geneticliteracyproject.org/2017/03/06/led-nigeria-africa-gradually-opening-door-genetically-modified-crop-cultivation/

[43] See: https://geneticliteracyproject.org/2017/03/06/led-nigeria-africa-gradually-opening-door-genetically-modified-crop-cultivation/

[44] See: https://geneticliteracyproject.org/2017/03/06/led-nigeria-africa-gradually-opening-door-genetically-modified-crop-cultivation/

Zambia are members of a study group to research the regulation and commercialization of Bt cotton in India, where it accounts for 95 percent of cotton output. Bt cotton has been so successful that India is now the largest producer of cotton in the world and the second largest exporter. Also, China is speeding up commercialization of GM crops, such as corn and soybeans. Thus, two major partners of Africa in the South (India and China) are going in this direction, and reindustrialization ambitions of Africa in the field of textiles and cotton reach out in this way. Reindustrialization depends on modern technologies, and GM technologies may support such revitalization strategies (not only in textiles, but also in food and chemical industries).

### 3.3 Production, Processing, Value Chain Integration and Fortification of Food Crops in Nigeria – Responses of Farmers and Consumers need more recognition by Policymakers at all government levels

A coherent public food fortification strategy is needed to support food security in Africa. Fortification of food has become a very important element of the food security policy. Already in 2003 South Africa has mandated fortification of all maize meal and wheat flour. Specific fortification standards were prescribed by the responsible authorities. These regulations had not only relevance for food manufacturers, but also for importers or for any other traders of maize meal or wheat floor. The fortification regulations and standards were also applied to any products having a 90% meal flour content, such as bread.[45] The fortification standards for Vitamin A, iron, zinc, etc. were scientifically calculated, based on data made available from professional organizations in South Africa (such as medical associations). So, South Africa was very early on the way in setting concrete nutritional standards and introducing related educational programmes to create awareness and acceptability. Also, other African countries were following, not only with fortification of maize meal and wheat flour, but also with fortification of cooking oil, sugar and salt. Recently, a new African Maize Fortification Strategy (AMFS) was inaugurated for the period of 2017-2026, and this by 14 countries in Africa.[46] Also rice is becoming part of the fortification initiatives. In 12 African countries fortification of rice imports is seen as an opportunity to improve nutrition. Mali has introduced a voluntary and market-based rice fortification programme. So, the programme of fortification is broadening and widening.

But, fortification has meanwhile got a regional dimension, especially in West Africa. Standards for the West African region as also for other African regions

[45] See the review from the South African Journal of Clinical Nutrition (SAJCN): www.sajcn.co.za/index.php/SAJCN/article/viewFile/57/53

[46] See the programme of the Food Fortification Initiative (FFI) for Africa/Enhancing Grains for Healthier Lives: http://www.ffinetwork.org/regional_activity/africa.php

facilitate regional trade and strengthen the national policies on food security. But also, international advice is sought. African policymakers rely on the recommendations of the World Health Organization (WHO) for wheat and flour fortification. However, a great task is the mobilization of the private sector (agricultural processors and food industry) in Africa to move in this direction. The background is simple, as without private business the main actors to implement fortification are not in the value chain. If private business remains outside and if the public institutions are remaining weak, then only international and some local NGOs will respond to the needs of providing fortified food. "Smarter Futures", a public private-civic partnership, is such an NGO and is giving to fortification initiatives technical expertise and training support directed to flour millers, government food control staff, and to other relevant stakeholders in Africa.[47] Such initiatives are now also supported by the 17 Sustainable Development Goals (SDGs), as many NGOs see the context of SDG 2 (Zero Hunger) with the other SDGs; the interactions and spillovers are a major theme of the SDG Index. So, since the Agenda 2030 of 2015 there were changes in regard of the role of fortification, as SDG 2 (Zero Hunger) is not only looked at as a quantity problem, but also as a quality problem, to provide sufficient, healthy and safe food for everyone.[48]

South Africa and Nigeria were the first two countries in Africa to fortify flour. While South Africa has obviously developed strong institutions to monitor fortification, this is not the case inn other African countries. More regulatory monitoring is needed in Nigeria to realize the many prescriptions of standards in the daily life by adequate implementation measures.[49] The list of fortification standards in Nigeria for so many products is impressive, but the lack of monitoring is pervasive.[50] Looking at two decades of food fortification in Nigeria leads to rather disappointing results, as the vitamin A fortification policy had little impact on the Nigerian households' access to vitamin A fortified food; the high prevalence of vitamin A deficiency was not significantly corrected.[51] There were losses of nutrients due to inadequate fortification, exposure of fortified food to sunlight by retailers, gaps in regulatory monitoring, and unclear quality control procedures by the processing

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[47] See on the NGO "Smarter Futures": http://www.smarterfutures.eu/

[48] The complete title of SDG 2 is: "End hunger, achieve food security and improved nutrition, and promote sustainable agriculture"; this is a very wide interpretation and so it relates to many other SDGs.

[49] See: https://legacy-etd.library.emory.edu/view/record/pid/emory:dwdsm, and the Abstract through the link: *ffinetwork.org/about/stay_informed/.../NigeriaThesis2013.pdf*..

[50] See the list of food fortification regulations, September 2002, containing 16 food products for Nigeria; for the web access: www.food-fortification.com/.../MANDATORY_FOOD_ENRICH..

[51] See the study by Busari, 2007; Web Access: https://legacy-etd.library.emory.edu/view/record/pid/emory:dwdsm

companies.[52] Despite of the many mandatory forms of fortification legislation, the reality of food fortification is not so favourable because of the serious implementation gaps.[53] And, so far these implementation problems have not been solved at national and regional governance levels. Therefore, regular household surveys and monitoring reports on the real situation of food fortification are requested.

The case of cassava in this Unit 3 of Volume 20 also shows that much more than monitoring of the final product is needed. A careful analysis throughout the whole value chain is needed, as micronutrients are added during the various steps food processing; only in this way it is possible to assess the progress of fortification. Mandating fortification in food processing is ineffective because of inadequate compliance of firms, because of ineffective regulatory monitoring, and because of technical problems in the production process. The Strengthening African Processors of Fortified Foods (SAPFF) project uses a holistic approach combining training with improving the local business environment in Africa. But, SAPFF is supported by the huge US milling and grain trading business, as the key US grain multinationals are decisive part of the initiative.[54] It is a training and networking programme for Nigeria, Kenya, and Tanzania, but mainly based on US business interest. Training is provided mainly for 94 processors, but there are shorter training programmes for 200 smaller firms in Africa. Again, all these initiatives are private-public-civic partnerships. Necessary is however not only the setting of scientifically based standards, but also a state control of the whole process of food fortification, and a state responsibility for food fortification monitoring. All this needs to be done along the full processing chain, from the raw material to the final product. South Africa seems to have such a system, but this is not the case in Nigeria.

The difference of this bio-fortification strategy (as an element of a new food security policy) to the sometimes highly praised Green Revolution for Africa (which emphasized yield increases) is great. The poor did not receive a balanced nutrition supply, as bio-fortification was not a major part of the Green Revolution.[55] Bio-fortification can be a tool to support the poor in terms of access to micronutrients. Bio-fortification measures had some successes in Uganda and Mozambique, also in other African countries, although identifying them clearly is difficult. But again, these successes were not based on strong public institutions.

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[52] See on the study by Busari, 2007: https://legacy-etd.library.emory.edu/view/record/pid/emory:dwdsm and the abstract through: *ffinetwork.org/about/stay_informed/.../NigeriaThesis2013.pdf*

[53] See the list of fortification legislation for Africa: http://www.ffinetwork.org/regional_activity/africa.php

[54] See on the role of the SAPFF project: http://www.technoserve.org/our-work/projects/strengthening-african-processors-of-fortified-foods

[55] See: https://borlaugleap.org/article/can-bio-fortified-foods-help-africa-achieve-food-security

Not public institutions have achieved the successes, but private initiatives, like HarvestPlus, and other NGOs which are leading in the scene. Looking at the history of HarvestPlus, one can see that private interest and first projects led to the initiative, but public institutions never have taken on a prominent role (except in South Africa). There is now a new endeavour to involve governments and public institutions in spreading the impact of bio-fortification.[56] Therefore, bio-fortification makes much sense if it is designed and implemented as part of integrated food security polices, agriculture policies and agro-industrial processing policies. The integration of the issue of bio-fortification into a coherent policy framework is not the case in Nigeria, and only to some extent it is found in the respective politics of South Africa. Also, bio-fortification is too often confused with modern biotechnology, what leads to barriers for accepting bio-fortification techniques; but bio-fortification is also possible with conventional breeding techniques and with agronomic practices. Such barriers are blocking the spread of bio-fortified food products. Acceptability issues in regard of bio-fortified products arise also because of colour (such as in the case of yellow cassava) and/or flavour (such as in the case of sweet potatoes with orange flavour), These differences from colour and flavour of traditional crops are then possibly associated with GMOs. A further problem is that many experts see simply “diet diversity” as the best way for the consumers to get the optimal quantities of micronutrients. However, diet diversity requests another agricultural policy and food security policy based on a diversified production pattern in farming units. But poor countries and poor people lack the conditions for diet diversity, and bio-fortification is then exploited by some firms as a profitable business at the expense of the poor people (see the critical evaluation by J. Ferrao/V. Bell/T. Fernandes, 2017).[57] To avoid such a business with profits at the bottom of the income pyramid, a coherent national food security strategy is requested. A new policy needs to look more carefully at production diversity and diet diversity in rural smallholder economies, and to investigate the role of market access by smallholders to increase trade for diet diversity and the role of off-farm incomes to supplement the household incomes in rural areas to buy more food diversity.[58]

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[56] See on the history of HarvestPlus: http://www.harvestplus.org/about/our-history

[57] See the critical evaluation by J. Ferrao/V. Bell/T. Fernandes, 2017 as PDF: https://www.ecronicon.com/ecnu/si/ECNU-01-SI-05.pdf

[58] See on production diversity and diet diversity: http://www.globalissues.org/news/2017/12/19/23817, and the research programme on ADDA/Agriculture and Dietary Diversity in Africa: https://www.uni-goettingen.de/de/adda-agriculture-and-dietary-diversity-in-africa/510739.html

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# Indigenous Agricultural Technology in Nigeria: A Case Study of the Nigerian Stored Products Research Institute (NSPRI) and the National Centre for Agricultural Mechanisation (NCAM)

**O. I. Ogunyemi[1] and A. S. Adedokun[2]**

## 1 Introduction

Indigenous technology is important in every economy as it is the native and locally adapted application of knowledge and capacity in achieving specific tasks, be it in production, service or consumption. There is no modern technology without root to basic indigenous technology that can be linked to a specific locality. Such home-generated and home-grown applications of scientific arts and technological devices have been on in Africa for ages. African ways of production, though still mostly elementary, are indicative of her indigenous technology process. All countries in Africa have been making efforts to improve their local technology for market-oriented production, but such efforts have too often not yielded the desired results. The efforts have been built upon the opportunities (Siyanbola *et al*, 2012) which are available for economic transformation, international competitiveness, and prosperity if the indigenous technologies are improved upon. Realising the inherent economic advantage of indigenous technologies, Nigeria has been on the fore-front of harnessing the indigenous technological capabilities of her human resources through an institutionalised system for agricultural production. In this connection, the country has kept on sustaining the Nigerian Stored Products Research Institute (NSPRI) since 1960, and it has established the National Centre for Agricultural Mechanisation (NCAM) to achieve improved agricultural production through home-grown technology advancement (the year of establishment of NCAM was 1974).

The relevance and importance of indigenous technologies are many. They are good alternatives, especially if improved upon, to imported advanced technologies that are usually expensive (Ibitoye, 2011) and are beyond the reach of most of the farmers who predominantly operate on a small scale. Indigenous technology can

[1] O. I. Ogunyemi (Ph.D), Agricultural Extension and Management Department, Lagos State Polytechnic, Lagos, Nigeria, E-mail: woleoguns@yahoo.com
[2] A. S. Adedokun (Ph.D), Economics Department, University of Lagos, Akoka, Yaba, Lagos, Nigeria, E-mail: brobayunilag@gmail.com

easily be adopted and adapted by the farmers as it is not usually alien to their knowledge and is not complex for their comprehension. Indigenous technology can easily be improved upon by the local producers and users and by the home scientists as the technology is passed on from generation to generation within an appropriate environment. Despite of the inherent advantages of indigenous technology, Africa has only demonstrated few improvements in local technology which have emanated from institutionalised efforts at technology development.

Consequently, production and income levels of African farmers and other producers relying on indigenous technology have been very low compared with their counterparts in the Western world. The continent is struggling to feed her citizens and is backward in market-oriented production. Questions arise: Is Africa not making any efforts towards solving the problem of insufficient food production, and what are the reasons? Are there local and indigenous technologies that have been developed to enhance food production? These are the questions set for answering in this paper. The objective is to showcase some of the indigenous agricultural technologies that have been developed in Nigeria towards food production sufficiency. Nigeria has a positional advantage in Africa being the most populous black nation in the world. It does appear that if local technologies are available for agricultural production in Nigeria, their transformation would be easier since people are becoming aware of their existence and they can adopt them with or without improvement. Such technology can also easily be spread to other African nations.

Nevertheless, publications on indigenous technology are not as many as those on other indigenous study areas like knowledge. Indigenous technology has past, present, and future outlooks (Abdulkareem, 1992). The present technologies are more efficient than those of the past, and the future holds better indigenous technological opportunities for Africans. Indigenous technology is therefore important, especially for Nigerian communities that are mostly peasant. The occurrence of climate change necessitates responses of farmers to keep up production through adaptation, and this task is closely linked with developing further indigenous technology (Adebayo et al, 2011). The relevance of indigenous technology in local and across border market competitiveness is reported by Labe (2008) and Siyanbola et al. (2012). Indigenous technologies are also relatively cheap, adapted to the purchasing power of the small farmers, and are environment-friendly (Dayanatha, 2006).

Siyanbola et al. (2012) report that there is no country without a base of indigenous technologies, and the local technologies of aluminium pottery, bronze casting, and leather tanning were mentioned to be peculiar with the south-west, south-south and north-west/central regions of Nigeria. However, Sofoluwe et al. (2013) report that indigenous technology is mostly pertinent in rural Nigeria in controlling crops pests and diseases. Realising the importance of indigenous technology, Africans observe the 13th September of every year as the African Day for Technology and Intellectual Property. This is in line with the decision and resolution made by the African Union (AU) Council of Ministers and the Assembly of Heads of State and Government in July 1999, at Addis Ababa, Ethiopia that requested all African nations to use the day to arouse the hidden inventive, creative and innovative spirit of Africans to facilitate the acceleration of technological development in the continent (NOTAP/National Office for Technology Acquisition and Promotion, 2013).

## 2 Framework and Methodology for Studying Indigenous Technologies towards Agriculture Development

### 2.1 Theoretical framework

One of the most important indicators of a country's level of development is the ability to attain food sufficiency through agricultural mechanisation, achieved through stages of transformation in line with most development theories. Development theories see agricultural development as the building block for industrial development because agriculture provides food for the teeming population and as agriculture also serves as a source of industrial raw materials which are required for an industrial revolution. Because of these facts most economic theories on development generally have a direct link with agricultural development. Some of these theories are the linear stage theory, the Neo-classical dependence model, and the False paradigm. But this paper dwells primarily on Rostow's stage theory, which is an integral part of the linear stage theories, and thus serves as a theoretical basis for the study.

According to Todaro and Smith (2009), Rostow's theory explains development as emanating from five phases: the traditional society, the pre-condition for take-off into self-sustaining growth, the take-off, the drive to maturity, and the age of mass consumption. The "traditional society stage" is the first stage in development where the nation, though agrarian production, is organised into an orderly society that depends on the subsistence system of farming. This stage of development limits innovation as science and technology application is limited. As at now, so many countries in sub-Sahara Africa are still at the traditional society level, being a result of poor technology incubation and slower technical progress when compared with other continents in the world. However, recent attempts by some of these countries in developing their technology capacity through indigenous approaches have given an impetus to the quest for change through industrialisation.

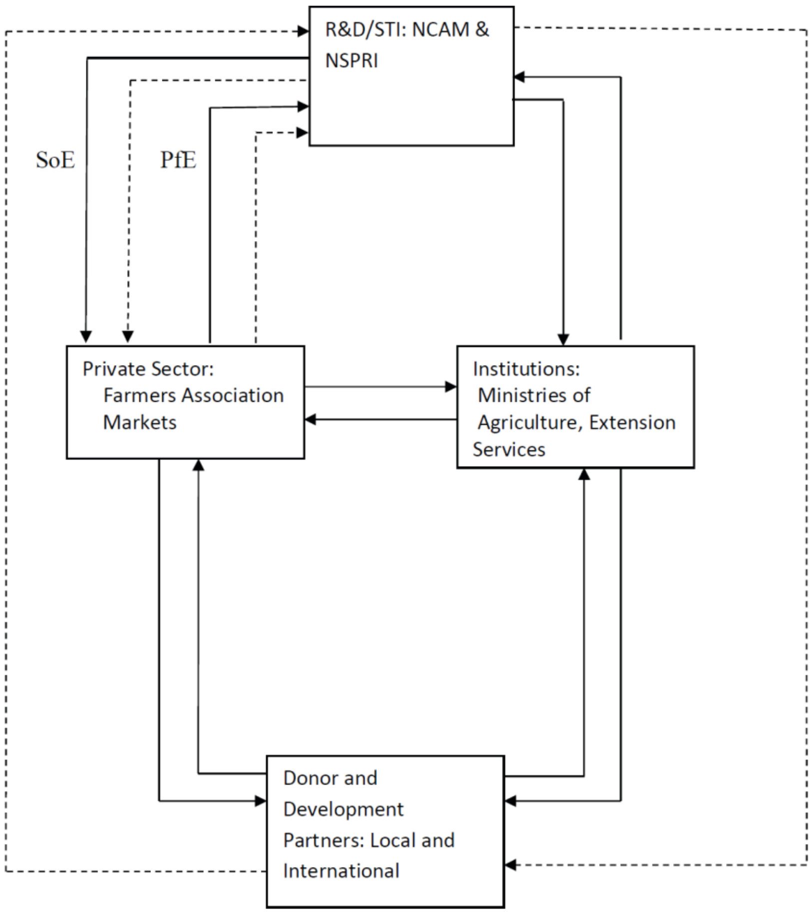
The "pre-condition for take-off stage" gives the necessary conditions that must be fulfilled before a meaningful development can take place. For a country to move up the ladder of development, energy provision is assumed away. Apart from the fact that there is sufficient production of all types of energy, such as electricity, fossil fuels, etc., the cost of energy must be moderate to serve as an incentive for production. Availability of a good road network, organised markets, well-functioning institutions, and of law and order are necessary pre-conditions for industrial take-off in any country.

The “take-off stage” remains a crucial stage in any human society. The stage is characterised by massive productivity increase that is the norm in a modern society. This stage also witnesses mass application of technology and modern scientific discoveries to stimulate growth in agriculture, industry, and in international activities. The period often witnesses massive capital imports, including agricultural equipment which is required to achieve economic growth. New agricultural and industrial techniques spread, as agriculture is commercialised and as increasing numbers of smallholder farmers are accepting the new improved methods and the higher efficiency that comes with it. This agrarian revolution increases productivity through application of modern science and technology allowing for an increase of food production at the rate necessary to avoid the Malthusian prediction.

The next stage after the take-off stage is the “drive to maturity stage”. This stage presupposes that the growth in output stabilises as parts of the country’s income are re-invested in production to make the country self-sufficient in food and in industrial output production. At this stage, the society will have strong institutions that will support growth and the political will to execute decisions that will promote economic prosperity. This is the stage in which the society moves on to mass consumption of goods and services (“age/stage of mass consumption”). The structure of the economy changes in favour of services provision as both heavy and light industrial and agricultural machinery employment are relatively reduced while services provision becomes more prominent among economic sectors.

The indigenous technology can be likened to the first stage of Rostow’s growth theory of the traditional society. With availability of physical and human resources in Nigeria, the country can move to the next stage of pre-condition for take-off and the take-off stage in agricultural development through the efforts of institutions such as NCAM and NSPRI. In Nigeria, through increased research and development (R&D) expenditure in the agricultural sector, the country can drive to the maturity stage and move to the stage of mass production and consumption (see figure 1).

**Figure 1: Interrelationship and flow of information and materials between Farming Equipment R&D Institutes, Farming Markets, Government Agencies, and Development Partners**




**Note:**
Key:
SoE – Supply of Equipment, Information and Training
PfE – Payment for Equipment and Other Services
--------- No Linkage
⟶ Linkage and Direction of Flow of Materials

**Source:** Authors' construct

## 2.2 Conceptual framework

A conceptual framework was developed (see figure 1) to identify what is expected from the study and to look at the interconnections between R&D/STI institutes, agricultural ministries and extension services, farmers' associations, and the farming community, the users of agricultural technologies, as well as the local and the international funding agencies. In the framework, the continuous line represents that there are links while the broken line stands for the absence of links. The research institutes get financial support in the form of subsidies from the Ministries of Agriculture and use the extension service department for liaising between them and the farmers. The farmers, the farming markets, and the farmers' associations obtain supplies of fabricated farm machines, equipment and technologies from the research institutes and they pay for these deliveries. Donor agencies give the research institutes, the farming population, and the agricultural ministries and extension service departments financial and technical assistance and obtain feedback from them in terms of responses how to make the farming materials (equipment and machines) available to the farmers at affordable prices and desired quantities and qualities. So, there is a whole system of actors which is connected deeply

## 2.3 Methodology

The area of study is Nigeria, a country in the West Africa Region of the African Continent. The study used both primary and secondary data which are mostly qualitative. The primary data were obtained through the key informant interview (KII) approach of 8 and 6 senior staff of NSPRI and NCAM respectively in Nigeria and through observation of the developed technologies. Thirty-five (35) expected end-users of the technologies were also interviewed and administered with a questionnaire through convenience sampling, but 32 responses were successful for the analysis. The end-users were among the arable crops farmers within and around the Lagos State Polytechnic Community, Nigeria. The academic community has undeveloped large expanse of arable land that is cropped by scores of farmers and a cooperative farm settlement within the neighbourhood. The secondary data were procured from the internet, journals, and publications of the two organisations in focus. The interview was conducted with pre-drawn questions by the researchers through face-to-face discussions and telephone conversations. The questions asked covered the mandate, the objectives, and the problems of the institutions, the developed technologies, their operations and applications, and the spread of technologies to the farmers. Pictures of some developed technologies were taken with the help of a digital camera, and with their uses and applications recorded as part of data. The data were analysed with descriptive statistics: frequency, tables and percentages, and content analysis. A mapping of the location of the headquarters of the two institutions and the spread of their technologies was done. Moreover, an analysis of the institutions was done to highlight their mandates, and the economic relevance of their developed technologies vis-a-vis the role of the national innovation system (NIS) in Nigeria. The information used for these analyses were obtained from secondary sources and using the KII approach.

A Probit model was also used to examine the effects of farmers' attributes on the probabilities of their using the technologies developed by the two organisations. The Probit equation is simply specified as:

$Y^* = \alpha + \beta_i X_i + \varepsilon_i$
Y is represented as 1 if $Y^* > 0$ and 0 if $Y^* \leq 0$
$Y^*$ = Probability of use of technology (if respondent uses technology Yes = 1, otherwise - No = 0)
$\alpha$ = Intercept
$\beta$ = Coefficient of Vector of Variable reflecting farmer
X = Vector of variables reflecting farmer.
i = Variable Number 1, … , n
$X_1$ = Gender (Male = 1; Female = 0)
$X_2$ = Farming Experience (Years)
$X_3$ = Awareness of NCAM/NSPRI technology (Yes = 1; No = 0)
$X_4$ = Farm size (Hectare)
$X_5$ = Income per annum (Naira)
$X_6$ = Years of formal education (Primary School = 6, Junior Secondary School = 9, Senior School Certificate = 12, National Certificate of Education/National Diploma = 15, First Degree = 16, Master Degree = 17, Doctorate Degree = 20 years)
$X_7$ = Major occupation (Farming = 1, Non-farming = 0)
$\varepsilon$ = Error term

This model will highlight the respective role of attributes of farmers for the probability of using the technologies from the NCAM/NSPRI institutes. This analysis may help to spread the equipment further to new groups of farmers.

## 3 Results and Discussion

### 3.1 The Institutions in Focus

#### *3.1.1 The NSPRI*

The history of NSPRI dates to pre-political independence of Nigeria times. Between 1950 and 1954, the institute was under the name of West African Stored Products Research Unit and was supervised by the Federal Ministry of Trade. In 1960, when Nigeria got her independence from Britain, its name changed to NSPRI under the supervision of the National Science and Technology Development Agency. It became a semi-autonomous research institute by Act No. 5 in 1977. NSPRI was founded to produce low and medium level technical manpower in produce inspection, post-harvest handling of food, and pest control. The focus of the institute before 1960 was on export crops, but her mandate was increased to include research into local food crops, extension and training. The headquarters of the institute are in Ilorin, Kwara State, Nigeria, with outstations in all the ecological zones of the country (NSPRI/Nigerian Stored Products Research Institute, 2013 and ARCN/Agricultural Research Council of Nigeria, 2013).

According to ARCN/Agricultural Research Council of Nigeria (2013), the mandate of NSPRI includes the following tasks and functions:

- i. Improvement and maintenance of quality of perishable crops, including all roots and tuber crops, fruits and vegetables and other similar crops.
- ii. Improvement and maintenance of the quality of durable crops, including cereal grain, pulses, and oil seeds, from the farm level to the commercial level including export.
- iii. Improvement and maintenance of the quality of tree crops, including cocoa, kola, palm produce, coffee, and cashew.
- iv. Designing, fabricating and developing post-harvest equipment to the pilot plant stage; specifically conduct studies in the improvement of food storage structures, primary processing equipment, and food packaging.
- v. Improvement in the primary processing methods of meat, fish, and related products.
- vi. Methods to improve the skills and the capacity building in regard of post-harvest technology through formal training of farmers, industrialists, food handlers, and inspectors.
- vii. Developing food standards to improve the quality of food commodities after harvest, which will aid in the marketing of the produce. Also, conducting studies on the impact assessment of technologies and processes which are developed by the Institute.
- viii. Provision of advice on problems associated with stored products, and materials used in storage, pest control, including storage structures, new insecticides, new items of equipment, and new techniques.

ix. Conducting studies on stored products, pests, pesticide formulation, and residues and mycotoxin surveying.
x. Creating a database for published research findings and a human resources directory in post-harvest science.

*3.1.2 The NCAM*

According to Azogu (2009), NCAM (2013), and Ademiuyi et al. (2013), the NCAM was established in 1974 in Ilorin, Kwara State, Nigeria, and no institution like it has been established in any other African country since then. So, it has a unique position on the African continent. The exact objectives of the centre are: to encourage and to engage in adaptive and innovative research towards the development of indigenous machines for farming and processing techniques; to design and to develop simple and low-cost equipment which can be manufactured with local materials, skills and facilities; to standardise and to certify, in collaboration with the Standards Organisation of Nigeria (SON), agricultural machines, equipment and engineering practices which are in use in Nigeria; to bring into focus mechanical technologies and equipment developed by various institutions, agencies or bodies, and to evaluate their suitability for adoption; to assist in the commercialisation of proven machines, equipment, tools, and techniques; to disseminate information on methods and programmes for achieving speedy agricultural mechanisation; to provide training facilities by organising courses and seminars, specially designed to ensure sufficiently trained manpower for appropriate mechanisation; and to promote cooperation in agricultural mechanisation with similar institutions inside and outside of Nigeria and with the international bodies, connected with issues of agricultural mechanisation (NCAM, 2013).

The two institutes are bureaucratic in nature, operating with public service rules. They have boards, members of which are appointed by the government**.** The implication of this is that board members may be sacked at any time, especially if there is a change of government which usually causes instability in obtaining approval for certain innovation projects. However, under democratic conditions, board members may serve up to four years which is the period for every government before a new one can take over and appoints its own choice as boards' members of various agencies and parastatals of government. NCAM and NSPRI however enjoy a relatively stable board governing system. But, undue political influence may adversely affect the operations of the institutes; the spread of innovations to a state governed by an opposition party to that which is controlling the federal government can be stopped or slowed down against the principle for which the institutes were established.

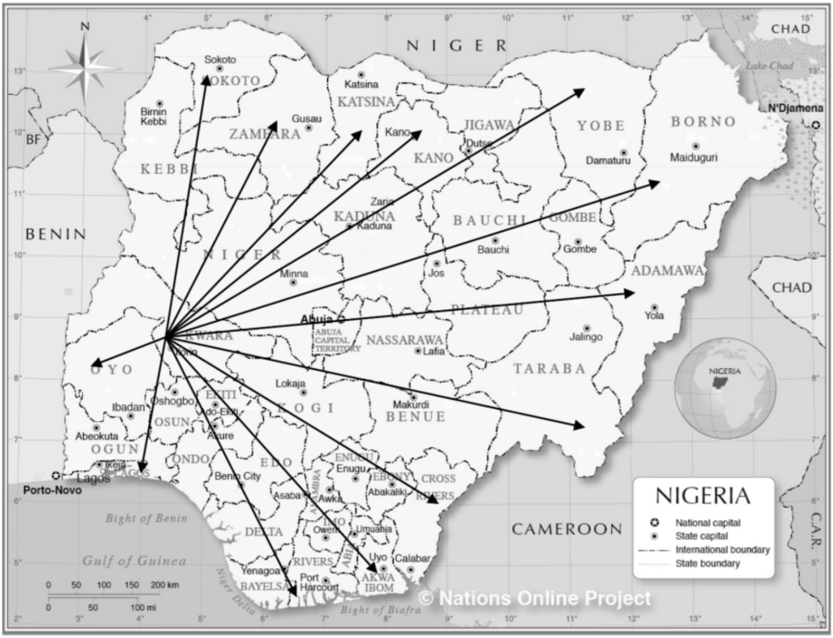
The Minister of Agriculture (MoA) also has a great influence on the operations and the budgetary allocations to the institutes and can influence their leadership composition. Nigeria operates a central government that is powerful financially and politically. The operations, the activities and the spread of technologies from NCAM and NSPRI therefore depend on the impetus given by the federal government through the Minister in charge of Agriculture. All the staff of the institutes are worthy of their profession but no matter how innovative they may be in thoughts and actions, their activities in bringing out new technologies and innovations are subject to the approval of superior officers. Innovative ideas that do not convince the superior officers subjectively or objectively are not approved for further action and that marks the end of such advances at least for the time being. Innovative ideas should be allowed to thrive and should pass through trials with objective critics and being supported administratively towards realising an end-product which will benefit the farmers. It was observed that senior staff in the R&D departments of the two institutes are required to make scientific publications of their innovative works in journals for reaching promotions at certain grade levels. It is the opinion expressed in this paper that the promotion of staff should not be primarily based on publications as most innovations may end up in paper without generating actual physical outputs for end-users, the farmers. It will be more appropriate and beneficial to the economy if the staff in the R&D departments of the institutes are promoted and recognised based on the innovation they developed, introduced and multiplied for country-wide spread. This would contribute to a new and urgently needed market-orientation of the two institutes.

*3.1.3 The location of NSPRI and NCAM and the spread of their technologies*

NSPRI and NCAM are headquartered in Ilorin, the capital of Kwara State by administrative and constitutional political structure in the north-central zone of Nigeria as shown in figure 2 (see below). The institutions have liaison offices in some states of the federation. For instance, NSPRI has an office in Yaba area within Lagos Mainland Local Government Area of Lagos State. Also, NCAM seems to have liaison offices throughout the country.

The establishment of the two institutions was borne out of the country's desire to develop agricultural production technologies for improved productivity and prevention of post-harvest losses through installing proper storage facilities. They were deliberately located in Ilorin to aid an easy spread of innovative technologies as they get evolved. In figure 2, the arrows show how the technologies developed by the institutes are intended to be spread throughout the country. There is, in theory, no state of the federation that any developed technology or innovation will not pass through, depending on the plan and the available resource for achieving a rapid spread of technology.

**Figure 2: Map of Nigeria showing the direction of technologies flow from NCAM and NSPRI located in Ilorin, Kwara State**




Key: ⟶ Direction of technology flows and spread of new technologies

**Source:** One World - Nations Online (2017)

As it were, the spread of innovations from NCAM and NSPRI to the field are more in the northern part of the country, represented by eight arrows, rather than in the southern part with five arrows only. A closer observation of the map and the arrows shows that there is no state in the country that the innovations from the institutes do not pass through; though passage of innovations may not be concurrent throughout the country. Also, states like Kaduna, Kogi, Nassarawa, and Niger which are closer to Ilorin, the city of location of the institutes, have more spread of the institutes' innovations with more arrows passing through them than other states that are far away. Farmers around the Federal Capital Territory (FCT), Abuja, equally enjoy a better spread of agricultural innovations from NCAM and NSPRI. As expected, the two institutes' innovations and technologies are popular among the farmers within Kwara State due to their closeness to the institutes.

## 3.2 Indigenous technology production by NSPRI and NCAM

### *3.2.1 NSPRI indigenous technologies*

The institute has developed various technologies and has passed them to users. Some of the technologies with 100 per cent of local content are:

i. The improved ventilated crib for storing maize on the cob without the husk and other un-threshed grains.
ii. Rhombus for the storage of dry grains in the Nigeria dry regions.
iii. A multipurpose crop drier for drying various crops.
iv. Evaporative coolers for the storage of fresh fruits and vegetables.
v. Large-scale storage of fresh cassava tubers in humidity chambers and in trenches.
vi. Small-scale storage of fresh cassava tubers in moist sawdust in boxes.
vii. The ventilated yam barn for the storage of fresh yam tubers.
viii. The inert atmosphere storage for grain.
ix. Improved silo storage using inert atmosphere.
x. Multipurpose produce dryer.
xi. Other technologies for the storage of perishable crops, beverage, dry fish and meat.

These listed technologies are available in the institute's advisory booklets (NSPRI/Nigerian Stored Products Research Institute, 1982a; 1982b; 1983; and 1990), on the website, and in the occasional paper series; four of these technologies are however described as follows as a show-case of indigenous technologies.

*Fruits and vegetable shed:* The shed is good for rural fruits depots and on farm collection sites. It can be used as a transit collection centre providing a cool micro-environment which assists in reducing fruits and vegetable losses. It is made up of bamboos for the pillars and side walls and palm fronds/raffia thatch/grass for roofing. It is 5m x 4m x 3m in dimensions. The floor may be cemented for cleaning purposes and better handling of products. Slated bamboos are used to make the sides of the shed up to a height of 1.5m, and a wire net is used to cover the remaining 1.5m part up. In the urban area, concrete, block, bricks, timber, and corrugated sheet can be used for the construction of the shed. The use of the technology is to elongate the shelve life of fruits and vegetables by reducing the ambient temperature of the immediate surroundings of the product thus reducing the activities of microbes that can spoil the fruits or vegetable.

*Maize crib:* It is used in an airy area without bush. The long side faces the direction of the wind for good air drying of the grains. It is rectangle in shape, and length depends on the quantity of maize to be stored. The width is between 90 and 150cm. Cribs to be used in the wetter climatic areas should be approaching 90cm in width. To guard against rats, rodent guards are fixed on the four legs of the crib. The guard is made from iron or aluminium sheet which is cut to shape so that when fixed a cone is formed round the leg. Crib of the dimensions 150cm x 120cm x

120-150cm is used for 1000kg of maize. This technology is suitable for small-scale farmers to store maize during the pre-planting and post-planting periods which are lean periods for food and income. The farmers can sell the stored products during these periods and make more income, and they also obtain seeds for the next growing period instead of buying.

*Rhombus:* This can be mud or thatched rhombus and it is relatively cheap to construct in local setting. The type and cost of its construction depend on the capacity desired, location and availability of materials. Adejumo and Raji (2007) and Okoruwa et al (2009) reported that rhombus is one of the local and traditional methods of grain storage in Nigeria. A mud rhombus is made from a combination of mud and dry grass and is constructed like a building that structurally reflects a bin that rests on a large stone with a thatched roof. Upon completion, the farmer has a rhombus that consists of a floor assembly, a wall and a roof, with no external structural supports or pillars. There is no door as it is loaded through the roof by a multiple of 2 men. It is usually of a round shape but can also be cylindrical or spherical. The height ranges from 7 to 10 metres with a diameter varying between 3 and 7 metres; and the capacity is between 1,000kg and 8,000kg of un-threshed cereals and legumes (Adejumo and Raji, 2007). The rhombus has the shortcoming of not being moisture, rodent and air proof. The storage technology has the potential capacity of being transformed with modern materials to replace the mud and the thatched roof which the NSPRI is working on.

*Evaporative coolant system:* This is based on the basic scientific idea that evaporation produces cooling, and the principle was used to develop the pot-in-pot and metal-in-pot evaporative coolant structures. The process of evaporation in the structure enhances the relative humidity of the micro-environment where the coolant structure is placed. The pot-in-pot and metal-in-pot are the same only that the metal replaces the pot in the latter. In the pot-in-pot, a burnt clay pot of about 65cm height and a wall thickness of about 0.8cm is used, while the outside of the pot is coated with a polyethylene bag. This pot is placed inside another bigger pot with a space of about 7cm in between the two pots. In the space between the two pots or the pot and the metal is river-bed sand which is watered frequently. The fruits are placed inside the inner pot/metal. For the metal-in-block evaporative coolant, when the coolant is completed, the wall of the block is higher than the metal compartment in which the fruits are placed through a small door. In-between the wall and the metal compartment is river-bed sand that is watered frequently to keep moist. The structure is placed under shed for cooling purpose. These technologies are economically viable where electricity supply is a problem which is a common feature of Nigerian villages. If electricity supply is regular, a substitute for the technology is refrigerator coolant in which fruits are kept as observed in modern supermarkets.

*Storage in sawdust:* This is usually used for cassava. The equipment is a box constructed of hardwood or plywood with a lid that can be easily opened and closed. Alternatively, a closely woven basket can be used. The procedure is simple as materials required are sawdust, water, and the freshly harvested cassava tubers without wounds, to which 15 to 20cm of the stem is attached. The structure is used by spreading a layer of sawdust at the bottom of the box or basket followed by a layer of cassava roots arranged with the sawdust packed around each root so that the roots do not touch each other. Another layer of the moist sawdust is used to cover the first layer of roots before the second layer of roots is added in the same way as the first. The steps are followed until the box is filled. This technology is very good for tubers and useful for prolonging the storage life of cassava if it is to be kept for a long time and to prevent the tubers from wounds that are caused through abrasion. Damaging micro-organisms easily are penetrating the tuber through openings on their skin if kept for days.

*3.2.2 NCAM indigenous technologies*

The Centre is distinguished for having the highest gathering of agricultural engineers in sub-Sahara Africa (Ademiuyi et al., 2013). The Centre has developed technologies that have encouraged the use of mechanised tools and technologies through the fabrication of a great number of machines. The NCAM has developed equipment and machines in numbers of thousands since its inception in 1974. The local content of the machines and tools are 100 per cent in some cases, and somewhat less in others. Some of these technologies are described below in line with Azogu (2009).

*Manual Yam chipping machine:* This is for a manual operation with a capacity of 0.4 tonnes dice yam (chips) per day. It is good for small-medium scale processors. The main features are the knife that is attached to a handle, the puncher, and the cube-shaped steel sections.

*Bench Mounted Maize Sheller:* This consists of a conical shelling unit, a handle, and a housing unit. The whole unit is mounted on a bench or table. The potential output is approximately 40kg per hour. It can be used by large-scale farmers. It is made of locally available metal materials. This is developed to replace hand and finger shelling of maize grains from the cob which is tasking, and farmers often get their fingers' skin peeled off while shelling maize manually. Apart from this, the volume of grains shelled per unit period manually is low when compared with the maize sheller. A processor can shell between 10 and 20 cobs, if not more, depending on the size of the Maize Sheller while the Manual Sheller is still on one cob.

*Manual Seed and Fertilizer Broadcaster:* This is a multi-purpose device that can distribute granular materials such as seeds, fertilizers and pesticides. It is of low-cost with high degree of uniformity and precision. It consists of a cylindrical hopper with a conical bottom, a circular distributor disc with fins, one gear drive mechanism, hand crank, agitator, feed control lever, and strap for mounting the broadcaster on the shoulder. The machine has an output capacity of 4 to 5 hectares per day.

*Seed treatment drum:* This is a simple device for chemically treating seeds before storage and planting. The machine has a capacity of 20 to 25kg per hour. It has a cylindrical drum mounted on two bearings supported on an angle iron frame. It is a veritable alternative to manual mixing of seeds and chemicals which has inherent risks of chemical penetrating human skin and can be injurious to humans, especially if it touches the mouth. Also, the evenness level of treatment of the seeds with the drum is higher than that done manually.

*Manual Melon Washer:* This is used for washing melon seed after removal from its pod. The main features are perforated cylindrical drum, outer-cylindrical container, hopper, shaft and fibrous brushes. It is good for small and medium scale melon processors. Its capacity is 30 to 40kg per hour.

*Farm Level Paddy Par-boiler:* This is used in soaking paddy in water, heating and steaming over a time frame. It consists of a 50-gallon oil drum that is divided into two chambers called the soaking chamber and the steaming chamber. On the par-boiler are fitted perforated pipes and drain plugs. The equipment can be used for 70 kg of paddy rice in a batch, and the parboiling process lasts for only 3 to 4 hours.

*Hand-Push Weeding Hoe*: This is a push-pull type of device that is used for weeding and hoeing for crops sown in line. It consists of a rim made from mild steel rods and cone bearings. The wheel hand hoe is for weeding and hoeing in the inter-row spaces of the planted crops. The equipment is not good for crops planted on ridges. The output of this hoe is 0.03 to 0.05 hectare per hour.

*Hand seed planter:* This is also a device for planting seeds like guinea-corn, maize and soya-beans. It is made up of a seed tube, seed funnel, a handle, and a jaw-type of soil opener and seed spacing adjustment. It can drop one or two seeds from each seed funnel at a time.

*Pedal Operated Cassava Grater:* This is a cassava processing equipment to improve the traditional method of grating peeled cassava tubers into fine mash. The grater consists of a grating drum, a rectangular hopper, and drum housing a gear system and a pedal. The output capacity of the machine is dependent on the strength and stamina of the operators. However, two operators can produce 30 kg cassava mash in one hour. The electric, petrol or diesel engine power grater is available as a substitute for this technology. But for a smallholder processor, it is most desirable as the substitute is not economical in terms of availability, accessibility and cost. In some towns and villages in Nigeria, processors may have to travel long distance to a relatively large town to get fuel to power her processing machines. The technology replaces the use of hand to grate peeled cassava manually on a rough metal plate which is tedious with low output per unit time. The technology can be likened to the introduction of a bicycle to replace walking.

*Palm-nut Cracker:* This equipment has a capacity of 155kg per hour with a cracking efficiency of 94 per cent. It is used in cracking palm-nut. The machine is sufficiently good for the small and medium scale processor. It has as features; the hopper, the rotor assembly, the strike plate, the supporting frame, and the power source. A 3 to 5 horse power petrol engine is enough for its operation.

### 3.3 Economic evaluation of the described technologies

The technologies that have been described as developed by NSPRI and NCAM have moved agricultural production, processing and storage forward by some steps in terms of economic and social values in the following areas:

i. *Adaptive for MSMEs (micro, small and medium scale enterprises):* The technologies are designed for micro, small and medium scale agricultural businesses that are into the business of production, storage and processing of agricultural products. Rural households who are involved into market-oriented processing of maize and cassava, for instance, have adopted the Bench Mounted Maize Sheller and Pedal Operated Cassava Grater for their operations to boost output and income. Some households do make use of the former in shelling maize before milling. These technologies are not economically efficient for large-scale farming and farm produce processing. The two institutes should be working towards improving and developing the technologies for large-scale production that will be of a type of motorised mechanism.

ii. *Input-output efficiency:* With the use of the technologies, more output is achieved, with the same level of input, than is obtainable from manual operation. For instance, the Palm-nut Cracker reduces breakage of palm-nuts that is common with manual cracking involving the use of a hand-held stone or any other hard object to hammer dried un-cracked nuts on a hard platform. More nuts are also cracked per unit time with the cracker than with manual cracking.

iii. *Reduction of tediousness, drudgery, and wounds associated with manual operation:* Manual operations do make farmers and processors to get tired easily and to become wounded during operations. With the new technologies, like the Hand-Push Weeding Hoe, the Hand Seed Planter and the Seed Treatment Drum, farmers do not get tired in a short period of time, and farming/processing is not causing physical injuries to the body. Nevertheless, the limitation is that the technologies cannot be of use on large-scale operations.

iv. *The technologies are saving time and labour for the farmers which they can commit to other productive activities:* A field that is supposed to be planted for two days can now be planted within half of a day. Less labour is required for processing the higher volume of produce and for cultivating the field, as the technologies make the processor and/or farmer to operate faster and better than using pure manual inputs.

v. *More operations and more produce for more money:* Farmers and processors who adopt the technology earn more money as they can cultivate more land and can process more produce, which translates to more output, and upon selling, to more revenue to the adopters of the technologies.

vi. *Availability of substitutes:* In the meantime, NCAM, NSPRI, and other institutes, like the Federal Institute of Industrial Research, Oshodi (FIIRO), Lagos[3], are working assiduously on revolutionising the agricultural technologies for large-scale production. Until this is achieved, there will not be local substitutes for use in large-scale ventures for the technologies which are basically designed for the MSMEs (micro, small and medium scale enterprises). Foreign substitutes to the local technologies are available but may not be adaptive for the small and medium scale users because of the cost of procurement and shipment that may make them more expensive than the home-grown technologies.

All these arguments on economic viability reveal that there are many explicit advantages of using indigenous technologies from local production.

### 3.4 Level of technologies of NCAM and NSPRI and the role of the Nigeria National Innovation System in promoting the technologies

The stage at which NCAM and NSPRI are in terms of technology development can be said to be “above rudimentary level” but not at “sufficient level” that supports equipment and machinery provision for mass production of food crops and the storage of the produce for the take-off stage of the development process. For the technologies that have been developed by the institutes as described earlier, local materials are used mostly. NCAM is making tremendous efforts at motorising some of its equipment to be powered by engines to boost mechanisation for large-scale crop production and processing. NSPRI is equally making efforts within available resources at its disposal to launch post-harvest technologies for improved storage in all the states of the federation. The two institutes are working diligently in line with the national policy on innovation. However, limits are obvious being inherent in the two institutions and in the national innovation system (NIS) of Nigeria.

The national innovation system (NIS) is a composite of institutions and mechanisms for achieving technology improvement through introduction of new technology, through modification of imported, existing or locally developed technology, and through spreading technologies among economic agents in the country.

[3] See: http://www.fiiro.org/

The NIS, which is the stream of technology and information flows among citizens, businesses and institutions in an economy, is guided by the national policy on STI which is contained in a document accented to by the former President of Nigeria (FRN, 2011). In the STI policy, various objectives and strategies for achieving advances in STI were adequately spelt out. The robustness of the policy document confirms what African countries are known for, which is that there are brilliant ideas on paper, but that there is a very weak implementation of intentions. One of the areas of strategy which the STI policy covers is R&D, with the underpinning reason that there is a need to prioritise R&D along economic sectoral issues and needs. This will engender multidisciplinary and mission-oriented R&D activities in S&T being geared towards the generation, acquisition, storage, application and diffusion of S&T knowledge and innovations for national development. The document stated that the country has the objective of fostering sectoral innovative R&D activities, at the level of R&D institutions and firms that are largely demand-driven and market–oriented in line with national developmental goals.

For the agricultural sector, the strategies spelt out to achieve this objective are:

a. Improving agricultural productivity through cultivation of improved crop varieties and breeds of livestock and fisheries.
b. Enhancing technology uptake and diffusion of agricultural innovations to farmers.
c. Boosting labour-saving and low-cost gender-sensitive processing agricultural technologies.
d. Initiating and nurturing appropriate and innovative technologies for breeding, feeding, health and management of livestock and poultry.
e. Enhancing agricultural waste management and utilisation.
f. Developing home-grown technologies for value addition of agricultural produce.

From the list of strategies stated, b, c, e and f directly affect NCAM and NSPRI. Since 2011, six years down the lane, when the document came into reality, the two institutes have not benefited from the implementation of the action plans for achieving market-oriented innovations. A chief precondition of implementing the action plans is adequate funding. Also, important is as well an effective coordination and feedback mechanism on participative and collaborative efforts towards STI. These elements should become part of the NIS, which is however not attainable due to bureaucratic bottlenecks within the various agencies of government.

The NIS should therefore support the spread of new technologies to farmers and the application of such technologies, through conscious efforts of monitoring and coordinating the agricultural research activities in the various institutes like NCAM and NSPRI, which are both saddled with the responsibilities of bringing out innovation for farming activities and production. The NIS should advocate improved support and adequate funding for technology improvement for production and post-harvest activities for all farmers, without jeopardising the interest of the female gender who often are involved in post-harvest processing, in many villages and towns of the country and in Africa in general. The NIS should give direction and establish guidance for the achievement of labour-saving, low-cost and gender-sensitive innovations in the agricultural sector. It has been one of the operational flag-ships of the STI institutes in Nigeria to ensure women empowerment through newly developed technologies. The NIS should also support efficient and effective agricultural waste management and economic usage for improving the well-being of farming communities. The development of technologies which support the achievement of waste utilisation in agriculture will create employment, income, and will improve the general well-being of farmers. NCAM and NSPRI are keyed into this; developing technologies for processing and transforming agricultural waste to useful products like organic fertilizers. In Nigeria, agricultural produce is often sold to the local or foreign markets without value addition. The NIS, realising the enormous opportunities of job and wealth creation in value addition of agricultural products, should support the production of innovations and technologies for agricultural processing among farmers. Adequate funding should be foreseen by the NIS for the development of technologies that will boost value addition in the agricultural sector.

However, there are too many hopes in the wording used above what the NIS should perform towards agriculture and agro-processing for value addition. Reality is different, and the two institutes are regrettably not brought into real innovation chains. The innovation chain is not including the two institutes in an organized way. This has implications for all stakeholders in the process of producing, using, and modifying indigenous technologies.

## 3.5 Farmers attributes in relation to NCAM and NSPRI technological innovation usage

### *3.5.1 Age and gender distribution of respondent farmers and their perception of NCAM and NSPRI*

From table 1a (below) we see that the demographic features of the sampled farmers show that 65.63% and 34.37% were male and female respectively. The implication of this is that the Nigerian agricultural space is a mixture of both genders in significant sizeable proportions. The years of farming experience of the respondents reveals that 56.25% have 1 to 5 years of experience, while 15.62% of the respondents possessed 6 to 10 years of experience. Those with over 20 years of farming experience were representing 18.75% of the total respondents. The distribution of the two demographic features implies that the respondent farmers could give reliable information on the two agricultural technology institutes in focus.

On the perception of the farmers on the two technology institutes, it can be seen from table 1b (below) that 21.88% of the respondents were aware of NCAM services, while 78.13% were not aware. Low awareness of NCAM services implies that this group of agricultural machine/equipment end users could not have access to the services of NCAM and its indigenous technology and mechanisation products. Moreover, 87.50% of the respondents claimed that the services of NCAM were not readily available, while 12.50% claimed that they were readily available. The revelation from this survey suggests that there is need for NCAM to embark on a nation-wide awareness campaign for the propagation of agricultural mechanisation in Nigeria and of its products and services. Though between 40 and 50 per cent of the farmer reported availability of extension services for the technologies of both NCAM and NSPRI, most of the farmers do not use the technologies. This is in opposition to the report of Ashraf et al. (2015) that access to extension services and formal education positively influence awareness and adoption of innovations. Perhaps, if the technologies are available in large quantities, a good proportion of the farmers will be aware and can be using them. Akinwale et al. (2012) report that research outcomes in Nigeria have not been patented and commercialised for industrial application and marketing despite of the fact that basic and applied research constituted the largest share of the R&D accomplishments in country.

**Table 1a: Demographic features of respondent farmers**

| Feature of Farmer | Frequency | Percent |
|---|---|---|
| Gender | | |
| Male | 21 | 65.63 |
| Female | 11 | 34.38 |
| Total | 32 | 100 |
| Years of Farming Experience | | |
| <1 | 1 | 3.13 |
| 1 – 5 | 18 | 56.25 |
| 6 – 10 | 5 | 15.62 |
| 11 – 15 | 0 | 0 |
| 16 – 20 | 2 | 6.25 |
| > 20 | 6 | 18.75 |
| Total | 32 | 100 |

**Source:** Field Survey (2016)

**Table 1b: Perception of respondent farmers about NCAM and NSPRI**

| | NCAM | | NSPRI | |
|---|---|---|---|---|
| **Perceptive feature** | Fre-quency | Percent | Fre-quency | Percent |
| Awareness by Farmers | | | | |
| Yes | 7 | 21.88 | 2 | 6.25 |
| No | 25 | 78.13 | 30 | 93.75 |
| Total | 32 | 100 | 32 | 100 |
| Readily Availability of Technologies | | | | |
| Yes | 4 | 12.5 | 3 | 9.37 |
| No | 28 | 87.5 | 29 | 90.63 |
| Total | 32 | 100 | 32 | 100 |
| Availability of Extension Services for Technologies | | | | |
| Yes | 14 | 43.75 | 15 | 46.88 |
| No | 18 | 56.25 | 17 | 53.12 |
| Total | 32 | 100 | 32 | 100 |
| Use of Technologies | | | | |
| Yes | 3 | 9.37 | 2 | 6.25 |
| No | 29 | 90.63 | 30 | 93.75 |
| Total | 32 | 100 | 32 | 100 |

**Source:** Field Survey (2016)

Table 1b also shows that 56.25% claimed that there were no extension service providers for NCAM technologies, while 43.75% claimed that they had access to extension services on NCAM technologies. 90.63% of the respondents reported that they were not using NCAM technology because of the high cost of acquisition and maintenance, while 9.37% have been using NCAM technologies. This is a very small share in a country that desires to mechanise her farming system for improved large-scale productivity.

For NSPRI, by the survey results as shown in table 1, 6.25% of the respondents were aware of NSPRI services on storage technologies. 90.63% reported that NSPRI technologies were not readily available, and 53.12% claimed that extension services on NSPRI storage technologies were not at all available to them. Moreover, 6.25% were using the institute's technologies, while 93.75% were not using the technologies. Maybe that the latter group of farmers has in use alternative storage technologies; otherwise, they would have been incurring huge post-harvest losses which characterised Africa farming systems. So, we see that the NSPRI products are even less relevant than the products of NCAM for the respondent farmers, although the availability of extension services is relatively high for these products. Use of the products and availability of extension services for the products are not related strongly.

*3.5.2 Regression analysis of the effect of farmers' attributes on the probability of usage of NCAM and NSPRI technologies*

From tables 1a and 1b it can be deduced that gender, main occupation, and awareness of the organisations affected the level of non-usage of the organisations' technologies among the farmers. This was confirmed by Stata software that dropped the variables with the report that the three variables predicted failure to use the technologies perfectly. Therefore, only four independent variables, farm size, levels of farm experience, income, and education, were included in the probit regression as shown in Tables 2 and 3. Not one of the four variables were significant for the probability of using NCAM and NSPRI technologies; which suggests the dominant use of manual labour for farming operations by all the farmers. However, the coefficient of farm size indicated a positive relationship with probability of use of NCAM and NSPRI technologies in line with Ahmed (2013) and Mignouna et al. (2011). The implication of these findings is that the levels of farm experience, income, and education do not influence the use of the organisations' technologies in the study area, which are not widely in use.

**Table 2. Use of NCAM technologies - Probit regression estimates**

| Use of NCAM Technologies | Coeff. | Std. Err | Z | P>/z/ |
|---|---|---|---|---|
| Farm Experience ($X_2$) | -3.5727 | 9811.19 | -0.00 | 1.000 |
| Farm Size ($X_4$) | 19.7220 | . | . | . |
| Income ($X_5$) | -0.0001 | 0.08 | -0.00 | 0.999 |
| Years of Formal Education ($X_6$) | -3.5381 | 1557.43 | -0.00 | 0.998 |
| Constant | 49.2560 | . | . | . |
| /Sigma | | | | |

LR $CHI^2(4) = 8.9$ Prob > $chi^2 = 0.0637$ Log likelihood = $-4.700e^{-}09$
No. of observation = 32 Pseudo-$R^2 = 1.0000$
$z_{tab}$:1% = 0.005; 5% = 0.025; 10% = 0.05 where * indicates *p* values less than 5% (significant at 5%) ** Significant at 10 %
**Source:** Computed from field survey data (2016)

**Table 3. Use of NSPRI technologies - Probit regression estimates**

| Use of NSPRI Technologies | Coeff. | Std. Err | Z | P>/z/ |
|---|---|---|---|---|
| Farm Experience ($X_2$) | -0.0445 | 0.2078 | -0.21 | 0.830 |
| Farm Size ($X_4$) | 0.0061 | 0.8244 | 0.01 | 0.994 |
| Income ($X_5$) | $-4.8e^{-}07$ | $3.3e^{-}06$ | -0.14 | 0.885 |
| Years of Formal Education ($X_6$) | 0.4356 | 0.5835 | 0.75 | 0.455 |
| Constant | -7.5280 | 8.3589 | -0.90 | 0.368 |
| /Sigma | | | | |

LR $CHI^2(4) = 1.93$ Prob > $chi^2 = 0.7486$ Log likelihood = -3.4850
No. of observation = 32 Pseudo-$R^2 = 0.2169$
$z_{tab}$:1% = 0.005; 5% = 0.025; 10% = 0.05 where * indicates *p* values less than 5% (significant at 5%) ** Significant at 10 %
**Source:** Computed from field survey data (2016)

The results are in line, at least to a reasonable extent, with past studies which include Akudugu et al. (2012), Chi and Yamada (2002), Simtowe and Zeller (2006), and Mwangi and Kariuku (2015). According to Mwangi and Kariuku (2015), factors which determine the use of agricultural innovations are economic, household, social, and technological variables. Economic variables include farm size, cost and net gain of using a technology (Ahmed, 2013). Household factors are the level of formal education, age, gender, and the household size of the farmer. Institutional factors entail membership of social groups, access to extension agents, channels of acquisition of information, proven benefits of the technology (Akudugu et al., 2012), and credit access (Simtowe and Zeller, 2006). Technology factors include easy applicability of technology, characteristics of technology, compatibility of the technology to the environment, perception of farmers on the technology, and consistency of the technology with farmers' needs (Adesina and Zinnah, 1993; Chi and Yamada, 2002; Doss, 2003; Karugia *et al*., 2004).

The effect of farm size can be positive (Ahmed, 2013; Mignouna et al. 2011), negative (Harper et al. 1990) or neutral (Waller et al. 1998; Samiee et al. 2009). According to Ahmed (2013) and Mignouna et al. (2011), small farm size promotes labour-intensive and land-saving technologies. If the innovation supports land-saving, it is most likely that the small land holder farmers will adopt it if other related factors such as cost and net return from the use of the technology are favourable. Most of the farmers are of the type of small land holdings using manual operations and do not use NCAM and NSPRI products. One reason given by the farmers for non-use of the technologies of the two institutes is the high cost; this is a result which agrees with Makokha et al. (2001) and Foster and Rosenzweig (2010) that the high cost of the technology decreases the use of new technology.

Available literature indicates mixed results on the effect of other socio-economic variables on the farmers' use of innovations. The probit regression results of this study indicate that none of the variables are significant. In Mignouna et al. (2011), Okunlola et al. (2011) and Lavison (2013), education has a positive and significant effect on farmer's use of innovation, but Khanna (2001), Banerjee et al. (2008), and Uematsu and Mishra (2010) reported positive and insignificant effects. Also, Mignouna et al. (2011) reported that age has a positive effect, while in Adesina and Zinnah (1993) age has a negative effect on farmers' use of new technology due to inherent risk in the application of innovation as risk aversion increases with age. Omonona et al. (2005) reported that male gender favours technology adoption because the men have better access to and control of resources. Simtowe et al. (2012) mentioned that access to extension services and household size positively influence the use of innovations among farmers. The reason for the positive effect of household size was explained by Bonabana-Wabbi (2002), arguing that labour availability through a large household size relaxes labour constraints at the introduction stage of the new technology.

## 3.6 Linkages with the Farming Users

NSPRI and NCAM are marketing their products, the local innovative agricultural and storage technologies, to the farmers. The two organisations carry out training programmes, workshops and seminars for both commercial and non-commercial users of the new technologies. They also disseminate information through their extension officers. NSPRI experts participate in Monthly Technical Review Meetings (MTRM) and in Research Extension Farmers Input Linkage System (REFILS) in all the states of the Federation where such gatherings take place. But the effectiveness of such linkage actions should be questioned and so should be studied carefully. This linkage is shown in the conceptual framework of this study presented in figure 1. The study revealed that both small and medium scale farmers are limited in their technology level and their technological adaptation, incapacitated by the high costs of machine imports so that they are forced to look inward for affordable locally fabricated equipment that meets their needs. But the farmers are willing to adopt and to purchase the equipment only if they are reliable and of low acquisition and maintenance costs.

### 3.7 The role of States and Local Governments in local agricultural technologies development, adoption and spread

The State and Local Governments as the second and third tier of government in Nigeria are limited financially as most of them depend on the monthly allocation from the federal purse without which they cannot pay their employees' salaries not to mention implementing any project such as financing STI activities. Consequently, the two tiers of government do not provide financial support for the two institutes in focus, as they belong to the Federal Government.

However, some states governments have and run Colleges of Agriculture and Universities with Faculties of Agriculture which develop technologies that farmers can use. Some of these institutions collaborate with NCAM and NSPRI in carrying out the mandate given to them by their State Government in assisting farmers with improved technologies to boost production. But the problem is adequate funding of research and of innovations development for the multiplication and marketing of such technologies. Technologies developed do too often end up on the shelf as reports.

Also, some of the State and Local Governments have Extension Departments and Agricultural Departments respectively, that collaborate with NCAM and NSPRI in the effort towards spreading the technologies among the farmers, through awareness creation, training on their use, and informing about their availability for purchase. This role is often hampered by systemic inefficiency, partly due to bureaucratic bottlenecks. Through farmers' groups, like cooperative societies, the State Extension Departments and the Local Government Agricultural Departments interact with the farmers and get them informed of the available technologies which are developed by NCAM and NSPRI, but there is a gap in the delivery of this service to the farmers because of the lack of funds.

### 3.8 Collaboration with other (inter)national development and non-governmental donor/funding agencies

NSPRI does its work in collaboration with the Nigerian Export Promotion Council (NEPC)[4], the National Agency for Food and Drug Administration and Control

[4] See: http://www.nepc.gov.ng/

(NAFDAC)[5], the Agricultural Research Council of Nigeria (ARCN)[6], and other Agricultural Development Agencies (ADAs) in the country. Similarly, NCAM also works cooperatively with agencies like the Small and Medium Enterprises Development Agency of Nigeria (SMEDAN)[7], and Agricultural Development Agencies (ADAs) in the country. The two organisations also work with the Standards Organisation of Nigeria (SON)[8] to ensure high standards in the fabrication and the assembly of equipment with local content. The figure 1, the conceptual framework for this study, reflects this relationship as well. In the figure, there is a linkage between NCAM and NSPRI, the Ministries of Agriculture and the Extension Services Departments, and the farming community. However, there is no link between the R&D/STI institutions and the funding/donor local and international agencies. Although, these two organisations (in the field of R&D/STI) make agricultural equipment based on the needs of the farmers in the country, the equipment is not made readily available to the farmers; these technologies are not adequately multiplied for availability to and affordability by the small-holder farmers. International donor agency interventions on STI are not evident in Nigeria. It is only the UNESCO that provides advisory and training services on STI policy to Nigeria with the establishment of an International Advisory Board for Nigeria which is part of the UNESCO (United Nations Educational, Scientific and Cultural Organisation) project for the reform of the Nigerian Science and Innovation System (UNESCO, 2005). And, there is no recent information on the output of this project.[9] The UNESCO Science Report - Towards 2030 (UNESCO Publishing, Paris 2015) contains some information on general terms for West Africa.[10]

## 3.9 Funding of the NSPRI and NCAM

R&D/STI organisations in Nigeria rely solely on Government subventions. This subvention however is skewed in favour of recurrent expenditure which is between 60% and 80% of the total budget. As shown in table 4, the budgets of NCAM from 2010 to 2016 probably may have sub-summed R&D expenditure under the capital allocation. While a large portion of the budgets was devoted to personnel costs, it is obvious that the smaller proportion which is remaining can only be shared by equipment and capital acquisition alongside with research and development (R&D) expenses.

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[5] See: http://www.nafdac.gov.ng/
[6] See: http://arcn.arcnigeria.org/
[7] See: https://www.smedan.gov.ng/
[8] See: http://son.gov.ng/
[9] See: http://www.unesco.org/new/en/natural-sciences/science-technology/sti-policy/country-studies/nigeria/
[10] See: http://en.unesco.org/unesco_science_report

In 2010, NCAM should have spent 64.78% of its total budgetary allocation of ₦498,096,223.00 on personnel cost, while NSPRI had 68.57% of its budget ₦789,486,502.00 on the same budget position. These budgetary allocations respectively represented 0.85% and 1.34% of the total budgetary allocation to agriculture of ₦58,768,238,205.00. In 2011, the NCAM budget for personnel and overhead costs was 59.86% of total budgetary allocation, leaving 40.14% for capital expenditures and research and development (R&D). This was an improvement of about 20% in the allocation to capital vote between 2010 and 2011. The improved funding for R&D should have been reflected in the productivity of the organisation, with the knowledge that NCAM is an organisation which promotes indigenous technologies for agricultural mechanisation in Africa with a substantial turnout of fabricated technologies some of which were described in section 3.2. The 2011 allocations to NCAM and NSPRI of ₦665,096,223.00 and ₦935,387,146.00 were 1.51% and 2.13% of the total agricultural budgetary allocation (₦43,985,520,694.00) respectively; these proportions are better than those of 2010. More recent data, up to 2016, do not show great deviations from this pattern. But, substantial changes can occur from one year to the other (see below).

Also, from table 4 one can see that the NSPRI total recurrent expenditure have declined from 74.67% in 2010 to 63.02% in 2011. This implies that more resources were freed to useful sub-heads of capital/R&D, which stood at 36.98% against 25.33% in 2010. By 2014, there was not much difference in the budgetary structure of NCAM, which had devoted 60.44% on recurrent expenditure and so leaving 39.56% for capital which embodied R&D. The observed improvement in budgetary allocations of NCAM between 2010 and 2014 is obviously a reflection of a renewed effort at capacity building for developing solutions to the problems of agricultural equipment in Africa; this means that the potential of the institute's relevance for Africa's development is increasing. It is also a reflection of the seriousness with which the federal government was implementing the then existing Agricultural Transformation Agenda (ATA) policy.[11] However, the case of NSPRI was rather different in 2014 as the institute fell back to a higher recurrent expenditure share, and was devoting only 21.43% on capital/R&D. Despite of the observed improvement of the budgetary allocation to the entire agricultural sector in 2014 - to ₦66,644,675,939.00 from ₦43,985,520,694.00 in 2011, the proportional allocation to the two institutes has declined between the two periods. The per cent allocation of the agricultural budget to NCAM was reduced from 1.51% to 0.90% while that of NSPRI nose-dived from 2.13% to 1.15% between 2011 and 2014 in that order.

[11] See: http://fmard.gov.ng/home/ata-nigeria/ and https://www.afdb.org/en/projects-and-operations/project-portfolio/p-ng-aab-003/

In 2016, the total allocation to agriculture further increased to ₦76,753,672,275 from which the portion which was allotted to NCAM has increased to 1.56% while that of NSPRI has decreased to 1.11%, representing ₦1,198,311,942.00 and ₦851,518,183.00 respectively. Nevertheless, NCAM has succeeded in living up to her mandate by cutting budgetary allocation on recurrent expenditure and increasing the allocation to capital/R&D in 2016. The budgetary allocation to capital/R&D stands at 64.59%. This should enable the institute to carry out adequate research on the type of equipment that will meet the needs of the MSMEs and of the large-scale farmers on the continent to reduce the burden of importation of equipment. Equipment and machine importation is one of the items that currently dominate Nigeria's and other African countries' import bill; this affects the exchange rate and the foreign exchange reserves adversely, especially for countries experiencing dwindling foreign exchange earnings. Once the importation of agricultural machinery and of other products like consumables is abated, the exchange rate of the domestic currencies in sub-Saharan Africa will substantially improve. But there is much to be desired in respect of the shares of the agricultural sector budget for NCAM and NSPRI; the government needs to improve on their allocation to these institutes to achieve such a high level of multiplication of production of technologies that the lower unit costs of production will translate into reduced prices for technologies to be paid by the farmers. An allocation of funds to these institutes with a share that is less than 2% of the funds for the entire agricultural sector may not support the achievement of this feat.

NSPRI is still behind in the quest for providing Africa with solutions to Africa's problems in storage technology as its budgetary allocation is still skewed in favour of personnel costs. If NSPRI can work tenaciously to provide storage technologies such as silos for grain crops and the rice and grains farming projects in Lagos and Kebbi States which are known as the Lake rice, Nigerians will be encouraged and wholly support the ban on grains importation.[12]

In 2016, partly due to improved budgetary allocation to Capital/R&D, the second phase of the Agricultural Equipment Hiring Enterprise (AEHE) under the Mechanisation Intervention Programme (MIP) was launched by NCAM. The Centre added 60 new (AEHE) Centres to facilitate an easy access to locally fabricated equipment by the farmers. According to the Minister of Agriculture, Chief Audu Ogbe, ''through these 60 AEHE Centres, we will have 2,000 direct jobs created for the unemployed youths; 100,000 hectares of land mechanized; 500,000 metric tonnes of food added to national production'' (The Guardian, 17 January 2016: 1). This was made possible by improved funding to the institute in the previous years, especially in 2014.

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[12] See more on the Lake rice initiative: http://www.vanguardngr.com/2017/01/making-lake-rice-available/

**Table 4: Selected Years of Budgetary Allocations in Naira to the National Centre for Agricultural Mechanisation (NACM) and to the National Stored Products Research Institute (NSPRI)**

| Year | Total Agricultural Budget (A) | Institute | Total Personnel (Percent of Total Allocation) | Total Overhead (Percent of Total Allocation) | Total Recurrent (Percent of Total Allocation) | Total Capital (Percent of Total Allocation - B) | Total Allocation to Institute/% of Total Agricultural Budget – A (B) |
|---|---|---|---|---|---|---|---|
| 2010 | 58,768,238,205 | NCAM | 322,644,995.00 (64.78) | 75,451,228.00 (15.15) | 398,096,223.00 (79.92) | 100,000,000.00 (20.08) | 498,096,223.00 /0.85 |
| | | NSPRI | 541,354,945.00 (68.57) | 48,131,557.00 (6.10) | 589,486,502.00 (74.67) | 200,000,000.00 (25.33) | 789,486,502.00 /1.34 |
| 2011 | 43,985,520,694 | NCAM | 322,644,995.00 (48.51) | 75,451,228.00 (11.34) | 398,096,223.00 (59.86) | 267,000,000.00 (40.14) | 665,096,223.00 /1.51 |
| | | NSPRI | 541,354,945.00 (57.87) | 48,131,557.00 (5.15) | 589,486,502.00 (63.02) | 345,900,644.00 (36.98) | 935,387,146.00 /2.13 |

Continued on next page.

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| Year | Total Agricultural Budget (A) | Institute | Total Personnel (Percent of Total Allocation) | Total Overhead (Percent of Total Allocation) | Total Recurrent (Percent of Total Allocation) | Total Capital (Percent of Total Allocation - B) | Total Allocation to Institute/% of Total Agricultural Budget – A (B) |
|---|---|---|---|---|---|---|---|
| 2014 | 66,644,675,939 | NCAM | 306,551,090.00 (51.20) | 55,327,959.00 (9.24) | 361,879,048.00 (60.44) | 236,833,721.00 (39.56) | 598,712,769.00 /0.90 |
| | | NSPRI | 565,917,690.00 (73.87) | 36,056,092.00 (4.71) | 601,973,782.00 (78.57) | 164,160,500.00 (21.43) | 766,134,282.00 /1.15 |
| 2016 | 76,753,672,275 | NCAM | 385,816,046.00 (32.20) | 38,560,424.00 (3.22) | 424,376,470.00 (35.41) | 773,935,472.00 (64.59) | 1,198,311,942.00 /1.56 |
| | | NSPRI | 559,752,315.00 (65.74) | 25,129,034.00 (2.95) | 584,881,349.00 (68.69) | 266,636,834.00 (31.31) | 851,518,183.00 /1.11 |

**Source:** Budget Office of the Federation, Federal Republic of Nigeria (2010, 2011, 2014 and 2016)

With the mentioned developments of improved budgetary allocation to R&D and to AEHE, NCAM, as the only institution with the mandate to mechanise Nigeria's agriculture, is at the forefront of the Mechanisation Intervention Programme (MIP) to increase the spread of usage of locally fabricated light and heavy agricultural equipment. The Centre is aware and does take cognizance of the fact that in the process of mechanising Nigeria's agricultural space, there will be the need to adopt appropriate indigenous technology because of the topographical features of Nigeria's arable land that requires special purpose equipment to be used. This is evidenced from table 5, on the response of the staff of the organisations to whether the technologies to be developed should be in line with characteristics of the topography existing in all parts of the country.

However, the overall quite inadequate level of funding of the two institutes by the government is reflecting the lack of interest given by Nigeria to STI. The University World News (2014) reported that Nigeria has the capacity to be a country to be reckoned with on STI but has paid little or no attention to its development since 1964 when the National Council on Scientific and Industrial Research (NCSIR) was founded and later replaced by the Nigerian Council for Science and Technology (NCST) in 1969. Later the National Science and Technology Development Agency (NSTDA) was established in 1977, and then the Federal Ministry of Science and Technology took over these functions in 1979.[13] The United Nations Educational, Scientific and Cultural Organisation (UNESCO) assisted the country to establish four research councils, which are the Agricultural Research Council of Nigeria (ARCN)[14]; the Nigerian Institute of Medical Research (NIMR)[15] which was replacing in 1977 the Medical Research Council of Nigeria (MRCN)[16]; the National Research and Innovation Council (NRIC) of Nigeria[17]; and the Industrial Research Council of Nigeria (IRCN). But, R&D was not seen as an important task in all these organisations as it was assumed that the oil revenues of the country were enough to cater for the country's needs. Anyway, a lot of administrative and organizational changes took place but without making these institutions to become more effective.

Also, poor implementation, coordination and evaluation rendered the first science and technology policy that was introduced in 1986 to bear no results. The policy was reviewed in 2003 with the inclusion of more participants, and in 2012 with including the additional word 'innovation' for a comprehensive STI policy. The newest policy also encountered inadequate funding, lack of continuity, and lack of consistency in its adoption and implementation by successive Nigerian governments. This is also partly responsible for the non-popularity of the 13th Day of September every year that has been declared for celebration by the African Union (AU) as the Day of Technology and Intellectual Property since July 1999 at Addis Ababa, Ethiopia, and in fact this Day was adopted by all AU member states.

The funding of STI in Nigeria is very poor compared with other countries. For instance, in 2007, Nigeria spent 0.219% of her GDP while the United States of America (USA), South Africa, China, Singapore, and Brazil spent 2.627%,

[13] See on the history of these institutions: http://www.iiste.org/Journals/index.php/PPAR/article/view/6965
[14] See: http://arcn.arcnigeria.org/
[15] See: https://nimr.gov.ng/
[16] See by IANPHI/International Association of National Public Health Institutes: http://www.ianphi.org/membercountries/memberinformation/nigeria.html
[17] See on the lack of coordination in this field of action: http://allafrica.com/stories/201602151348.html

0.883%, 1.384%, 2.337%, and 1.082% of their GDP on STI respectively (World Bank, 2016). Nigeria's spending on STI falls short of the 1% of GDP recommendation by the UNESCO. To boost the efforts at actualising the objectives of the STI policy, the Government of Nigeria has approved the plan to establish a National Research and Innovation Fund (NRIF)[18], an STI Council each at State levels, and a National Research and Innovation Council (NRIC)[19]; the National Office for Technology Acquisition and Promotion (NOTAP) was also established as an agency in the Ministry of Science and Technology (MST).[20] Till now, some states are yet to inaugurate their STI Councils and with inadequate funding, these councils and agencies will achieve little or nothing. So, Nigeria continues with the building of organizations, but institution-building is more than setting up a bureaucratic organization. Institutions work only if there are direct working relationships with the ultimate clients/customers/beneficiaries/addressees of an organization.

A further comparison of Nigeria's spending on STI with other countries shows that while the governments in Nigeria and all over Africa are the major financiers of STI, private sector funding for STI is extremely small; private industrial sectors in Africa do not finance and execute STI programmes to a reasonable extent. Public industrial sectors in Africa are not executing STI programmes as government funding is directed mainly to public universities and to research centres. Funding by the private sector and industrial funding in OECD (Organization for Economic Cooperation and Development) countries and in Emerging Economies (EEs) are of greatest importance for STI projects.

According to Hall and Van Reenen (2000), the industrial sector accounts for 70% of R&D funds in Japan and South Korea, for 66% in Germany, for 68% in the USA, and for 44% in Canada, while Nigeria provides 96.4% as direct government funding, while the business sector and the higher education sector account for only 0.2% and 0.1% of the R&D funds (Akinwale et al. 2012). This means that the private sector has no role in STI development, with the implication that public R&D is not associated with the business sector and its products and processes. This also means that R&D in Nigeria is not enhancing directly export competitiveness and industrial diversification. For agriculture and agro-industries this means that these value chains are not upgraded by R&D and by STI as technology transfers are not taking place in time.

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[18] See: https://scitechafrica.wordpress.com/2016/04/23/nigeria-to-setup-a-national-research-and-innovation-fund/

[19] See the draft of the NATIONAL RESEARCH AND INNOVATION BILL, 2016 (available as aa PDF)

[20] See: http://www.notap.gov.ng/

**Table 5: Evaluation of NCAM and NSPRI by staff of the organisations**

| S/N | **Question** | **NCAM** | | **NSPRI** | |
|---|---|---|---|---|---|
| | | Yes Frequency (%) | No Frequency (%) | Yes Frequency (%) | No Frequency (%) |
| 1 | Organisation depends majorly on government subvention | 6 (100.00) | 0 (0.00) | 8 (100.00) | 0 (0.00) |
| 2 | Organisation sells its technologies to farmers | 6 (100.00) | 0(0.00) | 8 (100.00) | 0(0.00) |
| 3 | The costs of your technologies are high for the farmers | 3 (50.00) | 3 (50.00) | 5 (62.50) | 3 (37.50) |
| 4 | Organisation have functional extension unit | 6 (100.00) | 0 (0.00) | 8 (100.00) | 0 (0.00) |
| 5 | Organisation receives financial support from State or Local Governments | 0 (0.00) | 6 (100.00) | 0 (0.00) | 8 (100.00) |
| 6 | Organisation receives financial support from local or international donor agencies | 0 (0.00) | 6 (100.00) | 0 (0.00) | 8 (100.00) |
| 7 | Indigenous technology development should be in tandem with Nigeria's topographical features | 6 (100.00) | 0 (0.00) | 8 (100.00) | 0 (0.00) |
| 8 | Organisation collaborates with farmers' groups to create awareness of your technology | 6 (100.00) | 0 (0.00) | 8 (100.00) | 0 (0.00) |
| 9 | Organisation collaborates with States Ministries of Agriculture | 6 (100.00) | 0 (0.00) | 8 (100.00) | 0 (0.00) |
| 10 | Organisation has spread across the country in terms of application of its developed technologies | 4 (66.67) | 2 (33.33) | 6 (75.00) | 2 (25.00) |
| 11 | Organisation can be self-sustaining without government financial support | 2 (33.33) | 4 (66.67) | 0 (0.00) | 8 (100.00) |
| 12 | Organisation has achieved its mandate in terms of local technologies development and applications | 3 (50.00) | 3 (50.00) | 5 (62.50) | 3 (37.50) |

**Source:** Field Survey (2016)

### 3.10 Assessment of NCAM and NSPRI programmes by the staff of the two organisations

From table 5, we see that all the staff interviewed agreed that the organisations mainly depend on Federal Government subventions, but that there no financial support from State and Local Governments, and from donor agencies, that they sell their technologies to farmers, and that they have functional extension departments. The financing of the organisations from only one window, the Federal Government of Nigeria, is partly because it is the owner, and as all ministries, agencies, parastatals and most states in the country depend on federal financial allocations for survival. In terms of cost of technologies, 50% of NCAM staff agreed that the costs of organisation's technologies are high for the farmers, while 50% disagreed on this matter; for NSPRI the shares are 62.50% and 37.50% respectively. This support the response of some farmers presented in table 1b that the organisations' technologies are expensive for the farmers to acquire; apart from non-availability at certain locations, this is a major reason behind the non-usage of the technologies by the farmers. The consequence is to improve on cost competitiveness of equipment and/or to mobilise subsidies for these products to be able to sell them to the farmers.

All the staff reported that the organisations relate with farmers' associations and States' ministries of agriculture to boost awareness and sales of the technologies developed by them, and to enhance training of the farmers on their applications. This is in line with the conceptual framework for the study, but the collaboration is, however, not strong enough to give the desired results of awareness and "commonness" of the technologies which are developed by the two organisations; these results matter at least in the study area which is Lagos State. But 66.67% and 75% of the staff of NCAM and NSPRI said that their organisations have been successful to spread across the country, while 33.33% and 25% said that their organisation did not have spread all over the country respectively. So, there is a different view on the ascribed successes from the side of the staff. 33.33% and 0% of NCAM and NSPRI said that their organisations can survive without government subventions, while 50% and 62.5% respectively thought that the organisations have achieved their mandates of developing local technologies for agricultural production. NCAM could survive on its own, perhaps due to machines and tools that it develops, but for the storage technologies of NSPRI, there is more to desire in the country as farm products commonly get spoilt if they are not sold on time, and too often to prevent them from spoilage, farmers sell at cheap prices. Both organisations have great chances to utilise the available market potential, if the value chain of their products and services is rearranged and improved.

## 4 Indigenous technologies promotion and problems of technological development institutes

### 4.1 Promotion of indigenous technologies

Through training sessions and workshops, users are trained on how to construct some of the technologies since most of the materials are obtainable within the localities. This is also achieved through publications of leaflets, pamphlets and booklets, in which the uses and procedures of making these machines are clearly explained. The technicalities of the equipment which are discussed in this paper support the argument that in Africa there is a fertile ground for indigenous technologies which can be used for improving productivity in agriculture.

Indigenous technology promotion in Nigeria should be considered as a development initiative that brings together all the relevant stakeholders. These are the enterprises, especially the informal sector ventures and groups of producers, the business associations like the various chambers of commerce and industry, as well as the research and innovation institutions. All these actors should work together to get Nigeria through to the desired technology destination that supports production and consumption. Government will be expected to consistently provide an enabling environment of policy implementation and adequate funding for its STI institutions.

Presently, the informal sector is a formidable segment of the economy, comprising the MSMEs which are known for advancing technology development through indigenous inventions, adaptations, adoptions, and modifications while performing the role of a catalyst of industrialisation (NBS and SMEDAN, 2010). Despite of this assertion, there exist perceived gaps between the MSMEs and the STI institutions. The latter should move closer to the MSMEs, through their groups of producers, to make their research outcomes relevant and compatible with the needs and production capacities of the informal sector ventures. This step will also have the derived benefit of integrating informal sector businesses into the formal sector, as the STI institutions which are government agencies are learning to deal constructively with the informal sector ventures. The STI institutions need to understand how the informal sector ventures are operating and producing.

### 4.2 Problems of the organisations

The identified problems of the two organisations include underfunding, inadequate training and re-training of staff, erratic power supply, and problems of a bureaucratic set up of institutions which usually prolong the decision-making time. However, a fundamental problem is the lack of focus towards the clients, the customers and the beneficiaries of the work done by these government organisations. There is a lack of incentives to act in the interest of the clients, customers and beneficiaries. In Africa, due to low incomes, institutions are inadequately funded, but this is becoming a more severe problem for institutions in the field of STI development. The two organisations mainly depend on government subventions for funding with little or no private sector and international funding.

Specifically, the problems of the STI institutions remain unresolved because of lack of political power and the consistent lips service given to industrialisation efforts. Nigerian leaders have over the decades been using arm-chair implementation approaches to promote STI instead of standing up to support long-term and consistent STI strategies. The huge oil revenues were used to support the imports of plants, machinery, and of other technologies for production purposes instead of building up an own production and STI base. But the recent fall in oil revenues has provoked a situation where Nigeria can no longer support huge imports bills. Therefore, between 2015 and 2017 the government started to be actively approaching STI development and local production initiatives, abandoning hitherto favoured arm-chair approach which was used over the years since the 1970s when the oil revenues became high. Arm-chair approaches to STI development involve in-door arrangements in which scientists, technologists and public-sector managers in charge of STI are not interested in developing competitive procedures to support the most appropriate solutions and funding mechanisms. These STI administrators too often do not visit the designated laboratories and fields for achieving the objectives of their respective STI mandates.

Importers of technologies, either intended for selling or using them, are ready to go for locally produced technologies if they can offer the same service at the same or at lower cost compared with the imported technologies. Locally produced technologies which compare favourably with international standards will save the country scarce foreign exchange, while the users and importers will save time when they can buy instead of imported products appropriate local equipment. Manufacturers will be ready to adopt local technologies with cost advantage, proven reliability and steady availability.

Government's technology development institutions have not really assisted in making indigenous technologies available through multiplication. Most of the available technologies that have been developed locally are being displayed as exhibits for formal and informal visitors and for presentation in annual reports. Though this is not unconnected with inadequate funding, parts of the funds that the STI institutes have been receiving should have been spent on multiplication and marketing of the technologies with clear-cut strategies for reaching out to end-users. Another institutional factor is the practice of government officials that see travelling abroad to import technologies as opportunities of spending and benefiting from public funds, as such foreign trips are embarked upon with approved trip financial allowances. With the available oil revenues in the coffers of government, government officials deliberately prefer to import technologies for distribution amongst local producers which include farmers; these officials have in mind direct pecuniary benefits in the form of trip expenses, and in some cases, more benefits are realised through over-invoicing of import bills.

### 4.3 STI policy and agricultural policy in Nigeria

The latest STI policy of Nigeria is comprehensive and adequately addresses the perceived shortcomings of the past policies on technology advancement as explained in section 3.4 on the national innovation system. It addressed all sectors of the economy and sufficiently makes provisions for developing STI for agricultural production, storage and processing. In view of this, the policy is appropriately compatible with past and present agricultural policy documents of the government-called Agricultural Promotion Policy (APP).

APP is to be implemented within a period of five years from 2016 to 2020 and was launched in June 2016 by the Nigerian Minister of Agriculture in Abuja, the Federal Capital Territory, as the APP and Strategy Document. The new agricultural policy replaced the Agricultural Transformation Agenda (ATA) of the country that was introduced in 2011 by the former Federal Administration that expired on May 29, 2015. The new policy was packaged to consolidate on the successes of the ATA and to close-up its observed gaps that are germane to agricultural development (FMARD/Federal Ministry of Agriculture and Rural Development, 2016).[21]

The APP identified three areas of focus for agricultural development. First, productivity enhancements comprising of eight sub-areas that are access to land, soil fertility, access to information and knowledge, access to inputs, production management, storage, processing and, marketing and trade. Second, crowding in private sector investment which has two sub-areas: access to finance and agribusiness investment development. Third, institution realignment with six sub-areas that are listed as institutional setting and roles, youth and women, infrastructure, climate smart agriculture, research and innovation and, food, consumption and nutrition security. Each sub-area is given attention under value chain constraints, policy objective, proposed policy reform, enabling programme, and supporting programme. A cursory or detailed look at the document will praise its robustness.

On institutional arrangement that included research and innovation, the APP and Strategy Document states that "Agricultural research is recognized as a critical enabler of economic growth. It is therefore prioritized by the constitution and explicitly assigned as the primary responsibility of the Federal Government on the Concurrent Legislative List. Thus, the importance of agricultural research on the policy agenda of the Federal Government, towards national food security, import substitution and job creation cannot be overemphasized. To this end, the Federal

[21] See on FMARD: http://fmard.gov.ng/

Government will engage its institutions and bodies at different locations in the country, to conduct research for increased agricultural productivity and to make the research results available to farmers and other actors in the agricultural development of the states.

In this regard, institutions and organizations owned by the Federal Government that make up the National Agricultural Research System (NARS) comprise 15 Commodity-based Research Institutes, 11 Federal Colleges of Agriculture, a specialized National Agricultural Extension Institute, over 50 Faculties of Agriculture in regular Federal Universities; and 3 specialized Universities of Agriculture. The activities of these institutions come under the purview of the Agricultural Research Council of Nigeria (ARCN), which oversees their operations. In addition, Nigeria hosts various international research institutions, e.g. the International Agricultural Research Centre (IARC), and the International Institute of Tropical Agriculture (IITA).

However, despite the existing institutional capacity, the NARS has not been able to engineer a significant and sustainable agricultural growth that would ensure national and household food security, create wealth and employment, and make Nigeria a competitor in the global food markets. Part of that is the result of a weak mechanism for translating research into field usage. The well documented weaknesses in the extension system as well as a failure to properly incentivize innovation at the inventor level are contributing factors. Going forward, Nigerian agricultural research will have to contend with the need to become climate smart. That shift will require different research priorities, development of new varieties, and a more rapid co-creation cycle with industry and operators''.

The major constraints of R&D&I which are identified in the policy document are that information and knowledge are not within the reach of end-users because of

i. weak research-extension linkages so that technologies or innovations generated are not effectively delivered to farmers or commercialized for the benefit of end users. In other words, research results are not made accessible to end-users;

ii. the fact that research outputs are not demand-driven; and because of a departure in the programmes of the universities of agriculture from their statutory mandate in relation to the programmes of FMARD;

iii. a lack of investment in staff and equipment in research; poor and irregular funding for agricultural research and extension; and

iv. non-funding to introduce and apply innovations.

The policy objectives of the R&D&I are to strengthen research and innovation on priority areas, to disseminate outputs with the reform to enhance the effectiveness and efficiency of the agricultural research system, to shift the focus partially to make output more climate smart, and to pursue the reform of the ARCN to reposition the agency and to strengthen the delivery of its mandate activities. The enabling programmes to achieve these initiatives as spelt out in the APP document are:

*i. Access to information and knowledge:* This will be obtained through the

a. implementation of the information and knowledge management (KM) framework, including strengthening the capacity of stakeholders to access information, to aggregate existing information on innovations (of research, projects), and to enhance access through various means of delivery, like SMS, radio, and extension services;
b. documentation and dissemination of innovations and good practices;
c. targeting of research to address key priorities and to ensure a close interaction with end-users; Climate Smart Agriculture (CSA) is one tool to be used for this.

*ii. Preparation of longer-term research programmes:* This requires

a. setting of key priorities with aligned funding from government, development partners, and the private sector;
b. ensuring a greater role for efficient monitoring and evaluation systems on outputs and finance.

*iii. Reorientation of research systems:* This entails

a. enhance efficiency and targeting of the national agricultural research system (ARCN and institutes);
b. review need and relevance of measures and past initiatives as establishing A) a Competitive Agricultural Research Grant Scheme; B) a Centre for Crop & Animal Improvement for Training of Breeders; C) Spin-off Companies in Research Institutes & Colleges; D) Strengthen existing Adopted Villages (AVs), Agricultural Research Outreach Centres (AROCs), and Agricultural Research Technology Transfer Centres (ARTTCs).

*iv. Access to Finance:* This will be achieved through and engender

a. Access to Mechanisation;
b. Drive formation of start-ups and venture funds to commercialise innovations; to partner with private investors;
c. Review and revise rules governing intellectual property in the ARCN system to ensure that innovators are appropriately rewarded.

As supporting and complementary programmes, the measures proposed are enhancing access to finance, especially for equipment; access to information and knowledge, especially on innovations and financing options; access to mechanisation, and improving storage, processing and enhancing marketing.

The policy thrusts to achieve the research and development thematic aspect of the agriculture promotion objective in Nigeria are listed as

i. provision of incentives for NARS to improve its ability to attract talent, and maintain productive partnerships (domestic and foreign);

ii. expansion of research community's capacity to leverage digital innovations to lower the costs of field work;
iii. incentivisation of NARS to engage with farmers more broadly and at lower price / cost as a step for ultimately improving the extension services to farmers.
iv. reformation and reposition of the ARCN to strengthen it for a more effective delivery of its mandate activities, with a special emphasis on the following aspects:
a. review the process for granting intellectual property to researchers at ARCN institutions;
b. encourage the set-up of start-ups and venture companies to license and to commercialise existing and future intellectual property emerging from the ARCN.
v. empowering and strengthening of the ARCN to set up and drive the national intellectual agenda for agricultural research through the following actions
a. resuscitate the Competitive Agricultural Research Grant Scheme;
b. reactivate the process of establishment of the Centre for Crop and Animal Improvement for the Training of Breeders;
c. pursuing, vigorously, the establishment of spin-off companies in research institutes & colleges;
d. support FMARD in negotiations with the World Bank towards securing funding for the West Africa Agricultural Productivity Programme WAAPP-2 Nigeria that is expected to commence in 2017[22];
e. strengthen existing Adopted Villages (AVs)[23], Agricultural Research Outreach Centres (AROC), and Agricultural Research Technology Transfer Centres (ARTTC) and the establishment of new ones.
f. establish selected commercial farms to demonstrate research results in managing large-scale agriculture development.

Obviously, a great number of institutional initiatives is recommended, although Nigeria has seen so many failures in this regard. A consolidation of working initiatives and institutions should be the first aim of all the proposed reforms.

The APP recognises and places premium on a mix of private-sector and public-sector initiatives for participation in agricultural production processes and facilities provision. However, no direct mentioning of NCAM and NSPRI was done in the APP and Strategy Document. Only the phrase 'Federal mechanization institute' is mentioned under the heading of mechanisation, as it is one of the sub-

[22] See on the initiative: http://waapp.gov.ng/
[23] See on the role of scientists supporting Adopted Villages: http://thenationonlineng.net/adopted-villages-the-journey-so-far/

sections of production management. It is stated as ‘enhance skill building for mechanization maintenance via partnership with private sector, vocational schools and the federal mechanization institute to train technicians to maintain equipment’ and so is regarded as one of the enabling programmes to achieve the mechanisation objective. Apart from this, neither NCAM nor NSPRI was specifically mentioned in the robust document.

The non-mentioning of NCAM and NSPRI is a pointer to the inherent weakness of the policy document. It is doubtful if the APP will make significant impact like the ATA which it sets to outperform. Except with adequate funding and recognition of existing institutions that are promoting indigenous agricultural technologies, little or no effect will be attained by 2020 in terms of improved agricultural productivity through the pillars of mechanisation and storage facilities. Specific targets and actions should have been set out for the agricultural STI institutions rather than referring to the objectives and actions that are lumped together for the institutions under NARS and NARC. However, this drawback can be played down if the NARC can bring out an actionable document with specific and measurable targets, and with appropriate monitoring and evaluation (M&E) tools, to guide the relevant STI institutions towards driving the APP initiatives and to achieve its objectives.

### 4.4 Indigenous technologies, agricultural production and efforts towards food sufficiency in Nigeria

The functions of NSPRI and NCAM and the technologies developed by them point to indigenous technology efforts of boosting agricultural and food production. The widespread reach of available local technologies should promote agricultural production, processing and prevent post-harvest food losses. Fruits and vegetables get lost in quality and quantity at wholesale and retail levels in Nigeria, despite the availability of local storage technologies that can enhance their shelf-lives and the quality preservation. But the knowledge of their availability is not wide spread among farmers and perhaps also among farm produce processors and sellers in the country. In most of Nigeria’s fruits and vegetable markets, these products get deteriorated after a few days, although a shed can be constructed for them with 100 per cent local content to increase their shelf-lives, as it was proposed by the institute (NSPRI).

The study acknowledges the fact that both NSPRI and NCAM are making concerted efforts to register their activities in the technological space in Nigeria. But the developed indigenous technologies by the two institutions are still at a preliminary level, so that the innovation chain needs to become completed; a fully working agribusiness value chain is requested. There is a need for projects and programmes to be geared towards moving the technologies from the traditional development stage to the take-off stage which precedes the industrialisation era and the age of mass production (according to Rostow's theory). The country should pro-actively make available and implement policy frameworks to enhance the technological sector towards mass food production for the rising population. This requires making funds available for R&D as well as encouraging machinery innovations in the agricultural sector. The available indigenous technologies in Africa with institutional supports for their transformation are pointer to a future technological advancement in the continent.

## 5 Conclusions and Policy Recommendations

There are technologies available in Nigeria which are targeted at improving agricultural production, processing, and reducing post-harvest losses of farmers. The NSPRI and NCAM are two organisations located in Ilorin, Kwara State, Nigeria which are producing equipment and machines with local content for these purposes. The organisations are living up to their mandates, but much still needs to be achieved. Many technologies have been introduced into the markets and are being used, but others, such as those which could be used for reducing losses of fruits and vegetables, are not yet successfully working. Such technologies should be spread to reduce the substantial losses of product, at wholesale, retail, and home levels.

The argument of this study is that government institutions, such as the ministries of agriculture (both at Federal and State levels), can act as coordinating agencies for bringing together the various stakeholders in the Agricultural Equipment Sector (AES), essentially the farmers, the actors in the organised private sector, the equipment leasing companies, the farmers cooperatives, the R&D/STI institutions, and the funding agencies. They can also complement the operations of the extension services of the two institutions forcefully. This will reduce Nigeria's dependency on imported equipment for which locally made alternatives exist.

The limited sources of funding also limit the R&D institutes' ability to produce enough agricultural equipment which is required by the market. Therefore, donor agencies, both local and international, should assist in funding research & development and the commercialisation of research & development outcomes in these organisations. These actions are important for market penetration and an easier access by smallholder farmers and farmers associations to new technologies. Funding from government, of which 60% to 80 % is for overhead expenditures and for personnel emoluments, cannot promote STI to the point of generating new products and processes which are introduced on a large-scale basis to the farming sector. Funds from donor agencies would also be needed for achieving the objectives of the institutions which are fabrication of agricultural machines and storage facilities. Nigeria and other African countries should therefore promote STI through proper funding.

STI funding in Nigeria is inadequate, being below the respective UNESCO recommendations. Nigeria and other African countries can, however, learn a lot from some emerging countries, like Brazil, China, and India, which are strong in terms of agricultural machinery production and related extension services. In Brazil, significant agricultural growth and development that have been witnessed are anchored on deliberate government agricultural, industrial and STI policies. These policies are backed up by adequate funding and financial investment in research; the programmes of the Brazilian Embrapa Institute[24], an agricultural research institute, give proof of this orientation. According to Barrientos and Amann (2017), the Brazilian government has sponsored research through the institutes and has co-opted the research outcomes into family farms which dominate the country's farming sector. The research outcomes are important for irrigation facilities, maintenance, and crop production for export markets. Nigeria must learn from such experiences as the task of achieving STI objectives on agriculture mechanisation and storage through her institutions like NCAM and NSPRI needs to be backed not only by adequate funding, but also by coherent policy frameworks.

In China, citizens, corporations and individuals are carried along in the affairs of the nation that include rapid development of STI and accelerated economic development. Also, there exist functioning governance machineries and structures at all levels. More so, China is strong on R&D financing for food commerce, the food industry, and the food markets. Through STI, the country's level of innovation has been on the rise, and agriculture has always been a priority in this effort. Development policies and plans are anchored on STI on a long-term basis and remain unchanged with new successive governments; this is contrary to what is commonly observed in Nigeria. There are consistent policy approaches in one period, but then followed by abrupt policy changes and sudden stops in policy implementation when new governments come up in Nigeria at federation or state level. For instance, the agricultural policy has changed in Nigeria, when the Buhari government came to power in May 2015, from ATA (with a frame of 2011-2016) to APP (with a frame of 2016-2020). The change was not based on a proper evaluation of ATA, or a strict planning for APP, but was done to create expectations among the voters and the followers in the bureaucracy.

Every government in Nigeria likes to be identified with its own policy framework, which leads to internal shocks in project processes and implementation. A new government is then a risk for project implementation and affects also sound policy frameworks. Rather than changing the policy framework under the guise of making up for the short-comings of the existing policy, also working policy frameworks are not retained. It would be much wiser to formulate additional objectives and strategies and to make them part of the implementation process. Taking care

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[24] See: https://www.embrapa.br/en/international

of the observed short-comings is the solution, not removing the whole policy approach from the former government. Nigeria should learn and practice transparent STI governance with the principle of inclusion; this would enhance the role of the two institutions. Once all stakeholders (researchers, farmers, policy-makers, business people, development partners and others) are carried along in developing an STI policy and are becoming part of the implementation process, without abrupt policy changes, the country's STI policy outcomes will have a new and a better story.

India is an interesting case of STI development. The country exports motor vehicles and tri-cycle to many countries, including Nigeria. This cannot be achieved without adequate funding and a policy framework that is consistent and sustainable over a long-term development process. Nigeria, however, made little or no efforts at transferring technology and localising STI outcomes, but was rather buying foreign technologies due to rising oil revenues without any intention to learn how they work and how they can be produced. Nigeria has no choice but to localise the imported technologies, equipped with adequate funding and by developing a coherent policy framework. Localisation of imported technologies and development of indigenous technologies are the two important strategies for Nigeria. The local government will also be prominent in STI activities, as this government arm is closest to the people, especially the farmers. Information on local innovations can easily be obtained from the local government, more so than from the state level and the federation level.

There must be a clear-cut policy framework on funding innovations and STI programmes at all tiers of government; the funding level of the federation should not be less than 1% of the country's GDP. State and local governments can apply the same percentage of their respective GDP on STI spending. The budgetary provision should be backed-up with a cash component. If a definite policy on STI funding is made and adopted, some tiers of government can even surpass the provision of funds, and if the funds are spent transparently, the outcomes will be great. Some states can even set up new STI institutions with the available funds.

Since each state of the federation in Nigeria has been mandated to set up a State Council on STI as outlined in the STI policy document, the comparative advantages of STI development strategies based on the resource endowment of each state can be exploited by each state council. Lagos State, for instance, is endowed with resources for fisheries, coconut and rice production; its STI development should be based on promoting innovations that will boost the production of the three products for local and export markets. Similarly, the Kano State Council on STI should focus on developing STI for groundnut and cotton production, while Rivers State should focus on STI for oil palm, rubber and cassava production for local and foreign markets. If all the 36 states can adopt this strategy based on comparative advantages, the overall complementarity of STI outcomes for Nigeria will create successes for Nigeria. Other countries would be able to learn from this true federalism. To boost the implementation of this STI comparative advantage strategy, every state and local government should develop its own STI policy to drive the national STI policy. The state and local government STI policy is local to the people, based on available resources within the locality and driven by the efforts of the people at the grass-roots. Such state and local government STI policies must be within the confinement of and should not be divergent from the national STI agenda and its long-term initiatives and ambitions. The federal initiatives can then be supported by state- owned STI institutions, with the state level STI policies then giving directions, also to the local government level.

All tiers of government should set targets that must be achieved on the STI frontier. For this, a strong monitoring and evaluation (M&E) framework and a respective office at each level of government must be set up. The M&E activities will be done with measurable STI variables that embrace critical success factors for each objective and strategy, for the deliverables, for the input and output components, as well as for the level of usage in the various sectors and spaces of the economy. Often, M&E is weak in Africa, and reports are written on the success and failure of projects and programmes by applying an arm-chair approach. This should not be the case for STI objectives, targets, policies, instruments, and outcomes; a new M&E framework is needed. The M&E staff at all levels should go beyond paper work and should be ready to go to the field to check STI activities and progress in line with the policy document.

Government can introduce tax cuts for companies and business ventures to encourage local innovations through financing, training and any other means, and/or should give incentives to use locally developed technologies. This will help to close the gap between government, STI institutions, and industries, and will bring them together as partners in progress. This new R&D&I-focussed tax policy will promote STI activities that boost production capacities and employment. Such tax cuts are aiming at an innovative industrial STI financing strategy, to follow a private sector-led financing strategy for STI development.

Nigeria should also develop a development plan which is based on STI. Presently, Nigeria does not have any document called National Development Plan. It is time to shift from the practice of governing without any plan to guide national efforts. The situation is partly responsible for policy summersaults and implementation inconsistencies that are often witnessed when there is a new government in office or whenever a new minister of a ministry is appointed. The Federal Government should come up with a development plan for the country, based on STI objectives which can then guide the state and local government policies. Each state of the federation will then bring out its development plan, that is sub-summed and within the framework of the national development plan anchoring on STI. If this is done, there will be swift technology development in all sectors of the economy and all over the country. This initiative will make all the citizens aware of STI as critical factors and forces for development.

A development plan that rests on STI will require that government identifies the innovation needs of industries in all sectors and links up with the STI institutions for the purpose of meeting the needs of the end-users. This will be a triple-loop strategy that brings government, industries and STI institutions together in achieving technology development for agricultural production, storage and processing. By so doing, the end-users, like the farmers and informal sector businesses that are into every stage of agricultural production, get captured in the STI activities. The government in this triple-loop strategy provides an enabling environment, the STI institutes produce innovations with available markets, comprising businesses which are ready to use them. An era of technology production without looking to the end-users will be gone. This strategy will solve the problem of non-multiplication of innovations that has led to their non-availability in the market and to the end-users. This strategy will need to be supported by effective and efficient intellectual property and patent rights certification machineries spread across the country.

In connection to the National Development Plan, the Federal Ministry of Science and Technology (FMST) should produce a National Road Map on Technology and Innovation (NRMTI) for a period of 50 years, reviewable every decade, in which the state governments should fully participate. This is necessary as the SMEs, the Industries and Industry Associations, and the STI Institutions, which will be the major actors in the implementation of the road map, are closer to the second tier of government than to the Federal Government. Likewise, the Road Map should be designed to have the private sector as the financial spring board while the government provides the enabling environment to achieve the set goals. The funding of the STI Road Map should shift focus from the government and tilt towards private sector funding through SMEs and large-scale manufacturing and industrial enterprises in line with the trends to be seen in countries which have attained technological development. The Road Map should be of clearly defined measurable objectives, time frames and functions for all the stakeholders.

One major component of the innovation end-users is the MSMEs which are mostly in the informal sector. For the enormous benefits which they accord a nation, a strategy of grouping the enterprises into sectors of the economy and linking them directly to STI institutions will further boost the triple-loop action for local technology promotion. The MSMEs operate in all sectors of the economy and in all geographical areas of the country. They can therefore become veritable means of spreading innovation. Also, they are the basis of industrialisation in all countries, especially so for Nigeria. Nigeria should give a clear mandate to Federal STI institutions to work with the states and the local governments in which they are located, to rapidly engage MSMEs for technological innovations. Both, the technology institutions and the MSMEs need strong support from advocacy groups.

Similarly, as part of efforts at exploiting the MSMEs to enhance technology and innovation, the National Board for Technology Incubation (NBTI), which has almost 30 branches (Adaramola, 2014) which are spread across the states of Nigeria, should be given a marching order by the Federal Government to collaborate with MSMEs and to open its gates to more individuals who have technological ideas for multiplication and for establishing related businesses. This will further boost technology-based entrepreneurship and will make the NBTI to be achieving its mandate, which is helping companies to start operations in the country by creating connections between management, financial capital, technology, labour, and other resources to achieve viable business ventures. To support these efforts, the NBTI should also deepen and widen its collaboration with the academia and the R&D institutions in the country.

There is an on-going global trend towards e-agriculture, e-innovation, and m-agriculture as well as m-innovation and Nigeria should neither be left out or stay behind. E-agriculture and e-innovation respectively entail the use of information communication technologies (ICTs) for sharing and accessing information, ideas and resources among stakeholders in the agricultural sector, and ICTs successfully bring STI institutions and users of innovations together in any industry for sustainable rural and urban development. The application of ICT is a practice that is gathering moment every day in Nigeria. The Nigerian government and other tiers of government should enhance ICT literacy among the Nigerian citizens. Access and availability to internet and tele-density should be improved upon by according more relevance and strength to communication agencies and companies. This is important because internet access is easily achievable through mobile phones anywhere in the country, when the networks of telephone service providers are available. Through e-agriculture and e-innovation, information on the users' needs and the stock of available innovations can be brought to application. The information can then circulate easily between STI institutes and the users of innovations respectively. Government can also easily monitor how information on innovations spreads in the country. With the current number of telephone service providers in Nigeria, there is a huge potential for e-agriculture and e-innovation to gain ground and the new media are becoming more and more popular over time in the country.

Relating to ICT application in agricultural production and innovation are mobile-agriculture and mobile-innovation. Mobile innovation, which is the use of mobile phones to link research institutions, users of innovation in the industry, and the government agencies together, should be accepted and adopted by stakeholders. Farmers in Nigeria have mobile phones which were used to get information on available inputs to them under ATA on price, places of payment, and pick-up. So, farmers in Nigeria are aware of the advantages of mobile-agriculture. There is a need for a strategy to initiate the use of mobile-innovation to spread the information on available innovations and instructions on their usage to end-users.

Similarly, mobile agriculture that has been adopted under ATA should be stepped up. As a deliberate strategy, public and private sector participants should set up a website for the provision of farm inputs and for market information on outputs which stakeholders can access through mobile phones. More so, buying and selling over the mobile phone through internet, e-mail and SMS should be encouraged by both, the private and the public sector. The mobile agricultural channel will also encourage electronic market systems for the periodical publication of prices of farm outputs at farm gates, township and urban markets, wholesale and retail points. This will also lead to the establishment of platform cooperatives, a business model where sellers and buyers of tangible and intangible farm inputs and outputs meet and pay for services electronically; as share owners of the business they are also entitled to parts of the profit. Nigerians will not find it difficult to engage in this business model as they are already used to the workings and internal mechanisms of different forms of cooperative businesses. There is urgent need to step up the existing strategy of promoting mobile phone and internet access for Nigerians to benefit from STI initiatives.

The available indigenous technologies are evidence that the African continent has the prospect to feed the population both now and in future. The study recommends more investment in indigenous technologies, promoting institutions like NSPRI and NCAM and encouraging wide-spread publicity and multiplication of the technologies which are developed there. Then the farmers will be able to contribute towards adequate food production for Nigeria. The support and improved funding from national and international donors and development partners, which presently are unavailable or largely inadequate, will make the fabricated equipment and machines less costly for the farming users. Extension linkages that are currently being done will result into the needed outcomes. There will be improved market access and utilisation of the machines by small farm holders and commercial farmers towards mass production and food sufficiency.

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# Economic Impact of Introducing Transgenic Pest-Resistant, Genetically Modified Cowpea In Northern Nigeria

**M. I. Abubakar[1], B. Ahmed[2], Z. Abdulsalam[3], and M. K. Ajala[4]**

## 1 Introduction

Nigeria is the largest cowpea producer in West Africa and in the world (Mishilli et al., 2007; Nedumaran et al., 2015). The country produces 3.132 million tonnes per annum on 4.5 million hectares annually (Mishilli et al., 2007). Nigeria is also the largest consumer of cowpea with more than 400,000 metric tonnes in deficit (IAR/Institute for Agricultural Research, 2012). This necessitates the need to increase cowpea production in the region. In the past decade, the deficit in cowpea supply has been a major issue in cowpea production in West Africa in general, and especially so in Nigeria. In Nigeria, the deficit has increased up to 30% between 2000 and 2013 (FAOSTAT, 2014). Hence, there is the urgent need to increase cowpea production in the region.

Cowpea is scientifically known as Vigna unguiculata (L.) Walp.[5] The crop is popularly called beans in Nigeria, and it is the most economically important indigenous grain legume, and it is one of the most valuable crops grown by low-income smallholder farmers in northern Nigeria. The crop has high a potential to contribute to food security, income, and poverty reduction in the region. The role of cowpea lies in its economic and nutritional values (Singh et al., 2003). Despite of the importance of cowpea, its production in Nigeria is faced with many constraints/challenges including insect pests, diseases, drought, poor soil, and, so far, resistance to maruca insect pest has been limited (IAR/Institute for Agricultural Research, 2012). The negative effects of maruca on destroying the quality and quantity of cowpeas in Nigeria have been reported. Maruca vitrata[6] perennially

[1] Department of Agricultural Economics, Faculty of Agriculture, Usmanu Danfodiyo University, Sokoto, Nigeria (Musa Isa Abubakar, Email: miabubakar2004@yahoo.com)
[2] Department of Agricultural Economics and Rural Sociology, Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria (Ben Ahmed, Email: benujah@yahoo.com)
[3] Department of Agricultural Economics and Rural Sociology, Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria (Zakari Abdulsalam, Email: zakabd2009@gmail.com)
[4] National Institute for Animal Production, Shika, Ahmadu Bello University, Zaria, Nigeria (Margaret Kofo Ajala, Email: kofoajala@yahoo.com)
[5] See more on this grain product: https://en.wikipedia.org/wiki/Cowpea
[6] See on details: https://en.wikipedia.org/wiki/Maruca_vitrata

damages cowpea pods in the fields, and losses due to maruca infestation alone reach 80%. The cowpea pod borer reduces cowpea yields from 50-70% or even up to 80% in severe infestations (Machuka, 2002; AATF/African Agricultural Technology Foundation, 2014). This justifies the need for genetically modified (GM) technologies to develop cowpea seeds that can control the attack by pests, technologies which are resistant to pests and diseases in Nigeria.

Pest resistant GM cowpea varieties are a new technology developed by scientists in a laboratory in Australia, using biotechnology and genetic engineering techniques to confer resistance to insect pest known as Maruca vitrata (AATF, 2008). The pest resistant cowpea project is implemented in three countries in Sub-Saharan Africa (SSA), particularly in Nigeria, Burkina Faso and Ghana. The project is a public private partnership, coordinated by Africa Agricultural Technology Foundation/AATF (AATF, 2009), to promote technological interventions that will optimize cowpea productivity and utilization in Sub-Saharan Africa. In Nigeria, the project was established in 2009, located at the Institute for Agricultural Research (IAR), Samaru, Zaria, and has an expected terminal date in 2014. The nature of the project is confined field trials (CFT) and containment trials (IAR, 2012).

Biotechnology is a powerful tool that presents a range of potential environmental, social, and economic benefits, and may offer a sustainable solution to cowpea production pest problems (Sophia and Powell, 2000; Africa Agricultural Technology Foundation, 2009; Open Forum on Agricultural Biotechnology, 2009; Institute for Agricultural Research, 2012). It is one of the technologies which could generate economic growth and better living standards in Africa as well as alleviate poverty and hunger in the Third World, but political issues have slowed down the use of this option in Africa. In recent years, modern biotechnology is currently the focus of intense public and political debate. Also, many supporters of the technology are worried that the benefits of the technology may be overshadowed by the potential risks magnified by the media and by opponents of the technology (Sophia and Powell, 2000; Dofonsu et al., 2008).

The new pest resistant transgenic GM cowpea had already been tested in confined field trials (CFT) and containment trials in the Institute for Agricultural Research (IAR) in Zaria, located in northern Nigeria. GM cowpea is currently at field trial stage, but it is not yet available in the local marketplace. Nigeria has already passed the Biosafety bill into law in the year 2015[7] to regulate the use of GM

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[7] See details on the law: http://www.vanguardngr.com/2015/04/nigeria-gets-biosafety-law-joins-league-of-biotech-countries/. The National Biotechnology Development Agency (NABDA) and the Open Forum for Agricultural Biotechnology (OFAB) played a role in this and made several attempts to have the country signed and ratified an internationally binding Biosafety Protocol Known as Cartagena Protocol on Biosafety. The Cartagena Protocol on Biosafety addresses the safe transfer, the handling and the use of Living Modified Organisms (LMOs) as they may have adverse effects on conservation and

cowpea, to ensure safety to the environment and human health, and to allay the fear of the populace on the socio-economic consequences of modern biotechnology, especially among the small-scale farming systems (AATF 2009). In addition, the National Biotechnology Development Agency (NABDA)[8] and National Biosafety Management Agency (NBMA)[9] were established to ensure the full compliance and the use of the biosafety regulation in the country. In view of this, the Federal Government of Nigeria is considering if it is advisable and possible at all to introduce pest resistant genetically modified (GM) cowpea in the year 2017 in Nigeria, to boost cowpea production, contribute to food security, and enhance yields, thereby satisfying the needs of Nigeria's population and increase the local cowpea consumption (AATF, 2008). Before moving the new GM cowpea from regulatory approval to commercialization, it is important to understand how consumers evaluate the new technology. There is also the need to conduct a careful economic impact analysis to predict the welfare impact and the consequences of introducing the new GM cowpea to avoid a technology backlash as well as to provide guidance to policy makers in making well-informed decisions towards solving this public policy problem.

Dofonsu et al. (2008) were the first to report on the use of choice experiments (CEs) to estimate the net impact of pest resistant GM cowpea on net social welfare, given price and income risks in the Republic of Benin, a country in West Africa bordering Togo, Burkina Faso, Nigeria and Niger. Two different questionnaires were utilized in the survey, involving choice experiments only and combining cheap talk sessions with choice experiments to interview stratified random samples of 268 consumer families' and 112 cowpea growers in a survey in the cities of Cotonou, Porto-Novo, Parakou, and Malanville. The choice experiment involved a simulation of a market scenario being very similar the one that respondents are exposed to involving cowpea. In their experiment, the respondent is invited to imagine that he/she is in front of a seller in a market to buy cowpea. The seller then provides advantages and disadvantages of conventional and GM cowpea prior to offering these products at given prices to the client.

Choice experiments (CEs) were originally developed in the marketing and transportation literature and have been used for more than a decade to value private goods (Lusk and Schroeder, 2004). CEs have a role in consumer valuation, decision making and are found necessary in measuring economic impacts of new GM technologies (Dofonsu and Lowenberg- DeBoer, 2008).

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sustainable utilization of biodiversity, thereby looking at potential risks to human health. Read more about these important issues at: http://www.vanguardngr.com/2015/04/nigeria-gets-biosafety-law-joins-league-of-biotech-countries/

[8] See on this organization and the respective duties: http://www.nabda.gov.ng/

[9] See on the duties of this organization: http://www.nbma.gov.ng/

This study provides the departure point from the previous economic impact studies on pest resistant GM cowpea by using discrete choice statistical methods to examine the choices that consumers make prior to the commercial introduction of the new GM cowpea in northern Nigeria, rather than using the household model to capture the problem of the typical family in West Africa. In forecasting for a commercialization of new GM cowpea the discrete choice models predicted quite well, far more accurately than the procedures used by Dofonsu et al. (2008).

The objective of this study is to conduct economic impact analyses of introducing novel pest-resistant transgenic GM cowpea for major cowpea producing areas of northern Nigeria in order to test the hypothesis that introducing new GM cowpea varieties would have a negative impact on consumer welfare across the two surveyed states. Therefore, the study is of great developmental importance in regard of food security and agricultural development for Nigeria and other areas with cowpea production.

## 2 Stages of the Innovation Chain for New GM Cowpea

The first stage in the innovation chain is basic research. The basic research to the R&D stage in the innovation chain of the new GM cowpea involved funding for research by the Rockefeller Foundation at CSIRO in Australia (Commonwealth Scientific and Industrial Research Organization)[10] on developing a reliable transformation technique. Research on transformation methods has also been carried out at the International Institute for Tropical Agriculture (IITA)[11], in Nigeria, by EMBRAPA[12] in Brazil, and at various U.S. Universities. The United States Agency for International Development (USAID), through the Bean/Cowpea Collaborative Research Support Program (CRSP)[13], is funding the entomological and genetic studies needed to develop a resistance management plan. Also, the Network for Genetic Improvement of Cowpea in Africa (NGICA)[14] has organized efforts to deal with intellectual property issues, biosafety, and seed industry issues (Saket et al., 2004). The IAR that has the cowpea research mandate in Nigeria has been making efforts to organize a series of Agricultural Biotechnology Sensitization (ABS) Workshops on the development of Maruca pest resistance GM cowpea.

[10] See on this organization: https://www.csiro.au/
[11] See on this organization: http://www.cgiar.org/about-us/research-centers/international-institute-of-tropical-agriculture-iita/
[12] See on EMBRAPA, the Brazilian Agricultural Research Corporation: https://www.embrapa.br/en/international
[13] See on this collaborative effort: http://crsps.net/resources/by-crsp/bean-cowpea/
[14] See on this network: https://www.entm.purdue.edu/NGICA/

The presentations were made on the prospects for the release and commercialization of GM cowpea, on the insect rearing capacity, on the Bt cowpea project experience, and on regulating agricultural biotechnology.

The second stage in the innovation chain is the confined field testing (CFT) stage. As at 2014, confined field trials for testing the efficacy of the Bacillus thuringiensis (Bt) gene in controlling Maruca insect pest had been successfully conducted in the three countries, and Nigeria and Burkina Faso have progressed into multi-locational trials. The pest resistant GM cowpea project is also conducting studies on the safety for food, on feed, and on environmental risks assessment for regulatory approvals in the target countries before seed is released to farmers (AATF, 2009). In Nigeria, the new pest-resistant transgenic GM cowpea is currently at the field trial stage, but it is not yet available in the local marketplace.

The third stage in the innovation chain is the biosafety regulation/commercialization. Biosafety is a term used to describe efforts to reduce and eliminate the potential risks resulting from modern biotechnology, genetically modified organisms (GMOs), and of products thereof. Biosafety is therefore intended to minimize or eliminate the possible harmful effects of modern biotechnology on the environment, on biodiversity and on human health by using laws and guidelines (OFAB, 2009). The goals of biosafety are to determine in advance when hazards to human health and natural systems will result if any particular GMO is released into the environment; to anticipate when a given GMO or any of its product(s) will be harmful if it becomes part of human food; to discern whether a GMO will actually yield the benefits it was designed to provide; and to make as certain as possible that hazards will not arise when GMOs are transported, intentionally or intentionally, between different ecosystems and countries (OFAB, 2009).

Modern biotechnology regulation in Nigeria started in the early 1990s as researchers in biotechnology became competent in modern biotechnology research and when the need for precaution in the development of modern biotechnology became glaring globally. The development of a biosafety legal regime in Nigeria has followed an evolutionary pattern, with each successive step being an improvement on the preceding level, while taking cognizance of the country's national and international obligations in the field of biosafety. Nigeria is currently having installed the 1994 and 2001 Biosafety Guidelines and has developed the Draft Nigeria National Biosafety Bill (OFAB, 2009).

Nigeria has already passed the Biosafety bill into law in the year 2015 to regulate the use of GM cowpea, to ensure safety to the environment and to human health, and to allay the fear of the populace on the socio-economic consequences of modern biotechnology, especially among the small-scale farmers (AATF 2009). In addition, the National Biotechnology Development Agency (NABDA) and the National Biosafety Management Agency (NBMA) were established to ensure the full compliance and the use of the biosafety regulation in the country. In view of this, the Federal Government of Nigeria (FGN) is considering whether it will introduce pest-resistant genetically modified (GM) cowpea towards the end of the year 2017 to boost cowpea production, to increase food security, and to enhance yields, thereby satisfying the demands of Nigeria's population and to increase the local cowpea consumption (AATF, 2009). Before moving the new GM cowpea from regulatory approval to commercialization, it is important to understand how consumers evaluate the new technology. There is also the need to conduct a careful economic impact analysis to predict the welfare impact and the consequences of introducing the new GM cowpea in order to avoid a technology backlash as well as to provide a guidance to the policy makers in making well-informed decision towards solving this public policy problem.

## 3 Drivers and Obstacles towards introducing GM cowpea: The Farmers and the Consumers

The drivers focus on the role of Science, Technology and Innovation (STI) policies in promoting the understanding of biotechnology among farmers and consumers as well as on its applications for national development in Nigeria. The STI policies aim at facilitating brand recognition for Nigerian biotechnology products and at benchmarking progress. Also, it aims at ensuring compliance with biosafety and bioethics guidelines in biotechnology R & D under the National Science, Technology and Innovation Policy (NSTI, 2011).[15] Specifically, the main obstacle towards introducing the new transgenic cowpea is the very low consumer awareness in West Africa. Within the Network for Genetic Improvement of Cowpea in Africa (NGICA)[16] there has been a debate that African consumers are largely unaware of what genetically modified (GM) food is about and what the terminology concretely means (Saket et al., 2004). Little is known all over Africa and in Nigeria about the potential producer and consumer benefits of GM food in Nigeria. Also, awareness about the whole field of biotechnology and its applications is low even within the group of farmers. A baseline study on awareness of consumers and farmers on GM cowpea in West Africa is shown in Table 1.

[15] Further developments of Nigeria's STI Policies since the 2012 PRESIDENTIAL STATEMENT ON THE NEW NATIONAL POLICY ON SCIENCE, TECHNOLOGY AND INNOVATION should be considered in this context, as there will be impacts on biotechnology development.
[16] See more on this initiative: https://www.entm.purdue.edu/NGICA/

**Table 1**: **Awareness of Consumers and Farmers on GM Cowpea in West Africa**

| Countries | Consumers (%) | | Farmers (%) | |
|---|---|---|---|---|
| | Aware | Not Aware | Aware | Not Aware |
| Burkina Faso | 42 | 58 | 23 | 77 |
| Mali | 62 | 38 | 44 | 56 |
| Niger | 5 | 42 | 11 | 89 |
| Nigeria | 49 | 51 | 10 | 90 |

**Source:** Computed from Dofonsu et al. (2008)

Consumers are confronted with contradictory sources of information on GM crops, which could have a direct impact on consumers' perspectives and valuations. In addition to the lack of accurate information on GM benefits to African populations, GM cowpea cultivars are likely to be introduced just in a region which is characterized by serious concerns of consumers about GM crops; the consumers' perceived potential risks of ethical and health concerns about GM crops should be taken seriously (Dofonsu et al., 2008).

A driving force of introducing GM cowpea is that farmers believe that introducing GM cowpea is having the potential of reducing health hazards and of lowering the use of synthetic pesticides. Also, farmers view GM cowpea as a possibility to improve cowpea yields in a safer way. Consumers may view the GM product as a safer source of food compared to conventional cowpea, if their awareness and knowledge about the new product improves.

Biosafety regulation is key for acceptance of GM products. The capacity to regulate and to implement the rules and regulations is of decisive importance. Biosafety is a term used to describe efforts to reduce and eliminate the potential risks resulting from modern biotechnology, genetically modified organisms (GMOs), and products thereof. Biosafety is therefore intended to minimize or eliminate the possible harmful effects of modern biotechnology on the environment, on biodiversity, and on human health by using laws and guidelines (OFAB, 2009). The goals of biosafety are to determine in advance when hazards to human health and to natural systems will result if any particular GMO is released into the environment; to anticipate when a given GMO or any of its product(s) will be harmful if it becomes part of human food; to discern whether a GMO will actually yield the benefits it was designed to provide; and to make as certain as possible that hazards will not arise when GMOs are transported, intentionally or intentionally, between different ecosystems and countries (OFAB, 2009).

The issue of biosafety regulation in Africa is rapidly gaining momentum as more African countries are embracing GMOs. Nearly all African countries have signed and ratified the Cartagena Protocol on Biosafety[17], related to the Convention on Biological Diversity, and these African countries have also developed their bills and some of these are already passed into laws. South Africa already has a biosafety law and is currently growing and consuming genetically modified (GM) corn and cotton. Kenya also had recently passed a biosafety law and is currently carrying out GM potato field trials. Egypt also has a biosafety law. Mali and Burkina Faso, in West Africa, also have biosafety laws, and Burkina Faso is presently carrying out GM cotton-confined field trials/commercial releases. The African Union (AU) has developed a model for a biosafety law to assist member states in developing their biosafety laws, which was made use of in the development of the draft for the Nigeria National Biosafety Bill[18]. In addition, The Economic Community of West African States (ECOWAS) Commission is currently developing a common Biosafety Regulation in line with the National Biosafety laws/regulations existing for the sub-region. This is related to the facts that Africa has embraced modern biotechnology, and that West African states have common borders and free trade that may be very difficult to monitor (OFAB, 2009).

Modern biotechnology regulation in Nigeria started in the early 1990s, as researchers in biotechnology became competent in modern biotechnology research and when the need for precaution in the development of modern biotechnology became glaring globally. The development of a biosafety legal regime in Nigeria has followed an evolutionary pattern, with each successive step being an improvement on the preceding level, while taking cognizance of the country's national and international obligations in the field of biosafety. Nigeria has seen the 1994 and 2001 Biosafety Guidelines[19], and has developed since 2002 in a Committee the Draft Nigeria National Biosafety Bill and legislated it in 2009 (OFAB, 2009).

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[17] See details on the Protocol: https://bch.cbd.int/protocol/

[18] Referred to as National Biosafety Bill, 2010: A BILL FOR AN ACT TO REGULATE ACTIVITIES IN GENETICALLY MODIFIED ORGANISMS, TO ESTABLISH THE NATIONAL BIOSAFETY AUTHORITY, AND FOR CONNECTED PURPOSES

[19] The Biosafety Guidelines 1994 covered only agricultural modern biotechnology and were not actually approved by the government. And, these guidelines were developed before the advent of the Cartagena Protocol on Biosafety. The 2001 Biosafety Guidelines were approved by the Federal Executive Council as a fast track approach to encourage research and development of GMOs and the regulation of modern biotechnology in the country, having signed an internationally binding protocol. These guidelines are more encompassing on all biosafety issues beyond modern agricultural biotechnology; they are in line with the Cartagena Protocol on Biosafety. As the biosafety guidelines were not legally binding, there was the need to develop a policy and law in biosafety that would address the subject of regulating modern biotechnology in a more robust and encompassing manner. The Federal Executive Council (FEC) approved the development of a bill on biosafety and a national committee was inaugurated in 2002 for that purpose. A Draft Nigeria National Biosafety Bill was legislated in 2009 (according to a statement by Rufus Ebegba from the Federal Ministry of Environment, Abuja).

Furthermore, Nigeria has already passed the Biosafety Bill into law in the year 2015. The Biosafety Bill covers all modern biotechnology activities, including GMOs and other products of modern biotechnology and all germplasms. It defines modules of practice of modern biotechnology and the handling of its products (GMOs) to ensure safety to the environment and to human health. The Biosafety Bill is therefore intended to guide different segments of the society in contributing to safe applications of modern biotechnology. It defines offences and penalties for the violation of the act and covers socio-economic considerations in risk assessment.

Some of the major issues of biosafety regulation in Nigeria include risk assessment, substantial equivalence, risk management, precautionary principle/approach, benefit analysis, and products labelling. Biosafety regulation in Nigeria is aiming to regulate application and approval of GMOs for confined field testing, import, placing in the market, contained use or products thereof, ethical and socio-economic considerations, packaging, labelling, storage, transport, handling of laboratory practices in relation to GMOs or products thereof, standards of risk assessment, fees, waste from genetic engineering techniques, and contingency plans to manage emergency/unintentional releases. Nigeria needs to regulate GMOs in order to harness the potential which modern biotechnology has to offer in the field of improved food production, medicine/health, industrial growth and environmental protection, and to allay the fear of the populace on the socio-economic consequences of modern biotechnology, especially among the small-scale farming systems which are prevalent in Nigeria. Also, there is currently a lot of concern regarding the possible toxicity and allergenicity of food products derived from GMOs. There is, therefore, the need to minimize risks to human beings. The need to regulate GMOs is also due to concerns on the environmental consequences of the release of GMOs into the environment, especially the effect on biological diversity (OFAB, 2009). Important is the administrative capacity to implement the rules and regulations at all government levels.

## 4 Review of Related Studies

Dofonsu et al. (2008) were the first to report on the use of choice experiments (CEs) to estimate the net impact of pest-resistant GM cowpea on net social welfare, given price and income risks in the Republic of Benin, a coastal country in West Africa. Two different questionnaires were utilized in the survey involving choice experiments only and combining intensive talk with choice experiments to interview stratified random samples of 268 consumer families and 112 cowpea growers in the cities of Cotonou, Porto-Novo, Parakou, and Malanville. The choice experiment involved a simulation of a market scenario being similar the one that respondents are exposed to involving cowpea purchases and sales. In their experiment, the respondent is invited to imagine that he/she is in front of a seller in a market to buy cowpea. The seller then provides information about advantages and disadvantages of conventional and GM cowpea prior to offering these products at given prices to the client.

Choice experiments (CEs) were originally developed in the marketing and transportation literature and have been used for more than a decade to value private goods (Lusk and Schroeder, 2004). CEs have a role in consumer valuation, decision making, and are found necessary in measuring economic impacts of new GM technology (Dofonsu and Lowenberg-DeBoer, 2008).

This study provides the departure point from the previous economic impact studies on pest-resistant GM cowpea by using discrete choice statistical methods to examine the choices that consumers make prior to the commercial introduction of the new GM cowpea in northern Nigeria, rather than using the simple household model to capture the problem of the typical family in West Africa. In forecasting for a commercialization of new GM cowpea the discrete choice models predicted quite well, far more accurately than the procedures used by Dofonsu et al. (2008).

## 5 Experimental Methods and Procedures

The study was conducted in Kaduna and Sokoto states, Nigeria. The study areas are situated in northern Nigeria; it is an area of limited rainfall which is favourable to cowpea production (Norman, 1975). Kaduna state is geographically located in North-Central Nigeria and lies between latitudes $09^0$ 2' and $11^0$ 32' north of the equator and longitudes $06^0$ 15' and $80^0$ 50' east of the prime meridian. The climate varies from the North to the Southern part of the states. The vegetation is divided into the Northern Guinea Savanna in the South, while the mean annual temperature varies between $24^0$C and $27^0$C (Abdul Rahman, 2001). Sokoto State, on the other hand, is located within the Sudan Savanna vegetation zone in the North-Western part of Nigeria and lies within longitudes $3^0$ and $6^0$ E and latitudes $8^0$ and $13^0$ N (Obiora, 2014). Sokoto has a semi-arid climatic condition, characterized with low rainfall, varying widely in amount from year to year (500m-1300mm), and a long dry season. Diurnal and seasonal temperature fluctuations are very wide. Maximum temperature of $41^0$ C is attained in April while minimum temperature of $13.2^0$ C occurs in January. Humidity is very low during most parts of the year and solar radiation is relatively high due to the dry atmosphere and the clear skies (Obiora, 2014). Both Kaduna and Sokoto States have a high concentration of cowpea farmers. Cowpea has a great potential to increase its production and so also the farmers' income in the study area has a potential for increase (Mohammed and Mohammed, 2014).

This study compared responses to questions in a choice experiment (CE), for choices between GM and conventional cowpea with varying quality attributes, such as cowpea colour, grain size, insect damage, genetically modified organisms (GMOs), and price. A random sample of 208 cowpea consumers was selected and interviewed to evaluate the attributes of GM and conventional cowpea options in selected markets. Subjects were then asked to evaluate each scenario as if they were going to face the consequences of their choice. Participants were informed about their rights to accept or decline the interview, and it was made known that no one would face consequences for his or her unavailability or unwillingness to participate.

Data were collected in Zaria, Giwa, Sabon Gari, Chikun and Kaduna South Local Government Areas of Kaduna State as well as in Wurno, Sokoto North, Gwadabawa, Tambuwal, Sabon Birni and Bodinga Local Government Areas of Sokoto State in a choice experiment (CE) with designed questionnaires using R open source Programming Language (2011) version 2.13.1 R for Statistical Computing. The designed questions were asked in a CE to elicit preferences of consumers on GM and conventional cowpea. The experimental design of the CE comprises three options, namely the GM and conventional cowpea options, and a "none" option. The full factorial design was initially constructed to obtain 144 possible combinations of the attributes while an orthogonal fractional factorial design was later used to reduce the number of combinations to 12. A total sample size of 208 cowpea consumers were randomly selected for the survey.

In a CE, people make a series of repeated choices between different products defined by multiple attributes. In this CE, GM cowpea was described by key attributes such as cowpea price, safety from insecticide misuse, colour, grain size, genetically modified organisms, and insect damage. These attributes are potentially applicable in explaining choices between wide ranges of cowpea products to estimate consumer preferences. The stated choice (SC) data are generated by a systematic and planned design process in which the attributes and their levels are pre-defined without measurement error and varied to create preference or choice alternatives. In addition, information on socio-economic characteristics such as age, gender, education and income were also simultaneously collected.

Each participant indicated which of the three choices (GM, conventional cowpea, "None") they most preferred in each of the 12 CE questions. It is assumed that choices between GM and conventional cowpea are driven by an attribute-based utility function, which is specified as follows:

$$V_{ij} = \alpha PR_j + \beta_1 WH_j + \beta_2 BR_j + \beta_3 SA_j + \beta_4 SL_j + \beta_5 GMO_j + \beta_6 IND_j + \beta_7 Bt_j + \beta_8 Con_j \quad (1)$$

Where, $PR_j$ is the price for alternative j, $WH_j$ is the dummy variable which equals to 1 if the alternative j has white colour, $BR_j$ is the dummy variable which equals to 1 if the alternative j has brown colour, $SA_j$ is the dummy variable which equals to 1 if the alternative possesses safety from insecticide misuse, $SL_j$ is the dummy variable which equals to 1 if the alternative has large grain size, $GMO_j$ is the dummy variable if the alternative has GMO, $IND_j$ is the dummy variable which equals to 1 if the alternative has insect damage, $Bt_j$ is the dummy variable which equals to 1 if the alternative is the new GM cowpea, and $Con_j$ is the dummy variable which equals to 1 if the alternative is the conventional cowpea, $\alpha$ is the marginal utility of income (or marginal disutility of price), and $\beta_k$ are marginal utilities to be estimated. The attributes and their levels in the choice experiment design, and their relevance in decision-making are shown in Table 2.

**Table 2: Attributes, Levels and their Relevance in Decision-Making**

| Attributes | Levels | Relevance in decision-making |
|---|---|---|
| Price | ₦100, ₦ 150,₦ 250 | Cowpea purchasing decision |
| Colour | White colour, Brown colour | Purchasing decision and valuation of cowpea grain quality |
| Safety from insecticide misuse | Yes, No | Decision on health risks |
| Grain size | Large, Small | Cowpea grain quality valuation and purchasing decision |
| GMO | Yes, No | Purchasing decision and utilization of GMO cowpea |
| Insect damage | Yes, No | Willingness to pay, cowpea cooking and purchasing decisions. |

**Source:** Computed from Abubakar (2015), ₦ is the symbol for Nigerian currency

To estimate the consumer welfare effects of introducing the new GM cowpea, the methods outlined in Hanemann (1999) and Morey (1999) were followed. Especially, they show that compensating variation (CV) can be calculated as:

$$CV = -\frac{1}{\alpha}\left[\ln\sum_{j=1}^{2}\exp(V_j^0) - \ln\sum_{j=1}^{3}\exp(V_j^1)\right], \tag{2}$$

Where, $V_j^0$, represents the utility of option j in the initial condition when only conventional cowpea is available for sale (the other option is the choice not to purchase – that is., choose "none."). $V_j^1$, is utility in the situation where both GM and conventional cowpea are available for sale. Thus, the CV equation calculates the consumer benefit (in Naira per choice occasion) from having an additional choice option. The α represents marginal utility of income, which in a linear utility model is simply the coefficient estimated on "price" or "income".

## 6 Results and Discussion

Welfare analysis of the expected aggregate net benefit of introducing the new pest resistant transgenic GM cowpea in the marketplace (per choice occasion by Kaduna and Sokoto states) is presented in Table 3. The results revealed that releasing GM cowpea in the marketplace would have a significant higher net benefit on consumers at a 5% level. This finding is in conformity with the findings of Dofonsu et al. (2008) who reported that the welfare gain of US $51.9 million that GM cowpea would bring to producers far outweigh the welfare loss of US $ 1.5 million to consumers, so that the society in the Republic of Benin would, on aggregate, experience a net welfare gain of about US $ 50.36 million.

The aggregate benefit and percentile welfare confidence intervals were reported in Table 2. Results in Table 3 further showed that the aggregate benefit of releasing GM cowpea in the marketplace on consumers was estimated to be of about ₦ 242 billion (US $ 1.56 billion). The study suggests that releasing GM cowpea in the marketplace would improve the welfare of cowpea consumers in the study area. Moreover, Table 3 revealed that the aggregate welfare benefit for both Kaduna and Sokoto States were estimated to be ₦10 billion and ₦45 billion, respectively, and were statistically significant at 5% levels.[20]

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[20] See the note to Table 3 and the further notes here in footnote 20 on methodology. The estimates of the percentile confidence intervals reported in Table 2 above were obtained by performing parametric bootstrapping simulation, which was developed by Krinsky-Robb (1986). Bootstrap requires sampling with replacement, which means that one item can appear multiple times in the sample. The simulation procedure entails taking 1,000 independent random draws from the estimated parameter distribution, which is centred at the original value of the statistic (using the parameter estimates and the Choleski decomposition of the variance-covariance matrix as shown in the Appendix). The conditional logit parameter estimates and the variance-covariance matrix (see Appendix) were computed using R open source Programming Language (2011) version 2.13.1 for Statistical Computing, whereas the 1,000 random draws were taken using the random number generator in Ms Excel 2007. The Choleski factor is defined as a lower triangular positive definite, symmetric matrix (see as a reference to the Choleski decomposition: https://en.wikipedia.org/wiki/Cholesky_decomposition). It is a square root matrix (and the inverse square root matrix is the inverse of an upper triangular matrix).
The original data were 208 observations or samples generated without replacement from a cowpea population, meaning the samples were not taken from the same item twice. The study next resampled to get 1,000 resamples each of size 208 and computed the lower and upper bounds of the percentile net welfare confidence intervals. The bootstrapped confidence intervals were computed using the large function in Ms Excel 2007. To know the

In row 1 of table 3 the aggregate of Naira 96.20 is the weighted average of several benefit per choice experiments made for the individual sampled consumer. It is the aggregate measure obtained by calculating the benefit per choice made for each sampled person and taking the weighted average. The benefit per choice made was calculated using the compensating variation equation specified in equation 2 which shows the compensating variation that was used for the calculation. In row 5 the aggregate of 242.5 billion Naira was obtained as the product (multiplication) of 90.2*70,007684*12*3. In the paper the figure of 70 million people was taken as the aggregate urban population of Nigeria for the year 2010. A significant cowpea demand was reported for Nigeria in the year 2010 in urban areas of Kaduna, Abuja and Kano States. Hence, the paper used the urban population for that year in 2010. The figures for Kaduna and Sokoto States refer to the population in each of these States for the year 2010.

The welfare benefit estimates were obtained under the assumption of the average retail price of N250/kg of conventional cowpea (Exchange rate: US$1= N155) in the year 2013, which is the year of data collection. The net welfare benefit per year was obtained by multiplying benefit per choice made, valuation questions, and number of observations. The result is that the net welfare benefit for consumers in Sokoto State, as shown in Table 3 above, was higher (N 45,474,321,110 per year) than that of Kaduna State (N 10,911,075,751 per year). Abubakar (2015) found that the majority (87.80%) of the respondents said they were largely aware and 90.48% of the sampled cowpea consumers were somewhat knowledgeable of the transgenic pest resistant GM cowpea in Sokoto State, whereas only 12.20% of consumers were aware and some 9.52% of the sampled cowpea consumers indicated that they were somewhat knowledgeable about GM cowpea in Kaduna State. The huge gap in consumers' awareness of GM cowpea of about 75.60% might be attributed to the perceived knowledge of respondents. Respondents in Sokoto State had heard more about GM cowpea than respondents in Kaduna State. In view of this, the higher net benefit results because cowpea consumers were more likely to be informed about the transgenic pest resistant GM cowpea in Sokoto State than in Kaduna State, Northern Nigeria.

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95% confidence interval for the percentile of a standard normal variable or multivariate normal distribution ($\alpha$ = 0.05), the study needed to choose the $\alpha$/2th and (1-$\alpha$)/2th quartiles and generated 1,000 bootstrap resamples and order them. Using $\alpha$ = 5% or 0.05, then 0.05/2th = 0.025 multiplied by 1,000 resamples equals to 25, whereas (1-0.05)/2th = 1-0.025 multiplied by 1,000 resamples equals to 975.Therefore, the limits of bootstrapped confidence intervals for the percentiles reported in Table 3 lie between 25, 975 or between 0.025, 0.975 quartiles. The meaning of the confidence intervals reported in Table 3 in terms of the actual (ordered) bootstrapped data is that we can be 95% confident that the expected percentile net welfare benefit falls between 25 and 975 or between 0.025 and 0.975 quartiles.

**Table 3: Estimated Benefit of introducing GM cowpea into the marketplace across Kaduna and Sokoto States, Northern Nigeria**

| Items | States | | Aggregate |
|---|---|---|---|
| | Kaduna | Sokoto | |
| Benefit per choice made (₦) | 49.96 | 297.61 | 96.20 |
| Population | 6,066,562 | 4,244,399 | 70,007,684 |
| Valuation Questions | 12 | 12 | 12 |
| Cowpea Choice Options | 3 | 3 | 3 |
| Net Welfare Benefit (₦ per year) | 10,911,075,751 | 45,474,321,110 | 242,471,844,397 |
| Percentile Confidence Intervals | [18,774,403,213.72, 135,794,666,298.18] | [20,634,503,640.18, 149,248,714,015.00] | [1,860,100,426.46, 13,454,047,76.82] |
| Boot-strapped values from Willingness to Pay (WTP) | 1000 | 1000 | 1000 |

**Source:** Computed from Abubakar (2015) Sample size (n) = 208

**Note to table 3:** In the first row of Table 3, the aggregate is obtained from choice probabilities of the conditional logit model by sample enumeration. "Aggregate" refers to calculating the choice probabilities and taking the weighted sum of these probabilities. In the fifth row, aggregate is obtained from the simulated welfare estimates by using the Large function in Ms Excel 2007 for the range of bootstrapped welfare estimates at the 25 and 975 percentiles. The figures in the last row are the 1,000 observations drawn from multivariate normal distributions created using the coefficient estimates and the variance-covariance matrix from the conditional logit model using R statistical computing programming Language (See for this the Appendix for the computer printouts and explanation). To facilitate statistical inference, standard deviations of WTP (Willingness to Pay) are derived by generating a distribution of 1,000 WTP estimates using the parametric bootstrapping method proposed by Krinsky and Robb (1986). In the sixth row the percentile confidence interval lies between the 25 and 975 percentiles and were constructed for statistical inference.

## 7 Conclusions and Policy Recommendations

This study estimated the economic impact of introducing pest resistant transgenic genetically modified (GM) cowpea in Kaduna and Sokoto States, in northern Nigeria. The Institute for Agricultural Research (IAR) has the national mandate for cowpea research in Nigeria. The IAR has already completed the confined trials and field testing of GM cowpea in 2015. IAR is currently collaborating with the National Biosafety Management Agency in Nigeria to assess the role of GM products in Nigeria in the interest of farmers and consumers. GM cowpea is currently at the field trial stage. The seeds are expected to be in the market around the end of the year 2017. The innovation process at the market in the area depends on the capacity to control the quality of GM cowpea to facilitate the trade with such products in the ECOWAS region. The drivers towards commercialization of GM cowpea focus on the role of Science, Technology and Innovation (STI) policies in promoting the understanding of biotechnology among farmers and consumers as well as on its applications for national development in Nigeria. Specifically, the main obstacle towards introducing GM cowpea is that consumer awareness of pest resistant transgenic GM cowpea is still very low in northern Nigeria. Farmers have negative concerns on the potential risks of GM cowpea on the environment, while consumers have negative health concerns on potential risks of toxicity and ethics of genetically modified cowpea. The study concluded that releasing pest-resistant GM cowpea in the marketplace would have a significant and positive net benefit on cowpea consumers' welfare in the study area. This implies that releasing GM cowpea in the marketplace would improve the welfare of cowpea consumers. Finally, there is the need for crop breeders to improve cowpea attributes that consumers place a relatively high level of importance in. Most valued attributes, like large grain size and safety, need to be considered when introducing the new varieties of GM cowpea in the study area.

Because welfare measurement of this type is of great value to policy makers, it is recommended that before moving GM cowpea from regulatory approval to commercialization there is a need for the policy makers to ensure that introducing the new pest-resistant transgenic GM cowpea will be to the benefit of all stakeholders and will promote consumer welfare in the study area.

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## APPENDIX

### A: COMPUTER PRINTOUT FOR CONDITIONAL LOGIT PARAMETER ESTIMATES

CONDITIONAL LOGIT PARAMETER AND WILLINGNESS TO PAY (WTP) ESTIMATES

| Coe | f exp(coef) | se(coef) | z Pr | (>\|z\|) | | | | |
|---|---|---|---|---|---|---|---|---|
| Pr | -0.005 | 0.994916 | 0.001 | -9.306 | < 2e-16 | *** | WTP | |
| Cw | 0.098 | 1.102614 | 0.080 | 1.225 | 0.22044 | | 19.16609 | Cw |
| Cb | -0.076 | 0.926726 | 0.074 | -1.026 | 0.30509 | | -14.9306 | Cb |
| Sy | 0.952 | 2.590549 | 0.083 | 11.514 | < 2e-16 | *** | 186.762 | Sy |
| Sl | 0.474 | 1.60565 | 0.102 | 4.654 | 3.25E-06 | *** | 92.90892 | sl |
| Gmo | 0.143 | 1.154173 | 0.051 | 2.839 | 0.00452 | ** | 28.13277 | gmo |
| Id | -0.216 | 0.805458 | 0.072 | -3.002 | 0.00268 | ** | -42.448 | id |
| Gm | 1.667 | 5.294845 | 0.129 | 12.888 | < 2e-16 | *** | 327.0221 | gm |
| Con | 1.767 | 5.855582 | 0.130 | 13.616 | < 2e-16 | *** | 346.7725 | con |
| LL(0) | -2913.520 | | | | | | 34.09671 | cw_cb |
| LL | -2352.266 | | | | | | -19.7504 | gm_con |
| Pseu-doR | 0.193 | | | | | | | |
| N | 208 | | | | | | | |

**Note:** The parameter estimates were obtained from the estimation of the conditional logit econometric model. Despite the prevalent use of the conditional logit model (CLM) and the relative ease with which welfare estimates can be calculated from it, the utility of each alternative GM cowpea and Conventional cowpea is specified as a function of the attributes of each of the other alternatives. The coefficient estimates were also used in helping to draw the 1,000 observations created in the multivariate normal distributions in the bootstrapping simulation. The description of the symbols in the parameter estimates is as follows: Pr = Market price for cowpea per kilogram, Cw = White colored cowpea grains, Cb = Brown colored cowpea grains, Sl = safety attribute of cowpea grain from insecticide misuse, Gmo = Genetically modified organism, Id = attribute of insect damage, Gm = Genetically modified cowpea option, Con = Conventional cowpea option, LL(0) = Log likelihood at start of maximization, LL = log likelihood at convergence, PseudoR = is model fitness statistic, N = Sample size

## B: COMPUTER PRINTOUT FOR CHOLESKI DECOMPOSITION

CHOLESKI FACTOR/DECOMPOSITION (LOWER TRIANGULAR VARIANCE-CO-VARIANCE MATRIX)

| | Pr | cw | cb | sy | sl | gmo | id | gm | con |
|---|---|---|---|---|---|---|---|---|---|
| Pr | 0.000548 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cw | -0.03649 | 0.070874 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cb | -0.01176 | 0.041179 | 0.060594 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sy | -0.02697 | 0.015346 | -0.00124 | 0.076616 | 0 | 0 | 0 | 0 | 0 |
| Sl | -0.02999 | 0.008829 | -0.01827 | 0.06004 | 0.073718 | 0 | 0 | 0 | 0 |
| gmo | -0.00923 | 0.004458 | 0.004251 | -0.00849 | -0.01431 | 0.046377 | 0 | 0 | 0 |
| Id | -0.01359 | 0.027865 | -0.01326 | 0.017633 | 0.014546 | -0.00714 | 0.059008 | 0 | 0 |
| Gm | -0.04236 | -0.062 | -0.00667 | -0.06475 | -0.0275 | -0.01641 | -0.03078 | 0.06983088 | 0 |
| Con | -0.04186 | -0.0568 | -0.00594 | -0.06951 | -0.03811 | -0.01803 | -0.02233 | 0.05547813 | 0.04064 |

**Note**: The Choleski factor is the lower triangular matrix computed using R software. The Choleski factor is also referred to as the variance-covariance matrix. A matrix is the array of elements or symbols in rows and columns while covariance is a measure of how much two random variables vary together. All other symbols are defined above.

# Cassava Production, Processing, Value chain Integration, Fortification and Acceptability in Nigeria

**Alabi Reuben Adeolu[1], Daniel Izevbuwa Osasogie [1], and Onowu Endurance Omogor[2]**

## 1 Introduction

The Food Crop Sub-sector (with cassava, yam, maize, sorghum, millet, rice and cocoyam being the main food crops grown in the country) contributed about 28% to Nigeria's GDP, representing about 75-76% of the share of the agricultural sector's contribution to GDP (Toluwase and Sekumade, 2017). Root and tuber crops are staple food crops, being the source of daily carbohydrate intake for the large populace of Nigeria. The term "root and tuber crop" refers to any growing plant that store edible materials in the subterranean root, corm or tuber (Oke, 1990). Cassava is a member of this important class of food.

Cassava was first introduced to the Africa continent through the Congo River by Portuguese explorers and traders from Brazil, during the 16th and 17th centuries (Okigbo, 1980). From there it was diffused by Africans to many parts of Sub-Sahara Africa (SSA), over a period of two to three hundred years. In SSA, the diffusion of cassava can be described as a self-spreading innovation. It was initially adopted as a famine-reserve crop. In the Democratic Republic of Congo (DRC) where the crop was first introduced, millet, banana and yam were the traditional staples, but farmers adopted cassava because it provided a more reliable source of food during drought, pest attack, and during the "hungry season". When spreading across the continent, cassava has replaced traditional staples, such as millet and yam, and has been successfully incorporated into many farming systems (FAO, 2006). Cassava contributes more to the food security status of its producing and consuming households, and it becomes an even more important cash crop that can promote rural development (FAO, 2006). The average daily consumption of cassava in Nigeria is 600 grams per capita. More than 30 percent of the Nigerians consume cassava more than four times a week (IFAD and FAO, 2004). FAOSTAT (2017) showed that Nigerians derived an average of 257 kcal/capita/day from cassava which is more than the 241 kcal/capita/day derived from yam between 2000 and 2013. As the cost of production is low, cassava has a high poverty reduction potential (Asante-Pok, 2013). Akinpelu et al. (2011) mentioned that the consumption of cassava for poor households in urban areas is double that of non-poor

[1] Department of Agricultural Economics, Ambrose Alli University, Ekpoma, Nigeria
[2] Federal Ministry of Agriculture and Rural Development, Abuja, Nigeria

households, while in rural areas, the consumption of cassava by poor households is triple that of non-poor households. Egesi et al. (2006) argued that cassava has been transformed from a reserve commodity for support in times of famine into a staple food, and subsequently into a cash crop. A prior study conducted by Nweke et al. (1997) shows that cassava accounts for 21 percent of the income of the cassava-producing households. According to FAOSTAT commodity balances (FAOSTAT, 2017) cassava produced in Nigeria goes mainly to feed and food (with an average of 48 percent and 41 percent, respectively in the period 2000-2013, while the rest of it goes as waste (an average of 11 percent). The availability of cassava in a convenient food form, such as *gari*[3], played a major role in the increase of the per capita cassava consumption in Nigeria. Cassava was found to be the cheapest source of calories among all food crops in Nigeria (FAO, 2006). As family incomes increased, the consumption of cassava as dried root flour declined while consumption in convenient food forms such as gari increased. Dried cassava root flour is cheaper than gari because of the high cost of processing gari. Medium and high-income families were found to consume gari because it is cheaper and more convenient to cook than grains. The future of cassava as a rural and urban food staple will depend on cassava's ability to compete with wheat, rice, maize, sorghum and other grains in terms of cost, convenience and availability in urban markets[4].

Cassava can be produced with family labour, land, and a hoe and machete, making it an attractive and low-risk crop for poor farmers. Also, cassava is available to households in the form of simple food products which are significantly cheaper than grains such as rice, maize and wheat (Nweke et al., 2001). Cassava has several other advantages over rice, maize, and other grains as a food staple in areas where there is a degraded resource base, uncertain rainfall and weak market infrastructure. It is drought-tolerant; this attribute makes it the most suitable food crop during periods of drought and famine (IITA, 2009)[5].

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[3] *Gari* is a granulated and toasted cereal-like cassava food product which is convenient for consumption in urban environments because it is in a ready-to-eat form and it has an extended shelf-life. It is a major component of everyday diet in Nigeria, providing about 283 calories/person/day. According to IITA (2007), about 70 percent of the cassava produced in Nigeria is processed into gari and as such gari is the most commonly traded cassava product (IITA, 2007). The price of gari thereby serves as a reliable indicator for the demand and supply of cassava.

[4] The degree to which the future market demand for cassava for food consumption can be expanded however, would depend largely on the extent to which the quality and variety of cassava food products can be improved to make them attractive to a range of consumers in rural and urban centres.

[5] One of the critical variables in the expansion of the cassava area is the availability of improved processing equipment to remove water from the roots (the roots are composed of 70 percent water), and thereby to reduce the cost of transportation. Improved processing

There are two main categories of cassava varieties produced in Nigeria: *Manihot palmata* and *Manihot aipi*, or bitter and sweet cassava, respectively (Nwabueze, 2011). Over 90 percent of cassava cultivation in Nigeria is done by smallholder farmers. As a crop whose by-products have a wide array of uses, cassava is the most important food crop for Nigeria by production quantity next to yam, which is the most important food crop by value (FAOSTAT, 2012). Nigeria is the world's largest producer of cassava, with other top producers being Indonesia, Thailand, the Democratic Republic of Congo, and Angola (Okoye, 2015).

The vision for cassava in Nigeria is that if the cassava food system is improved, it will enhance rural industrial development and raise incomes for producers, processors and traders (Nweke et al., 2001). This is the reason for the great scientific interest in how Nigeria can increase the production and productivity of this important crop for food security amelioration in Nigeria. It is important to know how the value of this important crop can be improved through processing and fortification to increase its domestic consumption and to produce for the international market.

Apart from the introduction in Section one, the rest of the paper is divided into seven sections. Section two traces cassava production and productivity trends in Nigeria, Section three examines cassava development and improvement in Nigeria. Section four is on processing of cassava in Nigeria. Section five deals with integration of the cassava value chain. Section six presents the importance and acceptability of bio-fortified cassava. Section seven concentrates on the limitation of agricultural innovation as it relates to cassava development and processing, while section eight concludes the paper with policy recommendations.

## 2 Cassava Production and Productivity Trends

To improve the food security situation, the Food and Agriculture Organization (FAO) at the 8th Session of the Committee on Agriculture (COAG) in 1985 recommended the adoption of measures to broaden the food base through the promotion of local food crops of nutritional importance. At its 9th session in 1987, the COAG further requested member governments to give high priority to production and consumption of roots and tubers among which cassava is the chief. This is so because a great share of the populace derives their calories from cassava. The importance of cassava in the food supplies matrix is large if we consider the fact that cassava contributes about 41% to total food crop supplies in Nigeria in 2014 (FAOSTAT, 2017). FAOSTAT (2017) also reported that Nigeria alone in 2014

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and food preparation methods reduce bulk and make it possible for cassava products to be transported at reduced costs over poor roads to distant urban market centres.

produced 55 million metric tonnes of cassava from 7.10 million hectares, representing 46 percent of the 121 million tons of cassava which were produced in Africa. Cassava production in Nigeria is used almost exclusively for consumption as food and feed (Table 1a). The recently available data on cassava production in Nigeria reveal that cassava production increased from 32 million tonnes in 2000 to about 55 million tons in 2014 (Table 2). This translated to an annual growth rate of 3.24%. When this is compared with the Nigeria annual population growth rate of 2.63% (FAOSTAT, 2017) within the same time frame, this confirms the potential position of cassava in ameliorating food insecurity in Nigeria as earlier indicated by FAO as early as 1987 (see above). The increase in cassava production has been attributed to an increase in the area planted rather than effected through productivity gains. For example, 5.5 million hectares of arable land was devoted to cassava production in 2000, and this has increased to 7.10 million hectares in 2014[6]. So, the 29% expansion in land cultivated to cassava between 2000 and 2014 accounts for the 3.24% increase in cassava production in Nigeria.

The fact that the 3.24% growth rate, estimated as cassava production growth rate in Nigeria, is not competitive in global terms becomes glaring when this growth rate is compared with the cassava production growth rates of other major cassava-producing nations. For example, cassava annual production growth rates between 2000 and 2014 in Thailand, Ghana, Congo, and Angola were at 3.75%, 4.79%, 3.65%, and 6.48%, respectively (Table 2). This implies that Nigeria needs to do more to increase its cassava production as it currently contributes about 20% to total global cassava production in the World (Annex 1). The rate of cassava production expansion of Nigeria is not sufficient to supply world markets.

Table 1a reveals that cassava production is contributing to domestic supply at the level of 99.77%, meaning that cassava is contributing considerably to food security in the country. But also, yam is important (see table 1b) as Nigerians derived an average of 257 kcal/capita/day from cassava and 241 kcal/capita/day from yam between 2000 and 2013.

[6] FAO (2006) shows that harvesting cassava is the most labour-intensive field task in Nigeria where the TMS (Tapioca Mosaic Selection) varieties and improved agronomic practices have boosted yields by 40 percent. In Nigeria, the labour constraint has shifted from cassava weeding to cassava harvesting. Harvesting is now proving to be a serious constraint on the spread of TMS varieties especially during dry season.

**Table 1a: Cassava Food Balance Sheet (million tons) in Nigeria (2000-2013)**

| Year | Production | Export | Import | Domestic Supply | Food | Feed | Waste |
|---|---|---|---|---|---|---|---|
| 2000 | 32.010 | 0.000 | 0.000 | 32.010 | 17.326 | 10.755 | 3.929 |
| 2001 | 32.068 | 0.000 | 0.000 | 32.068 | 17.358 | 10.775 | 3.935 |
| 2002 | 34.120 | 0.012 | 0.000 | 34.132 | 14.696 | 16.924 | 2.512 |
| 2003 | 36.304 | 0.011 | 0.000 | 36.315 | 14.122 | 18.007 | 4.186 |
| 2004 | 38.845 | 0 | 0.000 | 38.845 | 15.121 | 19.267 | 4.457 |
| 2005 | 41.565 | 0.006 | 0.000 | 41.571 | 16.174 | 20.616 | 4.781 |
| 2006 | 45.721 | 0.004 | 0.000 | 45.725 | 17.794 | 22.678 | 5.253 |
| 2007 | 43.410 | 0.008 | 0.000 | 43.418 | 16.891 | 21.531 | 4.996 |
| 2008 | 44.582 | 0.013 | 0.001 | 44.596 | 17.343 | 22.113 | 5.14 |
| 2009 | 36.822 | 0.001 | 0.001 | 36.824 | 14.334 | 18.264 | 4.226 |
| 2010 | 42.533 | 0.002 | 0.002 | 42.537 | 16.557 | 21.096 | 4.884 |
| 2011 | 52.403 | 0.013 | 0.011 | 52.427 | 20.398 | 25.992 | 6.037 |
| 2012 | 54.000 | 0.001 | 0.015 | 54.016 | 21.036 | 26.784 | 6.196 |
| 2013 | 53.000 | 0.011 | 0.015 | 53.026 | 20.636 | 26.288 | 6.102 |
| Average | 41.956 | 0.006 | 0.003 | 41.965 | 17.128 | 20.078 | 4.760 |
| % of Domestic Supply | 99.77 | | | - | 40.81 | 47.85 | 11.34 |

**Source**: Computed from FAOSTAT (2017)

Table 3 shows that the cassava yield has almost stagnated between 2000 and 2014 as it reveals that the cassava annual yield in Nigeria grew by 0.45% within the period. The yield has in fact declined from 9.70 tonnes per hectare in 2000 to 7.72 tonnes per hectare in 2014. The highest yield of 12.22 tonnes per hectare was recorded in 2010. Since then, the yield of cassava has nosedived in Nigeria. This also establishes the fact that the increase in cassava production comes mainly from land expansion rather than through productivity gains. The decline in land fertility, without a compensating application of fertilizer to improve the land fertility, can be implicated for the stagnation of the cassava yield in Nigeria (Alabi et al., 2016).

**Table 1b: Yam Food Balance Sheet (million tons) in Nigeria (2000-2013)**

| Year | Production | Export | Import | Domestic Supply | Food | Feed | Waste | Other Uses* |
|---|---|---|---|---|---|---|---|---|
| 2000 | 26.201 | 0.000 | 0.000 | 26.201 | 9.170 | 5.240 | 2.620 | 9.171 |
| 2001 | 26.232 | 0.000 | 0.000 | 26.232 | 9.181 | 5.246 | 2.623 | 9.182 |
| 2002 | 27.911 | 0.000 | 0.000 | 27.911 | 10.037 | 5.582 | 2.791 | 9.501 |
| 2003 | 29.697 | 0.002 | 0.000 | 29.695 | 10.436 | 5.939 | 2.970 | 10.350 |
| 2004 | 31.776 | 0.001 | 0.000 | 31.775 | 10.992 | 6.355 | 3.178 | 11.250 |
| 2005 | 34.000 | 0.000 | 0.000 | 34.000 | 10.800 | 6.800 | 3.400 | 13.000 |
| 2006 | 36.720 | 0.000 | 0.000 | 36.720 | 12.204 | 7.344 | 3.672 | 13.500 |
| 2007 | 31.136 | 0.000 | 0.000 | 31.136 | 12.995 | 6.227 | 3.114 | 8.800 |
| 2008 | 35.017 | 0.000 | 0.000 | 35.017 | 13.512 | 7.003 | 3.502 | 11.000 |
| 2009 | 29.092 | 0.000 | 0.000 | 29.092 | 16.164 | 5.818 | 2.909 | 4.201 |
| 2010 | 34.162 | 0.000 | 0.000 | 34.162 | 15.913 | 6.832 | 3.416 | 8.001 |
| 2011 | 37.116 | 0.002 | 0.000 | 37.114 | 16.479 | 7.423 | 3.711 | 9.501 |
| 2012 | 40.000 | 0.000 | 0.000 | 40.000 | 16.000 | 6.000 | 4.000 | 14.000 |
| 2013 | 40.500 | 0.000 | 0.000 | 40.500 | 18.225 | 4.050 | 4.050 | 14.175 |
| Average | 32.826 | 0.000 | 0.000 | 32.825 | 13.008 | 6.133 | 3.283 | 10.401 |
| % of Domestic Supply | 100.00 | | | | 39.63 | 18.68 | 10.000 | 31.69 |

**Source**: Computed from FAOSTAT (2017), * "Other uses" include seeds to be replanted by the farmers, gifts, etc. (NBS, 2014).

While the cassava yield in Nigeria stood at about 8 tonnes per hectare in 2014, the yield in Thailand and Ghana stood at about 22 tons and 19 tons per hectare, respectively (Table 3). This implies that Thailand and Ghana can produce about 3 times of cassava output from one hectare of land compared with what Nigeria can produce from the same hectare of land. The table 3 also indicates that the average annual cassava yield in Nigeria (10.30 tons per hectare) is not only lower than the World average (11.40 tons per hectare), but that it is also growing at a smaller pace (0.45%) compared with the World mean annual growth rate of 1.27%. All these are threats to Nigeria's cassava production's global competitiveness.

**Table 2: Cassava Production (million tons) in Major World Cassava Producing Countries**

| Year | Nigeria | Indonesia | Brazil | Thailand | Ghana | Congo | Angola | Tanzania | World |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 32.00 | 16.10 | 23.30 | 19.10 | 8.11 | 0.83 | 4.43 | 5.34 | 176.00 |
| 2001 | 32.10 | 17.10 | 22.60 | 18.40 | 8.97 | 0.84 | 5.39 | 4.34 | 182.00 |
| 2002 | 34.10 | 16.90 | 23.10 | 16.90 | 9.73 | 0.86 | 6.52 | 5.18 | 184.00 |
| 2003 | 36.30 | 18.50 | 22.00 | 19.70 | 10.20 | 0.88 | 6.89 | 3.96 | 192.00 |
| 2004 | 38.80 | 19.40 | 23.90 | 21.40 | 9.74 | 0.93 | 8.59 | 4.44 | 204.00 |
| 2005 | 41.60 | 19.30 | 25.90 | 16.90 | 9.57 | 1.01 | 8.81 | 5.54 | 206.00 |
| 2006 | 45.70 | 20.00 | 26.60 | 22.60 | 9.64 | 1.07 | 9.04 | 6.16 | 223.00 |
| 2007 | 43.40 | 20.00 | 26.50 | 26.90 | 10.20 | 1.14 | 9.73 | 5.20 | 228.00 |
| 2008 | 44.60 | 21.60 | 26.70 | 25.20 | 11.40 | 1.20 | 10.06 | 5.39 | 234.00 |
| 2009 | 36.80 | 22.00 | 24.40 | 30.10 | 12.20 | 1.23 | 12.83 | 5.92 | 237.00 |
| 2010 | 42.50 | 23.90 | 25.00 | 22.00 | 13.50 | 1.15 | 13.86 | 4.55 | 243.00 |
| 2011 | 46.20 | 24.00 | 25.30 | 21.90 | 14.20 | 1.18 | 14.33 | 4.65 | 255.00 |
| 2012 | 51.00 | 24.20 | 23.00 | 29.80 | 14.50 | 1.27 | 10.64 | 5.46 | 259.00 |
| 2013 | 47.40 | 23.90 | 21.50 | 30.20 | 16.00 | 1.30 | 16.41 | 4.76 | 263.00 |
| 2014 | 54.80 | 23.40 | 23.20 | 30.00 | 16.50 | 1.33 | 7.64 | 4.99 | 270.00 |
| Average | 41.80 | 20.70 | 24.20 | 23.40 | 11.64 | 1.08 | 9.68 | 5.06 | 224.00 |
| Growth Rate (%) | 3.24 | 3.01 | 0.07 | 3.75 | 4.79 | 3.65 | 6.48 | 0.38 | 3.18 |

**Source**: Computed from FAOSTAT (2017)

Table 4 demonstrates that the labour productivity of cassava production in Nigeria has increased from 400 kg per farmer in the year 2000 to 579 kg per farmer in the year 2014. The average annual growth rate during the period was 1.71%. This is higher than the 0.45% annual growth rate which was estimated as land productivity in cassava production in Table 3 (cassava yield annual growth rate). This suggests that more needs to be done to increase land productivity than labour productivity in cassava production. It also confirms that poor land fertility is a major cause of the low yield in cassava production. Annex 2 also indicates that generally the annual growth rate in labour productivity in cassava production in Nigeria is lower than labour productivity growth in yam and rice. Table 4 also reveals that the annual growth rate of labour productivity in cassava production in Nigeria - estimated as 1.71% - is far less than the annual growth rate of labour productivity of 2.60%, 4.58%, 3.05%, and 3.75% estimated for the cassava production in Indonesia, Thailand, Ghana and Angola, respectively.

**Table 3: Cassava Yield (tons/hectare) in Major World Cassava Producing Countries**

| Year | Nigeria | Indonesia | Brazil | Thailand | Ghana | Congo | Angola | Tanzania | World Average |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 9.70 | 12.53 | 13.55 | 16.86 | 12.28 | 9.00 | 8.30 | 6.60 | 10.39 |
| 2001 | 9.60 | 12.94 | 13.54 | 17.53 | 12.34 | 9.00 | 9.41 | 6.56 | 10.70 |
| 2002 | 9.90 | 13.25 | 13.77 | 17.07 | 12.25 | 9.00 | 11.01 | 7.84 | 10.72 |
| 2003 | 10.40 | 14.88 | 13.44 | 19.30 | 12.69 | 9.14 | 9.57 | 4.57 | 10.76 |
| 2004 | 11.00 | 15.47 | 13.63 | 20.28 | 12.42 | 9.14 | 12.56 | 4.66 | 11.06 |
| 2005 | 10.99 | 15.92 | 13.61 | 17.18 | 12.76 | 9.16 | 11.76 | 6.11 | 11.14 |
| 2006 | 12.00 | 16.28 | 14.05 | 21.09 | 12.20 | 9.32 | 11.72 | 6.20 | 11.90 |
| 2007 | 11.20 | 16.64 | 14.01 | 22.92 | 12.76 | 9.50 | 11.54 | 6.67 | 11.95 |
| 2008 | 11.80 | 18.10 | 14.14 | 21.25 | 13.51 | 9.97 | 14.81 | 6.44 | 12.21 |
| 2009 | 11.77 | 18.75 | 13.86 | 22.68 | 13.81 | 9.85 | 15.18 | 5.47 | 12.24 |
| 2010 | 12.22 | 20.22 | 13.95 | 18.83 | 15.43 | 9.92 | 15.58 | 5.21 | 12.37 |
| 2011 | 11.21 | 20.30 | 14.62 | 19.30 | 16.01 | 10.18 | 13.36 | 6.28 | 12.41 |
| 2012 | 7.96 | 21.40 | 13.61 | 21.91 | 16.75 | 10.22 | 10.01 | 5.72 | 11.00 |
| 2013 | 7.03 | 22.46 | 14.08 | 21.82 | 18.27 | 10.38 | 14.05 | 5.51 | 11.00 |
| 2014 | 7.72 | 23.36 | 14.83 | 22.26 | 18.59 | 10.51 | 10.11 | 6.24 | 11.16 |
| Average | 10.30 | 17.50 | 13.91 | 20.02 | 14.14 | 9.62 | 11.93 | 6.01 | 11.40 |
| Growth Rate | 0.45 | 4.51 | 0.36 | 1.82 | 2.48 | 1.21 | 3.28 | -0.79 | 1.27 |

**Source**: Computed from FAOSTAT (2017)

Ghana seems to be doing better in all the relevant cassava production and productivity parameters which were examined so far. For example, cassava production grew at the average of about 5% in Ghana, while cassava production grew by about 3% in Nigeria (Table 2). While cassava annual yield growth almost stagnated at 0.45% in Nigeria, it increased by about 3% in Ghana during the same period (Table 3). While the labour productivity in cassava production in Nigeria grew by around 2%, labour productivity in cassava production grew by about 3% in Ghana (Table 4). Angelucci (2013) had attributed the success story in cassava production and productivity in most years in Ghana to the high accessibility to cassava seeds and to technical assistance, as well as to the farm input subsidy programme of the government. This should be a lesson for Nigeria to increase its cassava production and productivity by learning from such experiences as in Ghana. FAO (2006) has demonstrated that there are two important factors that are necessary for cassava transformation among other factors in Nigeria. These are cassava (quality) improvement and processing of cassava to higher value products. The next section discusses the issues of improvement in cassava production and processing of cassava in Nigeria.

**Table 4: Labour Productivity (tons per capita) in Cassava Production in Major Cassava Producing Countries**

| Year | Nigeria | Indonesia | Brazil | Thailand | Ghana | Congo | Angola | Tanzania |
|---|---|---|---|---|---|---|---|---|
| 2000 | 0.400 | 0.133 | 0.710 | 0.447 | 0.768 | 0.641 | 0.471 | 0.202 |
| 2001 | 0.396 | 0.141 | 0.692 | 0.433 | 0.839 | 0.645 | 0.561 | 0.161 |
| 2002 | 0.416 | 0.139 | 0.711 | 0.400 | 0.899 | 0.650 | 0.663 | 0.188 |
| 2003 | 0.437 | 0.152 | 0.680 | 0.470 | 0.930 | 0.654 | 0.684 | 0.141 |
| 2004 | 0.462 | 0.160 | 0.743 | 0.516 | 0.876 | 0.685 | 0.832 | 0.155 |
| 2005 | 0.489 | 0.159 | 0.811 | 0.413 | 0.849 | 0.729 | 0.834 | 0.190 |
| 2006 | 0.531 | 0.165 | 0.839 | 0.561 | 0.844 | 0.762 | 0.837 | 0.207 |
| 2007 | 0.498 | 0.165 | 0.843 | 0.680 | 0.882 | 0.796 | 0.882 | 0.171 |
| 2008 | 0.506 | 0.178 | 0.857 | 0.650 | 0.974 | 0.819 | 0.893 | 0.174 |
| 2009 | 0.413 | 0.182 | 0.790 | 0.793 | 1.031 | 0.828 | 1.117 | 0.187 |
| 2010 | 0.471 | 0.198 | 0.818 | 0.592 | 1.129 | 0.760 | 1.183 | 0.141 |
| 2011 | 0.506 | 0.200 | 0.835 | 0.602 | 1.177 | 0.770 | 1.202 | 0.141 |
| 2012 | 0.552 | 0.202 | 0.767 | 0.837 | 1.193 | 0.817 | 0.876 | 0.162 |
| 2013 | 0.506 | 0.200 | 0.724 | 0.866 | 1.307 | 0.825 | 1.329 | 0.138 |
| 2014 | 0.579 | 0.197 | 0.788 | 0.878 | 1.339 | 0.836 | 0.608 | 0.142 |
| Average | 0.479 | 0.171 | 0.773 | 0.598 | 1.011 | 0.752 | 0.879 | 0.166 |
| Growth Rate (%) | 1.71 | 2.60 | 0.72 | 4.58 | 3.05 | 1.72 | 3.75 | 1.35 |

**Source**: Computed from FAOSTAT (2017)

## 3 Cassava Development and Improvement in Nigeria

The development and introduction of improved cassava varieties has long been recognized as one of the key strategies for transforming the cassava industry and for enhancing the wellbeing of Nigeria's population (Dixon and Ssemakula, 2008). Cassava genetic improvement research has been conducted by African smallholders, by researchers in research stations, and by scientists in international research centres, such as the International Institute of Tropical Agriculture (IITA) in Nigeria and the Centro Internacional de Agricultura Tropical (CIAT) in Kenya. Farmers selected self-seeded plants from local varieties that possessed the superior attributes which they desire, such as high yield, early bulking, in-ground storage, pest and disease tolerance, processing qualities, a large canopy, and a low cyanogen level. The evolution of cassava breeding in Nigeria can be described as a human ladder. Starting in the 1930s, one generation of breeders climbed on the shoulders of the past generations until they came up with the Tapioca Mosaic Selection (TMS) varieties in the mid-1970s (Eke-Okoro and Njoku, 2012).

The IITA developed high-yielding mosaic-resistant varieties in six years (1971 to 1977) of research. The new TMS varieties out-yielded local varieties on farmers' fields by 40 percent without fertilizer (Akoroda et al., 1985; Eke-Okoro. and Njoku, 2012). And, Nweke et al. (2001) reported that the TMS varieties are superior to local varieties not only in terms of yield, but also in earliness and pest and disease tolerance, and that they are as good as the local varieties in terms of various post-harvest attributes and for intercropping[7]. The rapid diffusion of the TMS varieties in Nigeria was starting in 1977 and was facilitated by the increase in farm-level yield, the profitability of the new varieties, the collaboration between relevant agencies, such as the National Root Crops Research Institute (NRCRI), the World Bank, the International Fund for Agricultural Development (IFAD), and private sector actors (Eke-Okoro. and Njoku, 2012). The diffusion in Nigeria was also facilitated by the physical presence of the IITA in Ibadan in Nigeria. The IITA's cassava diffusion programme multiplied and distributed the TMS planting materials directly to farmers and indirectly through informal channels such as schools and churches. The IITA's diffusion programme mobilized the private sector, particularly the oil sector, for assistance in the distribution of the TMS varieties. The IITA's cassava programme also used the mass media, including the newspapers, and radio and television to publicize the availability and the benefits of the TMS varieties. The boom in the petroleum industry in the 1970s which led to an increase in the purchasing power of urban consumers and an increase in demand for convenient food products, such as *gari*, were also important factors in cassava production transformation.

According to Eke-Okoro and Njoku (2012), in July 1996 the Nationally Coordinated Research Programme (NCRP) was approved for cassava. Earlier national programmes, such as the Priority Research Projects (PRPs) and the National Agricultural Research Project (NARP), dove-tailed into the NCRP. The NCRP constitutes a step in the implementation of the Medium-Term Research Plan (MTRP) of the National Agricultural Research Strategy Plan (NARSP) for 1996 - 2010. Under the NCRP, well-focussed research programmes on roots and tubers crops were collectively planned and executed by the National Root Crops Research Institute (NRCRI). The major achievements in technology development under the NCRP as far as cassava is concerned include:

(a) Improved production technologies leading to increased national output of cassava from 23.3 million tons/annum in 1994 to 45.6 million tons/annum in 2010;
(b) Development of low cyanide as well as high yielding, pest and disease resistant, cassava varieties;

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[7] However, the cassava producers in Nigeria, who plant the TMS varieties and make *gari* available for sale in urban markets, complain that the peeling of the roots of the TMS varieties is labour-intensive. The roots of the TMS varieties are not suitable for the development of mechanized peeling because they lack uniform shape and size (FAO, 2006).

(c) Selection of high yielding, pest and disease resistant cassava varieties which are also suitable for intercropping;
(d) Development of cassava hand-peeling tools for peeling of cassava;
(e) Integrated control measures for the control of the African Cassava Mosaic Disease (ACMD), the cassava bacterial blight (CBB), and the cassava green mite (CGM) were developed and documented. The NCRP for cassava and yam are still being implemented until date in Nigeria.

Some salient factors contributed in several ways to the success history of cassava development in Nigeria. It is important to examine them because their continued implementation can help to ensure the sustainability of the leading role which Nigeria is playing in cassava production globally. Firstly, the contribution of the governments in Nigeria and the respective policies are of paramount importance in cassava development in Nigeria. Between 1960 and 1970, most agricultural policies were directed towards the export of crops (cocoa, rubber, oil palm, etc). However, since 1975 till date, most governments in Nigeria have decided as a matter of policy to promote and to reinforce research and development in cassava improvement and production. This singular policy of the Government of Nigeria has led to the diversification of cassava products into diverse food forms that were not in existence in the last two centuries in Nigeria. The Government of Nigeria (GoN) policy on food security, food self-sufficiency and diversification of the economy has encouraged agricultural policy makers to reinforce cassava development in Nigeria. The Presidential Initiative (PI) on cassava development and on export of cassava (and products) is a policy made to encourage cassava improvement in Nigeria. The Presidential Initiative (PI) on Cassava was launched in July 2002 to promote cassava as a foreign exchange earner for the country, and as an opportunity to achieve self-sufficiency in food production. Under the initiative, the government has set a 10 percent inclusion of cassava flour in wheat flour and a 10 percent blending of ethanol with premium spirit. It also made use of cassava starch as a requisite ingredient for industries (Ilona et al, 2017). However, various effects and mechanisms influencing cassava development in Nigeria need to be mentioned.

Firstly, during the first and the second democratic government administrations since 1999, cassava farmers across the country were encouraged to cultivate improved varieties to meet the upcoming market demand. The 10 percent cassava inclusion policy, however, suffered from a transition in government, a lack of support from the industry, and a lack of enforcement. A new government (2008–2011) contradicted the policy goal when the ban on importing cassava and cassava products, such as chips and starch, was relaxed. The demand-pull mechanisms created by the new Ministry of Agriculture’s Cassava Transformation Agenda (CTA), beginning in 2011, may have positively shifted farmers’ interest into improved cassava varieties. The policy aims to attract foreign direct investment (FDI) in cassava processing. Nigeria has also received more than $200 million in financing from China for the installation of 18 large-scale cassava flour processing plants. This trend of policy changes, and the resulting shifts in demand and other market variables, may have caused farmers to move into and out of cassava adoption (Ilona et al, 2017).

Secondly, National and International Financial Agencies and Organizations, such as the Food and Agriculture Organization (FAO), the United States Agency for International Development (USAID), the Deutsche Gesellschaft Fuer Technische Zusammenarbeit (GTZ), the International Fund for Agricultural Development (IFAD), the United National Development Programme (UNDP), the Generation Challenge Programme (GCP) of the Consultative Group for International Agricultural Research (CGIAR), and Counter-part Funds of Federal and State Governments in Nigeria have provided the enabling financial assistance which stimulated the development of many cassava varieties in Nigeria.

Thirdly, the initiation of research collaboration between national, regional and international research institutions greatly contributed to cassava development in Nigeria. Following the devastating effect of cassava bacterial blight in 1972 and the devastating effect of new strain of mosaic virus ravaging cassava in Africa, which was detected by IITA, Ibadan, the Federal Government of Nigeria (FGN) decided to reinforce research collaboration between IITA and NRCRI through the policy of the presidential initiative (PI) on cassava. This initiative led to the development and the release of five new cassava varieties to check-mate the virulent mosaic virus strain that is ravaging cassava in Africa. The exchange of information, extension services, and production of training manuals, such as the current manual on cassava stem and root production, produced by the National Root Crops Research Institute (NRCRI), in Umudike, Abia State (see: Eke-Okoro et al, 2005) provided information and practical knowledge, thereby encouraging cassava development in Nigeria. The publication of an extension guide on cassava in Nigeria by NRCRI is a useful tool for disseminating information among scientists, farmers and donor agencies. The training of Nigerian farmers and of local women and men on the production of value added products of cassava, embarked by NRCRI, is another milestone – leading to capacity building for cassava development in Nigeria.

Finally, the improvement of cassava varieties of diverse architecture and the wide adaptation encouraged further cultivation of cassava in areas that traditionally do not produce cassava. Cassava can now be grown also in some Northern states in Nigeria. This development has brought cassava cultivation to about 28 states out of the 36 states in Nigeria, thereby stimulating the expansion of cassava cultivation in Nigeria.

The importance of the application of science and technology to crop development is evident in Nigeria in the case of cassava development and improvement. For instance, Nigeria ranked fourth in cassava production in the World after Brazil, Zaire, and Indonesia in the 18th Century and the later part of the 19th Century (Eke-Okoro. and Njoku, 2012). However, the advances in cassava improvement and development in Nigeria which gave rise to improved varieties, that are high yielding and resistant to cassava pests and diseases, resulted in Nigeria being the World leader in cassava production till date.

## 4 Processing of Cassava in Nigeria

The importance of cassava processing is brought to fore in Table 5. The Table shows that about 77 million tons of cassava were processed and exported as dried cassava between 2000 and 2013 globally. This represented less than 3% of the 3,086.000 million tons of cassava that were produced during the period (FAOSTAT, 2017). The importance of processing of farm products before they can access international markets is evident. FAOSTAT (2017) reveals that while about 77 million tons of dried cassava was exported, only 0.92 million tons were exported as fresh cassava globally between 2000 and 2013. This suggests that an increase in the value addition of cassava can enhance the quantity of the cassava products that can be marketed internationally.

Out of the 77 million tons of dried cassava that were exported globally between 2000 and 2013, Thailand, Vietnam and Indonesia exported about 57 million, 15 million and 2 million tons respectively, while Nigeria did not export any dried cassava during the period. This indicates that Thailand, Vietnam and Indonesia exported 74%, 19% and 3% of the global dried cassava export. Angelucci (2013) has reported that apart from Thailand, Vietnam is also a major player in dried cassava export as it exported a major share of global dried cassava annually. Thailand, due its highly developed processing industry, is the leading world exporter of dried cassava chips which are mainly shipped to Europe and China as an ingredient for animal feed (Meridian Institute, 2009).

Table 5 also reveals that 24.02 million tons of cassava starch were exported between 2000 and 2013 globally. The greatest share of the starch export came from Thailand, Vietnam and Indonesia which supplied 20.03, 2.00 and 0.56 million tons of cassava starch respectively. This implies that Thailand, Vietnam and Indonesia supplied 83%, 8%, and 2% of the global starch export respectively. Ghana exported only 1,666 tons of cassava starch during the period, while Nigeria did not export any cassava starch during the period. It implies that Nigeria did not benefit from the 7,930 million US Dollars which accrued from the export of cassava starch globally. Thailand, being the largest exporter of industrial cassava products, is the world market price setter (Asante-Pok. 2013). Asante-Pok (2013) reported that Thailand and Vietnam dominate the cassava starch market, with Thailand controlling most of the market, but Vietnam is slowly gaining a foothold. According to Asante-Pok (2013), the chips production remains the easiest entry point into the cassava global value chain. China, which uses cassava chips as ethanol feedstock, is the most important global market for chips, where they are used as ethanol feedstock (Tijaja, 2010). A closer examination of the business of exporting cassava chips reveals that the viability of this venture is constrained in Nigeria by the fact that cassava is a local main staple compared to other major exporters of cassava chips, such as Thailand, where the commodity is not a major staple (IFAD and FAO, 2004).

**Table 5: Cassava and Starch Export from the Major Cassava Producing Countries (2000-2013)**

| | World | Nigeria | Ghana | Tanzania | Indonesia | Thailand | Brazil | Vietnam | Costa Rica |
|---|---|---|---|---|---|---|---|---|---|
| Cassava Dried Export (tons) | 76645743 | - | 19922 | 10479 | 1942455 | 57098797 | 4763 | 14636348 | 200140 |
| Cassava Dried Export Value (m$) | 11311.31 | - | 12.24 | 0.88 | 275.85 | 7894.01 | 3.62 | 2383.53 | 140.49 |
| Cassava Starch Export (tons) | 24019780 | - | 1666 | 3101 | 556851 | 20026919 | 154828 | 2002973 | 20 |
| Cassava Starch Export (m$) | 7929.85 | - | 0.59 | 0.29 | 177.27 | 6411.65 | 71.90 | 735.77 | 0.02 |

**Source**: Computed from FAOSTAT (2017).

In Nigeria generally, most of the products are not processed for export[8]. However, the product should be processed for export so that the country can access foreign exchange for the country development. Processing of cassava products will not only promote the export of cassava products but will also reduce post-harvest

[8] Table 1 suggests that cassava in Nigeria is a non-traded commodity. However, available literature (although limited) indicates a well-established informal export market (particularly towards neighbouring countries, such as Mali, Burkina Faso, Cameroon, and Benin (Asante-Pok, 2013).

losses estimated at 28% along the value chain in Nigeria (FAO, 2006), and will improve the value of cassava products even for home consumption[9].

Cassava roots are typically processed for human and industrial consumption. There are numerous uses of cassava in human consumption and industries. *Gari*, a roasted granule, is the dominant product and is widely accepted in both rural and urban areas. *Fufu* and *Akpu*, a fermented wet paste from cassava, are also widely consumed throughout the country, especially in the southern zones. Most processors however complain that the wet paste and ready-to-eat forms of *fufu,* that are currently sold, have a very short shelf life. Estimates of industrial cassava use suggested that approximately 16 percent of the cassava root production was utilized as an industrial raw material in Nigeria. Then, 10 percent was used as chips in animal feed, 5 percent was processed into a syrup concentrate for soft drinks, and less than 1 percent was processed into high quality cassava flour which is used in biscuits and confectionary, dextrin pre-gelled starch for adhesives, starch and hydrolysates for pharmaceuticals, and seasonings (IFAD and FAO, 2004).

Cassava-processing operations in Nigeria can be described at five levels of capacity. They are household (or cottage), micro, small, medium, and large. Household level processing typically does not employ any outside labour. The household consumes virtually all the processed products and sells a small amount to raise income for additional household needs. At present, most Nigerian processors fall within this category. At the micro-processing capacity, the employment of one or two units of labour may take place, while processing in such ventures a variety of cassava products. This enterprise typically uses "batch processing". Batch processing may take four hours per day and this would be sufficient for the owner/operator. Nigeria has a few cassava processors in this category of operation. The small and medium processing operations typically employ three to ten workers and are very sparse at present. Large scale cassava-processing is virtually nonexistent in Nigeria (IFAD and FAO, 2004)[10]. Large-scale operations are defined as enterprises employing 10-30 or more labourers. Large-scale operations would also have the capacity for large tonnage processing with wider marketing opportunities. It is safe to say that medium to large scale cassava-processing equipment and fabricators of this equipment are few in Nigeria. *Gari* is the only product being

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[9] The EU has allocated a quota of 145,000 tons of dried roots per year to the World Trade Organization (WTO) members, excluding China, Indonesia and Thailand. This quota has never been reached (FAO, 2006).

[10] In Nigeria, cassava can be processed as dried cassava, pasty products, and granulated products. In the case of fermented dried cassava, the fermentation is achieved in one of two ways: stacking in heaps or soaking in water for some days. The fermentation process, whether in water or in heaps, influences the taste of the final product. The longer the fermentation period, the stronger is the sour taste. Taste is an important attribute, especially for consumers who eat fermented cassava products and who desire the strong sour taste.

currently able to push the industry from a traditional to a semi-mechanized process (IITA, 2007). It has already been mentioned that very few large-scale plants are in operation today. This was not the case in the past years. In the late 1990s medium to large processing facilities were operating, many as starch manufacturers. However, many of these facilities have closed, because they were working at low and seasonal capacities[11]

The need for innovative cassava processing technologies is enormous. Traditional cassava processing has some undesirable attributes. It is time-consuming, provides low yields, and often lacks storage capacities. Many – considering cassava processing as unattractive - describe it as drudgery. In a typical village, *fufu* processors cultivate cassava in family lots to process *fufu* for weekly market days. Time is spent peeling roots, washing, soaking, wet sieving, and copiously adding water before pressing. *Fufu* processing requires no less than 14 steps. On sale day, time would be spent grating and bagging. Women typically carry out 70 percent of the work, such as: planting, weeding, harvesting, transporting cassava, peeling, soaking, bagging, and selling. The men carry out approximately 30 percent of the work, such as: land preparation, harvesting, transporting, and grating (IFAD and FAO, 2004)[12]. To prepare *gari*, fresh cassava roots are peeled, washed and grated. The resulting pulp is put in a porous sack and weighted down with a heavy object for three to four days to express effluent from the pulp while it is fermenting. The de-watered and fermented lump of pulp is pulverized and sieved, and the resulting semi-dry fine pulp is toasted in a pan. The grating, effluent expressing, pulverization, toasting, and the addition of palm oil are adequate to reduce cyanogen to a safe level (Hahn, 1989).

At the rural level, processors have demonstrated their ability to adopt low-tech and low-cost improvements to processing.[13] their ability to adopt low-tech, low

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[11]Peak Products Nigeria Limited is an example of a company that could adjust under adverse circumstances and thus remained in operation. Peak Products Nigeria Limited began cassava processing in 1998 with the sun drying of cassava flour. The flour was sold to bakeries and confectionaries through the Ogun State Agricultural Development Programme (Agro Processing Unit). However, some processors began to contaminate fermented cassava flour with unfermented cassava, and by 1999-2000 the flour bakeries and the confectionaries stopped asking for and using cassava flour. This forced Peak Products Nigeria Limited to shift to the production of sun dried cassava starch.

[12] The recent introduction of a tool like the grater has eliminated stacking and fermentation and therefore this tool saves time. The roots are simply peeled, washed and grated. The pulp is placed in a perforated container, covered, and put on it for about three hours, and the cyanogen are squeezed out along with effluent. The half-dried pulp is then dried in the sun to prepare cassava flour.

[13] A project sponsored by the Department of International Development (DFID), United Kingdom and now the European Union (EU) in cooperation with the Natural Resources Institute (NRI), University of Greenwich (www.nri.org) and the University of Agriculture

cost improvements to processing. There are three common types of mechanized cassava processing machines in use in Nigeria: graters, pressers, and mills. The mechanized graters were first introduced to the Republic of Benin by the French in the 1930s, and later they were modified in Nigeria in the 1940s by welders and mechanics, using local materials such as old automobile motors and scrap metal. Village entrepreneurs, who provide a grating service to farmers, own the mechanized graters. The mechanized grater operators allow the farmers flexibility in terms of working time and quantity of cassava grated. The fee charged is a small fraction of the cost of grating by hand. The commercial *gari* processors use the mechanized grater. The use of a mechanized grater has reduced gari processing costs by 50 percent, and dramatically has increased the profitability of gari production with the TMS varieties in Nigeria (Nweke et al, 2001; FAO, 2006). The mechanized presser is a simple hand-operated machine, which is made from wooden plates and used automobile jack, both of which are available in the villages. In Nigeria, mechanized graters and pressers are often both operated and maintained by the same village entrepreneurs in major areas of commercial cassava production. This enables farmers to have access to grating, pressing, pulverizing, and sieving services in a convenient location. Mechanized pressing reduces the processing time from several days to a few hours[14]. The traditional method of preparing cassava flour from dried cassava roots in Nigeria is to pound the cassava in mortar with a pestle. Today, mechanized mills are available to pound the cassava to any desired level in processing cassava to any desired products needed by the consumers. The components of the mechanized mill are also fabricated locally from scrap materials. A processing technology has also been developed for village level production of dried *fufu* flour using a simple drier that can operate in areas with or without electricity. The fabrication of user-friendly equipment for cassava-processing in Nigeria is also witnessing renewed interest. Since 1970, the Federal Institute of Industrial Research Oshodi (FIIRO) has provided a processing plant for the mechanization of cassava gari. National, regional and private fabricating centres have also demonstrated new processing equipment such as mobile graters,

Abeokuta (UNAAB) on the commercialization of traditionally processed products from cassava, such as *wet fufu and dried fufu*, has proven to be a successful initiative in South West Nigeria. This initiative has the potential to offer new opportunities to rural households – either through the sale of fresh roots or through processing and marketing. Several options exist for the commercialization of *fufu*, including the production of a shelf-stable product.

[14] Fermentation imparts a sour taste, which is cherished by consumers in some places, such as in South West Nigeria. Fermentation is not essential for the elimination of cyanogen in the preparation of gari because grating, pressing, pulverization, sieving, and toasting steps reduce the cyanogen in cassava to such a low level that gari is safe for human consumption.

modified fryers, dryers, and millers. Data on the adoption rate of this equipment, however, remains scarce[15].

The combined effects of the Presidential Initiatives on Cassava (PIC) in Nigeria, the policy plans, and some IITA-led projects jump-started the establishment of several medium-scale cassava processing enterprises between 2005 and 2008. By 2009, the number of companies and entrepreneurs that had invested in flash dryers for high-quality cassava flour (HQCF) or starch production had increased to 140–150, from a mere 6 in the year 2000 (Abass et al., 2016). Nearly 95% of the enterprises were for HQCF processing, with additional facilities for making traditional products such as gari and fufu. Cassava machinery and flour processing equipment were adopted by development agencies, NGOs, and research centres to increase household food security, to reduce food and raw material imports, and to extend market options for smallholder farmers (Abass et al., 2001)[16].

Research has been conducted on the engineering and mechanization aspects of the cassava flour–making process, especially on the design, scale-up potential, and functionality of processing equipment (IITA, 2006, Sanni et al., 2006). The efficiency of cassava grating has been improved; raising from a capacity of 0.30–0.50 tons fresh root/hour to 2.0–3.0 tons fresh root/hour. The efficiency of hammer milling has also been improved, from 0.25 to 0.40 metric tons flour/hour to 5.0 tons flour/hour (Abass et al., 2011). Mechanical cassava peeling, which did not exist at all, was developed to ease the process of making cassava flour. Peelers were developed with 0.6–0.8 tons fresh root/hour capacity (60–90% peel removal), as well as 8 tons (fresh root/day capacity twin basket) hydraulic presses for removing water from grated cassava roots and 4 tons (flour/day capacity) pneumatic dryers. Although many early designs of locally produced pneumatic dryers were inefficient in terms of energy consumption and/or product quality, this newly designed dryer is well-suited for drying cassava flour (Ove and Sardo, 2001).

Ehinmowo and Fatuase (2016) studied the extent of adoption of the improved cassava processing technologies by entrepreneurs in Nigeria. Among the technologies adopted, cassava mechanical graters were mostly utilized by the entrepreneurs (mean score of 154) compared to the traditional way of grating. Without

[15] Other processing research initiatives currently underway include: developing a thin-skinned cassava that would remain unpeeled, dried and used in poultry animal feeds. By leaving the thin skin on it increases the conversion rate but also increases the fibre content of the feed. Use of a yellow cassava in poultry feed is also being investigated as a positive contributor to making yolks more yellow and higher in nutrition.

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grating cassava (grinding of cassava into mash) in the production process, the different forms of processed output (gari, fufu, akpu, starch, etc.) from cassava cannot be achieved. The next most adopted cassava processing technology was the hydraulic press (mean score of 137). The peeler was the least technology adopted (mean score of 7), because it is necessary for the entrepreneurs to understand the technicality involved as well as the efficiency of the peeler when compared to the traditional knives used.

## 5 Integrating the Cassava Value Chain in Nigeria

Studies have shown that cassava has the potential to industrialize Nigeria more than any other product if the potential is properly harnessed (Coulibaly et al., 2014). Awoyinka (2009) affirmed years ago that Nigeria can earn about US$5 billion per annum from cassava and its by-products, making it a key foreign exchange earner, an instrument for job creation, and a catalyst for development. However, some improvements are needed for the cassava sub-sector to increase its contribution to human well-being. These improvements are anchored in value chain development. In the agricultural sector in general, the value-chain framework has been conceived as one of the strategies to bring more efficiency (Kumar et al., 2011).

Various key components (factors) are applicable to the understanding of the Nigerian cassava value chain in the consumption market (McNulty and Oparinde, 2015). Most important, the supply chain structure involves the interactions between smallholders (who are the major producers of cassava in the country), transporters, middlemen, processors, traders, and actors from other services sectors (as consumers' infrastructural constraints, such as access to market information, to roads, etc. are important and need to be overcome). These components (factors) are influenced by the nature of the governance structure, which in turn explains the nature of the value chain[17]. To promote the cassava sector, it is necessary to look carefully at the whole cassava value chain to identify room for improvements and for innovations.

Although preferences for different cassava products vary across Nigerian states and even from village to village, *gari* is overall the most popular cassava product. *Gari*, *fufu*, and *lafun* are especially valued by urban Nigerians for their

[17] The critical input suppliers for cassava cultivation are the farmers, the international research institutions (such as IITA/International Institute of Tropical Agriculture or CIAT/Centro Internacional de Agricultura Tropical), the Agricultural Development Programmes (ADPs), and the Roots and Tubers Expansion Programme (RTEP). They all provide stem cuttings: the most significant input after labour (Oguntade, 2013).

convenience and ease of storage[18]. Other high valued products made from cassava are High-Quality Cassava Flour (HQCF), starch, and ethanol. After being processed in village homes or in processing centres, the gari is loaded into 25-kg sacks and is then transported to the local market. Cassava farmers sell 10–40 sacks per week on average, adjusting their production level according to demand. Ninety percent of this gari is bought by traders, who are mostly women, and who bring the gari to urban markets. At the market, gari retailers purchase the product and sell it to the end consumer. *Fufu* and *lafun* have value chains very similar to that of *gari*, except that they require additional processing, which is usually done at the village or at processing centre level (Kambewa and Nyembe, 2008).

The High-Quality Cassava Flour (HQCF)[19] value chain is particularly different from the gari value chain, notably due to the inclusion of service millers that indirectly supply the product to urban markets. The HQCF value chain is nascent, fragmented, and informal. Farmers harvesting cassava can choose to sell to “garri ladies” (or “bread ladies”; these are local women who process tubers into traditional foods) or to industrial processors. This decision is taken at the time of harvest, typically without long-term contracts. After harvesting, tubers are transported to the processor in trucks. Cassava tubers must be processed within 72 hours of harvesting due to rapid fermentation that may affect the quality of flour derived from cassava. As a result, harvesting typically only occurs once a guaranteed buyer is identified. This precaution helps to avoid food loss during transportation. Upon arrival at the HQCF processing facility, the roots are weighted, and their starch content is measured. After processing, the HQCF is bagged and sent to the customers (mainly confectionery producers). End markets are concentrated in the South of Nigeria, in and around the major cities of Lagos, Ibadan and Abuja (Oguntade, 2013).

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[18] Cassava cultivation is dominated by smallholder farmers and household members who are engaged in both upstream (production) and downstream (homestead processing and marketing) activities. Different levels of processing can be observed. These include “homestead processing” by farmers’ wives, “commercial processing” by women who buy tubers for processing and selling in product form, and “toll processing” in which specialised professionals provide peeling, milling (grating), pressing, and frying services. There are also some industrial processors who buy cassava on a large scale for processing into High Quality Cassava Flour (HQCF), starch, ethanol, and other derivatives for use in other industries, as well as using it for gari, fufu, and lafun for the domestic market. Between these actors there are middlemen and women who perform various marketing functions (Oguntade, 2013).

[19] HQCF is used as a substitute for wheat flour in bakery and pasta products. Only a 10 percent substitution can be made without consumers noticing a difference in taste or other qualities, while substituting more than 50 percent of HQCF for wheat flour will result in brittleness in the products (McNulty and Oparinde, 2015). However, the higher the quality of the cassava flour, the more substitutable it becomes (Ferris et al., 2002).

Cassava starch is one of the best fermentable substances to produce ethanol[20]. The technology of producing ethanol from starch is internationally well-developed (Kuiper et al., 2007). After harvesting, the roots are chopped into chips and transported to drying floors. The roots are usually dried in the sun. Once the chips are dried, they can be stored for months. However, during storage, the starch yields decrease somewhat, depending on the storage temperature: typically, a 5% reduction of starch yield will occur in 8 months storage time (Abera and Rakshitl, 2004). Another advantage of using chips as intermediate products is the easy way of transportation. The ethanol production process consists of three basic steps, namely: Milling and liquefaction (this process breaks down starch molecules into its building block molecules: glucose); fermentation (this process converts glucose to ethanol); and purification (this process separates ethanol from other reaction products and inert materials).

Cassava starch is an important domestic and industrial raw material being used in the manufacture of various products, including food, adhesives, thickening agents, paper, and pharmaceuticals (IITA, 1992). It has many remarkable characteristics, including high paste viscosity, high paste clarity, and high freeze-thaw stability, which are advantageous to many industries. Cassava has been used as source of starch for decades. Cassava is high in starch content (70 – 85%, dry base / 28 – 35% wet base), and the starch from cassava is of a high quality compared to other starch sources. Cassava starch is used as a raw material in many industries, among which are to be mentioned the paper-, food- and textile industries. Cassava starch may be produced from fresh roots, by grating the roots, mixing the material with water, followed by sedimentation and sun-drying or by conductive heating.

Figure 1 summarizes the cassava value chain in Nigeria. The figure indicates the operators and the products at each stage of the value chain. It also shows links between the operators across the stages. The critical input suppliers for cassava cultivation are farmers, international research institutions (such as IITA or CIAT), Agricultural Development Programmes (ADPs), and the Roots and Tubers Expansion Programme (RTEP). They all provide stem cuttings: the most significant input after labour (Oguntade, 2013). As shown in the figure, the end products of cassava transformation in Nigeria are gari, lafun, fufu, composite flour, textiles, starch, glucose syrup, medicines, livestock feed, and alcohol. These products emanate from both traditional and industrial processing in the cassava value chain. For example, in the figure we can see fresh cassava tubers passing through the

[20] Currently sugar cane is the most widely used crop for bio-ethanol in the Tropics, but sugar cane requires a lot of water. Consequently, sites suitable for sugar cane growing are very limited (Kuiper et al., 2007). A much large area in the Tropics is available and suitable for cassava. Because of the high starch content cassava is a high yielding ethanol crop. However, a distinction needs to be made between yields from dried cassava chips and from fresh cassava roots.

marketing and processing stages and reaching households as gari. In the same token, we can see fresh cassava tubers passing through the marketing and processing stages and reaching industry as starch. The figure also shows the links in the value chain for end products such as lafun[21], fufu, composite flour, glucose syrup and alcohol, and for end users such as in textiles, medical services, and livestock feed industries. The figure 1 also shows that innovations along the whole value chain need to consider all the linkages, stages and interactions to be effective and comprehensive.

Oguntade (2013) studied economic losses along the cassava value chain in Nigeria. He assessed the cassava farmers' losses in the value chain. He revealed that the most significant losses occurred during harvesting, estimated at 4.95% of the total harvest, followed by losses occurring during storage of the finished product (1.94%), and losses occurring due to the small size of the cassava tubers (1.93%)[22]. Working on the gari processors' assessment of losses during their operations, he showed that losses resulting from the discard of small cassava tubers were estimated at 5.8% of the cassava being processed. This is followed by losses resulting from the discard of woody tubers, which were estimated at 4.1%. Losses during transportation of cassava tubers were said to amount to 2.2% of the cassava processed. Losses during the processing of the finished product were 1.6%, while losses during storage of the finished product were 1.11% (Oguntade, 2013). The starch processors' assessment of losses in their operations showed that a 5.5 % loss occurred during processing of cassava, and a 6.3 % loss occurred during storage of starch. The gari marketers' assessment of losses in their operations indicated that moisture was the most significant cause of gari loss during storage, accounting for losses of about 4.5%. Losses during transportation and losses during

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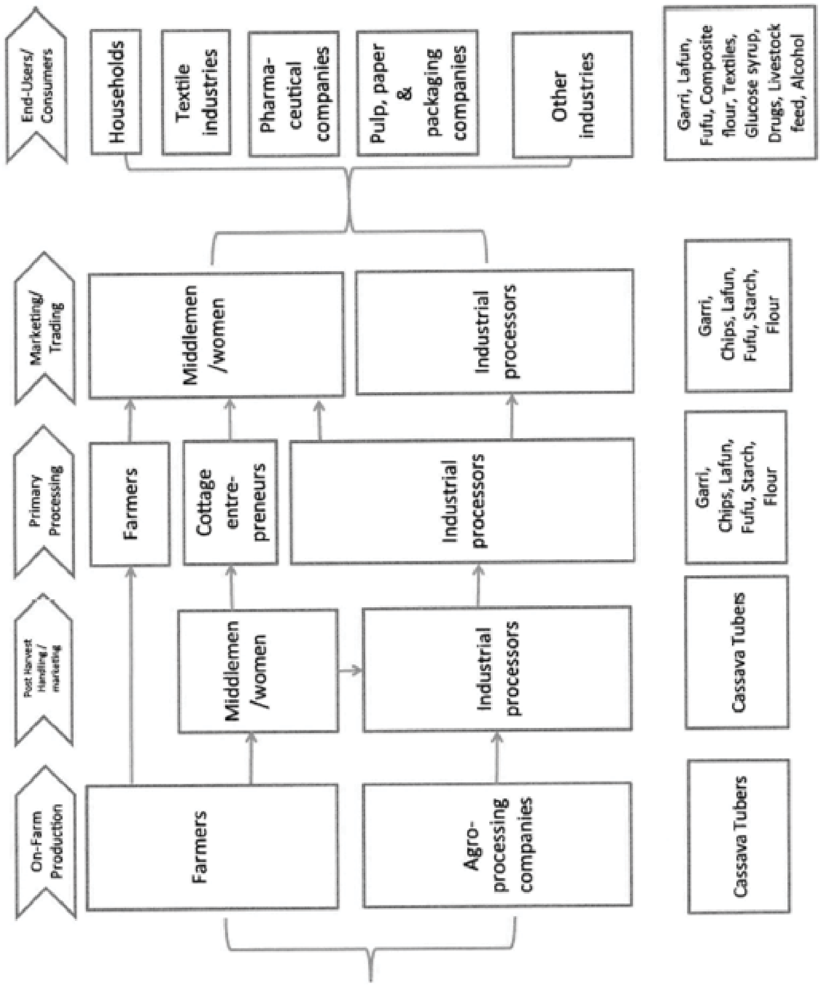
[21] Lafun is a fibrous powdery form of cassava; it is a similar product as fufu in Nigeria (Wikipedia).

[22] Losses during harvest are usually the result of the soil structure (cassava tuber may be difficult to uproot from clay soil, and this may result in damage to the tuber), of the season (when soil is dried it is difficult to pull cassava tuber out, and this may result in damage to the tuber), or of the harvester's skill level and equipment. The damaged roots either remain under the soil or are left on the farm by the harvester. Digging out tubers with machetes can also damage the tubers if not done skill-fully. It is for these reasons that losses during harvesting recorded the highest percentage in the survey. Losses also occur due to the small size of tubers. When cassava tubers are too small, they are difficult to peel. The very small ones are left on the farms after harvesting or discarded during peeling. When cassava is left on the field for too long, it can become woody. The woody parts of the tubers are discarded during peeling or processing. Farmers tend to keep cassava standing in the field as a form of storage, especially when prices are too low. Some of them experience losses during the transportation of tubers to the processing centres and during the transportation of gari back to their houses. Some losses are also recorded by farmers during storage of gari at home.

storage due to rodent pests were each estimated at 2.5%. All these figures indicate that there is considerable room for innovations - by new technologies, by adjusted products, and by organizational and marketing adaptations.

**Figure 1: Cassava Value Chain Diagram**




**Source**: Oguntade 2013

Oguntade (2013) also estimated losses in the cassava value chain in monetary terms. He demonstrated that the total losses at the farm gate in the cassava value chain accounted for 8.51% of the total harvest. The total loss of fresh cassava tubers during processing amounted for 12.1% of the total harvest. The loss during transportation was put at 8.47% of the total harvest. This suggests that the total cassava tuber loss along the value chain amounted to 29.18% of the total harvest. This implies that 29.18% of 54.80 million tonnes of total cassava produced in Nigeria in 2014 (see Table 2) were lost in the value chain. This means that 15.99 million tonnes of cassava were lost in 2014. If the quantity is valued at ₦ 10, 000 per ton (used by Oguntade 2013), and if this price is maintained as the selling price, this translated into a ₦ 159.91 billion or a 522 million US dollars loss in 2014.

Value chain actors do not coordinate well, and there is a lack of trust among them. Most sellers operate at the margin, and there is room to improve cost efficiency. Poorly coordinated and inconsistent government policies regarding import substitution and support of the cassava industry have impacted unfavourably on cassava prices and have driven investors away. The government policy of 10 percent HQCF substitution in bread has been poorly enforced and has resulted in a collapsed demand for HQCF.

The government policy has since been revised to a 5 percent substitution share, but enforcement is still an issue. High-quality cassava has the potential to earn a premium, but there is no grading system in place. Loans for inputs or technological advancement are difficult to obtain and have stiflingly high interest rates. Innovation in the marketing chain is uncommon, as entrepreneurial spirits are quickly crushed by scarcity of capital, high transport costs, and lack of market information flows. Investors in the sector are discouraged by high operation costs due to poor infrastructure, inadequate energy supply, difficult bureaucracy, and sub-optimal telecommunication facilities. Therefore, a huge number of factors needs to be considered when asking for a better integration and for an improvement of the cassava value chain.

## 6 The Importance of Bio-Fortification of Cassava and Its Acceptability in Nigeria

Frequently, consumers of cassava are at a greater risk of malnutrition - especially deficiencies in Vitamin A, iron, and zinc - than consumers of other diets, particularly those that are cereal-based (Fregene et al., 2010). A nutrition survey in cassava-consuming areas of Nigeria revealed inadequate Vitamin A and iron intake in 83% and 78% of the pre-school-aged children respectively (Gegios 2010). Vitamin-A deficiency causes a loss of 964,000 Disability-Adjusted Life Years

(DALYs)[23] in Nigeria annually; iron deficiency causes a loss of 596,000 DALYs in Nigeria (Fiedler, 2009). According to the World Health Organisation (WHO), an estimated 250,000 to 500,000 Vitamin A-Deficient (VAD) children become blind annually, with half of them dying within 12 months of losing their sight in Nigeria. And in pregnant women Vitamin A-Deficiency (VAD) causes night blindness and may increase the risk of maternal mortality. About 20 percent of the pregnant women and 30 percent of the children under five in Nigeria suffer from VAD. Current efforts to combat micronutrient deficiencies in Africa include supplementation, distribution of micronutrients to high-risk populations, addition to processed food, and bio-fortification, i.e. the genetic improvement of nutrient content of crops via field-based breeding or genetic engineering[24]. Bio-fortification, on the other hand, can achieve 100% penetration and, although it requires a substantial initial investment in research and dissemination, it is self-sustaining. Cost per DALY saved for bio-fortification is 20% less compared to supplementation (Nestel, 2006).

Bio-Cassava Plus (BC+) is a cassava-bio-fortification project funded by the Bill and Melinda Gates Foundation. BC+ scientists are engineering cassava for increased accumulation of β-carotene[25], iron, and protein to provide minimum daily allowances of these essential nutrients as a means of ameliorating the burden of malnutrition that accompanies consumption of cassava as a staple food. Proof of concept for the enrichment of these nutrients has been demonstrated in the model cassava cultivar 60444, which, in greenhouse and confined field trials in Puerto Rico, contains up to 40 μg/g dry weight (DW) of β-carotene (provitamin A), 40 μg/g dry weight of iron, 10% protein storage roots, and reduced levels of anti-nutritional cyanogens (Fregene et al, 2010).

In addition to the consumer benefit of improved nutrient levels, BC+ β-carotene rich GM events also have produced benefits in terms of extended shelf-life. Five of the events with the highest amounts of total carotenoids could be stored for up to 28 days after harvest, whereas the wild-type recorded up to 80% spoilage after 7 days. Reduced shelf-life of cassava roots, a result of Post-harvest Physiological Deterioration (PPD), is a major limitation to marketing of fresh roots. PPD begins 24 hours after harvest and can render the roots unpalatable and unmarketable within 72 hours. Short shelf-life affects cassava value-added chains because

[23] A measure of overall disease burden, expressed as the number of years lost due to ill-health, disability, or early death.
[24] Supplementation requires tremendous efforts to exceed the 90% coverage and must be sustained for many years (Berti and Rowley, 2001); few countries in Africa are able to run effective supplementation programmes.
[25] Beta-carotene is a powerful antioxidant, important in preventing certain cancers and slowing the progression of eye cataracts, among other health benefits.

it increases losses during processing and limits access to markets distant from production sites. Longer shelf-life was correlated with total carotenoid content ($r^2$ = 0.80) in the GM events[26], which is consistent with previous studies which are indicating that high levels of carotenoids in the roots (> 8 ppm fresh weight basis) delay PPD (Sanchez, 2005).

BC+ has achieved nutrient-enrichment of cassava such that if a 5-year-old child consumes 100 g/day of roots from the β-carotene, iron, or protein-rich GM events, (s)he will obtain 100% of the minimum daily allowance (MDA) of these nutrients. BC+ has, therefore, embarked on the expression of genes (for the above mentioned nutritional traits) in farmer-preferred cassava varieties in Nigeria (Fregene et al., 2010). Genetic transformations at the Donald Danforth Plant Science Center (DDPSC) have successfully generated transgenic lines of Oko-Iyawo, the most popular Nigerian variety of cassava, currently grown on 22 to 24% of the total acreage (about 4 million hectares of land) in Nigeria. Based on ex-ante impact studies for nutrient deficiency in Nigeria, a β-carotene- and iron-enriched Oko-Iyawo for Nigeria, and a β-carotene-, iron- and protein-enriched, and virus-resistant Oko-Iyawo imply successes for consumers and producers. Oko-Iyawo is resistant to the cassava mosaic disease (CMD), which is of viral origin and which is the principal production constraint of cassava in Africa.

An *ex-ante* socio-economic impact of BC+ was commissioned by the Bill and Melinda Gates Foundation and was conducted by Harvest Plus[27], a bio-fortification initiative of the Consultative Group on International Agricultural Research (CGIAR)[28]. The study established a baseline of DALYs lost, estimated the cost of development, and the rate of adoption of BC+ products, and presented a comprehensive economic impact analysis of BC+ products (Fiedler, 2009). This resultant cost-effectiveness analysis was expressed in terms of cost per DALY saved, a benefit-cost ratio, and an internal rate of return estimate. A cost per DALY saved of less than $248 is considered “very cost-effective” (Berti and Rowley, 2001); a benefit-cost ratio greater than 1.0 is considered as an attractive investment, and the higher the internal rate of return is the better is the outcome. The cost of developing and disseminating a BC+ product is estimated at $41.35 million over 30 years, broken down into four phases of $13.48 million (basic research, applied research, capacity building), $8.49 million (applied research, product development, regulatory approval, capacity building), $16.35 million (regulatory approval, release pro-

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[26] A genetically modified organism (GMO) and all subsequent identical clones resulting from a transformation process are called collectively a transformation event (WIKIPEDIA).

[27] See: http://www.harvestplus.org/

[28] See: http://www.cgiar.org/

motion, technology diffusion), and \$3.02 million (promotion, technology diffusion, monitoring and supervision, maintenance) (Fiedler, 2009). Although these costs are high, they are justified when considering the DALYs lost due to micronutrient deficiencies; each year's losses of DALYs due to deficiencies in Vitamin-A, zinc, and iron amass to 2.3 million in Nigeria. The study revealed that BC+ cassava varieties will be readily adopted by African farmers, achieving adoption rates of 20% in Nigeria. This, in turn, will lead to consumption rates of 67% in Nigeria. Well over half of these consumers live in rural areas. Accounting for these production and consumption adoption/acceptance rates and noting that the new cassava varieties have increased levels of iron (457%) and β-carotene (3,000%), when compared to wild types, the DALYs saved were projected at 617,000 in Nigeria (with bio-fortified cassava accepted). These numbers were then used to calculate the cost-effectiveness of the project, incorporating pessimistic and optimistic parameters. For the pessimistic model, the cost per DALY saved is \$57, the benefit-cost ratio is 18, and the internal rate of return is 24%. In the optimistic model, the results are \$33, 31, and 32%, respectively (Fiedler, 2009). In either model, the study suggests that bio-fortification is a cost-effective approach to reducing Nigeria's micronutrient deficiencies and the corresponding health problems.

Cost-effective strategies for farmer adoption and consumer acceptance of β-carotene and iron-rich cassava do entail a marketing and promotion plan. For example, *gari* is the most important food staple of the rural and urban poor and the gari market chains have extensive coverage; over 70% of cassava grown in Nigeria is used for gari production. A great advantage is that the deep yellow colour of high-β-carotene and high-iron-content cassava is similar the yellow gari product, made by addition of palm oil, and is already accepted by consumers. Although gari processing tends to lead to a depletion of β-carotene and iron, levels of nutrient-enrichment achieved in BC+ ensure that sufficient amounts of these nutrients remain to meet minimum daily allowances, based on the average quantity consumed and the bio-availability (Fregene et al., 2010).

In 2011, the bio-fortification crop delivery programme started with stem multiplication in ten Local Government Areas (LGAs) in each of the following four States; Oyo in the West, Imo in the East, Akwa Ibom in the South, and Benue in the North. In 2012, the programme expanded to six villages in each LGA, making a total of 60 villages per State and 240 villages in the four targeted States. The programme rolled out to 18 more States between 2013 and 2015, thus covering over 60% of all the States in the country and over 80% of the major cassava-producing States even though the level of coverage differs from one State to the other. The total land area under commercial stem multiplication and tuber production grew from 88 hectares in 2011 to 6,950 hectares in 2015 (HarvestPlus, 2015).[29]

[29] See: http://www.harvestplus.org/

Stem multiplication by the public sector dominated the early years, while commercial stem multiplication started very slowly in 2011 and picked up rapidly from 2014 onwards. Having "primed-the-pump" by initiating production of a substantial supply of pro-Vitamin A cassava, the expectation is that a burgeoning demand for yellow cassava will motivate future supplies. Commercial stem production is expected to account for over 90% of total stem supply by 2018 (Ilona et al., 2017). As of December 2015, HarvestPlus and its partners have cumulatively delivered over 2 million bundles of stems of BC+ cassava varieties to Nigerian farmers (Oparinde et al., 2016). Delivery channels have included direct distribution of free bundles of stems to smallholder farmers, farmer to farmer distribution, plus further informal diffusion, and direct marketing by commercial producers.

In the past, several improved cassava varieties have been introduced to farmers since the 1990s; but, their adoption rates are generally low (Oparinde et al., 2016). However, in the case of bio-fortified cassava, consumer marketing using print, television, and radio media were used extensively to communicate the importance of Vitamin A-cassava to consumers to create demand, and to investors to increase the product supply. For example, in a single village in Oyo State, the number of women processing Vitamin A-cassava into gari increased from 5 in 2014 to 35 women in 2016, following an increase in consumer demand for this product that resulted from a radio programme 'Sagbedoro'.[30] The radio programme was broadcast for 13 weeks by the Federal Radio Corporation of Nigeria (FRCN) and focussed on the importance of consuming more nutritious foods. Jingles were developed and translated into five local languages for creating awareness on radio and television prior to stem distribution. Overall, the frequency of jingle broadcast was higher for radio than for television because radio has a wider reach and is a primary source of information for rural households. However, the estimated number of people reached was highest for television compared with other media channels. This is attributed to the broadcast of the award winning *Yellow Cassava* and *Dada Oni Paki* movies.[31] Based on the data provided by the Federal Radio Corporation of Nigeria (FRCN) on the number of listeners and by the Cable Television (DSTV/Multichoice) on the number of viewers, it is estimated that over 50 million Nigerians have been informed (Oparinde et al., 2016). It is estimated that in each of the villages where Vitamin A-cassava varieties are currently being multiplied, at least 50% of households have already received infor-

[30] See: https://twitter.com/search?q=%23sagbedoro

[31] See: http://www.harvestplus.org/knowledge-market/in-the-news/nollywood-premieres-star-studded-movies-improve-nutrition-across and http://www.ifpri.org/news-release/nollywood-premieres-star-studded-movies-improve-nutrition-across-nigeria and http://sociablesusan.blogspot.de/2015/07/new-yoruba-movie-dada-oni-paki.html

mation on the importance of bio-fortification. “Farmer to farmer” information dissemination, field days, and radio jingles have all helped to increase awareness in non-target villages.

Phorbee et al. (2013) have shown that *Gari* from bio-fortified cassava roots, when processed traditionally, had appreciable bio-available beta-carotene, which can contribute to the fight against VAD and will improve the nutritional status in developing countries. They, however, concluded that the magnitude of VAD needed requires a combination of strategies, of which bio-fortification is just one. A consumer acceptance study conducted in 2011 in two Nigerian States revealed that, if delivered together with nutrition information, bio-fortified varieties were generally preferred both after sensory evaluations of taste, appearance and texture, and in terms of consumers’ willingness to pay (Oparinde et al., 2016)[32]. The traditional palm oil-mixed gari was preferred to that made from Vitamin A-cassava in Imo State, while gari made from a lighter coloured Vitamin A-cassava variety was preferred in Oyo State, where white gari is traditionally consumed (Oparinde et al., 2016). Phorbee et al. (2015) assessed the acceptability of bio-fortified cassava by consumers in Nigeria. Bio-fortified cassava was processed into Gari and assessed for consumer acceptability. Questionnaires on socio-demography and consumers’ preference were administered to 518 regular consumers of gari in Lagos state, Nigeria. A nine-point hedonic scale[33] was used to assess consumers’ preference for the Gari samples, prepared in form of *eba* (cassava porridge)[34] on some selected sensory parameters. The participants of the assessment by using *eba* which were selected cut across all ages, sex and occupation. Over 86% of the consumers liked the *eba* made from bio-fortified cassava in terms of all the selected sensory parameters and overall acceptability. They also expressed their willingness to plant, to use, and to consume bio-fortified cassava if available. Phorbee et al. (2015) concluded from their study that cassava bio-fortification seems a technically, economically and sustainably promising approach to control micronutrient deficiencies and to complement other intervention strategies.

[32] Dr. Akinwunmi Adesina, who was the Minister of Agriculture until May 2015 and is now the President of the African Development Bank (AfDB), played a major role as a key supporter of bio-fortification in Nigeria. Similarly, Minister of Health Onyebuchi Chukwu made it possible for bio-fortification to be recognized in the health sector as a potent strategy to improve nutrition. The inclusion of bio-fortified foods in the Micronutrient Deficiency Control (MNDC) guideline, which was ratified by the Senate Committee on Health in 2014, gave additional political momentum to bio-fortification in Nigeria.

[33] See: https://www.sensorysociety.org/knowledge/sspwiki/Pages/The%209-point%20Hedonic%20Scale.aspx

[34] See: http://www.allnigerianrecipes.com/fufu-recipes/garri-eba.html

## 7 The Limits of Agricultural Innovations in Cassava

Agricultural development in Nigeria is replete with examples of well-intended scientific advances that have had limited impact because they were not sustainably adopted by producers and consumers (Oparinde et al., 2016). For instance, numerous public-sector agencies were established in Nigeria in the 1970s and 1980s to develop and to diffuse mechanized cassava-processing machines. However, farmers have not adopted the machines developed by the government agencies because these machines are not as convenient and reliable as those developed by the small-scale private artisans (FAO, 2006). Important lessons for mechanization of food processing in Africa emerge from the analysis of the evolution of mechanized cassava-processing methods. Mechanization of food processing must be for products that have a market demand such as *gari.* Since most villages in Nigeria do not have electricity and as petroleum fuel is scarce and expensive, mechanized machines should be small and easy to fabricate and to repair by village artisans, using local materials such as old engines and scrap metals. Machines that are manually driven are more suitable for remote villages provided they can be fabricated and maintained by village artisans using local materials (FAO, 2006).

A cassava bio-fortification breakthrough has been criticised by Friends of the Earth Nigeria (FoEN), which told the International Institute of Tropical Agriculture (IITA) research team in Ibadan to stop meddling with one of Nigeria's key food crops, arguing that they were undermining biodiversity (Uchendu, 2013). Activists with the environmental group also say that two carrots can easily provide the daily Vitamin A-requirement. The opposition to dissemination and adoption of β-carotene- and iron-enriched cassava can be overcome through demonstration of the benefits to consumers (improved nutritional quality) and to producers/processors (extended shelf-life of storage roots). Other elements for countering such opposition include: adhering strictly to bio-safety protocols and regulatory requirements; being transparent by engaging key stakeholders in constant dialogue to communicate progress; and building confidence that the process is being properly and responsibly run. Other efforts include the publication of studies to address the issues of safety and product quality, and setting up local product-development committees to design and to implement communication and issue-management strategies (Fregene et al., 2010).

The Nigerian government policy of 10% cassava flour in bread, biscuits and other confectioneries could help to sustain the production of cassava and to restrict fund overflow for wheat importation (Adeniji, 2013)[35]. The simple and appropriate technology now exists for the application of cassava flour as a potential replacement for wheat flour in bread-making biscuits, pastries, and snack foods. In Africa, the amount of cassava used for food manufacture by the food industries is insignificant. For example, in Nigeria, in the late 1990s, an insignificant 3 tons of cassava was used per year for food manufacture compared with maize, using of it 133,000 tons (Onabolu et al., 1998). Use of cassava as a partial substitute for wheat in food manufacture will increase if the practice can result in a reduction in the prices of the manufactured composite cassava and wheat flour food products compared with the prices of the same products made with 100 percent wheat flour (Ukpabi, 2006). Unavailability of locally fabricated equipment is one of the factors militating against the commercial production of cassava flour in Nigeria, which consequently affects commercial composite bread-making wheat-cassava flour. Importation of the equipment may outweigh the savings in imported wheat flour, hence ruling out any justification for such an approach (Adeniji, 2013). Defloor (2005) also reported that getting quality cassava flour that will meet the need of the flour mills has remained a problem due to poor processing methods, varietal age, and environmental growth conditions of cassava.

## 8 Conclusions and Policy Recommendations

Cassava is a crop whose by-products have a wide array of uses; cassava is the most important food crop in Nigeria not only by production quantity but also because of its ability to reduce food insecurity with an associated implication on poverty reduction in Nigeria. However, cassava production in Nigeria is losing its production competitiveness due to declined production and productivity over time. Most of the cassava produced in Nigeria is not being processed to high value products. This limits the income-generating ability of cassava. Lack of value addition along the value chain also limits cassava marketability and its exportation in the international market. Some recommendations can be made to address the limiting factors that are confronting cassava, and to increase its productivity and marketability in Nigeria.

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[35] The promulgation into law, effective 1st July, 2006, of the mandatory inclusion of 10% cassava flour in bread produced in Nigeria is an important initiative towards cassava industrialization (Adeniji, 2013). Part of the policy included the implementation of a zero-import duty on cassava-processing facilities, implementation of a 65% and a 15% levy on wheat flour and wheat grain, respectively. In addition, bakeries that attain a 40% blending of cassava flour in bread-making would be granted a corporate tax incentive of a 12% rebate; and there is also the prohibition of cassava flour importation to further support the programme (GAIN, 2012).

Nigeria should ensure that productivity of cassava is increased in Nigeria through well-targeted input and credit subsidy programmes directed to the farmers. This will enable the farmers not only to purchase improved cassava stem (rather than replanting the old stem) and farm technologies that will enhance their yield. Extension arms of ministries of agriculture should be strengthened and empowered to rigorously disseminate information about improved cassava varieties that are high-yielding and disease-resistant. It has been pointed out that if fortified cassava is well introduced to the farmers with its nutritional benefits, many farmers will adopt it and many consumers will buy it.

Nigeria's cassava can retain its competitive edge only through investments in labour-saving production, harvesting and processing technologies. Therefore, engineers and breeders should join forces and figure out how to mechanize the peeling task by developing cassava roots that are uniform in shape and size and having skins that meet certain specifications. New technology is needed to reduce the amount of labour in the toasting stage of *gari* preparation. Harvesting machines should be designed to reduce the cost and time of harvesting, being the highest cost of production of cassava[36].

Plant-breeding will need to continue to produce high-yielding and competitive Vitamin A cassava varieties that address current challenges in the value chain. Increased participation of the private sector in stem production, processing and marketing should be strengthened by HarvestPlus and delivery partners for long term sustainability. Increased product diversification (products beyond gari and fufu) will broaden market opportunities and will sustain private sector interest in the bio-fortified food sector. HarvestPlus needs to strengthen its advocacy role in a broader sense to ensure more effective integration of bio-fortification into national agriculture and health programmes backed by policies.

Proper coordination of cassava value chain development and strategies is urgently needed in Nigeria. This will eliminate duplication of efforts by all the stakeholders involved in cassava value chain activities in Nigeria. The cassava value chain stakeholders should make efforts to strengthen the weak linkages among the stakeholders. The revenue generated from the increased levy on wheat flour imports[37] should be released and used to strengthen the weak aspects of the cassava value chain in Nigeria.

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[36] Harvesting represents 28% of the cost of production of cassava, while weeding which is the next most important activity in cassava production represents only 15% (Nweke et al., 2001).

[37] To reduce wheat imports, to stimulate local wheat and cassava production, and also to conserve foreign exchange, the Federal Government of Nigeria (FGN) has introduced a policy of compelling cassava flour inclusion in wheat flour and has also imposed an import tax (levy) of 15 percent on wheat grain (which has increased the effective duty from 5 percent to 20 percent).

Finally, there should be more uses to which cassava can be put into in Nigeria. For example, a poultry feed trial has shown that if cassava roots and leaves were combined in a ratio of four to one, the mixture could replace maize in poultry feed and reduce feed cost without a loss in weight gain or egg production (Tewe and Bokanga, 2001). If this important research finding is diffused and adopted by farmers and livestock feed producers, the amount of cassava used in livestock feed in Nigeria would increase. At present, cassava leaves have no market value except in countries such as the Congo and Tanzania where the leaves are consumed as a vegetable (FAO, 2006).

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## Annex Tables

**Annex 1: Cassava Production Contribution to World Production (%) by Major World Cassava Producers**

| Year | Nigeria | Indonesia | Brazil | Thailand | Ghana | Congo | Angola | Tanzania | Sub-Total | World |
|---|---|---|---|---|---|---|---|---|---|---|
| 2000 | 18 | 9 | 13 | 11 | 5 | 5 | 3 | 3 | 67 | 100 |
| 2001 | 18 | 9 | 12 | 10 | 5 | 5 | 3 | 3 | 65 | 100 |
| 2002 | 19 | 9 | 13 | 9 | 5 | 5 | 4 | 3 | 67 | 100 |
| 2003 | 19 | 10 | 11 | 10 | 5 | 5 | 4 | 2 | 66 | 100 |
| 2004 | 19 | 10 | 12 | 11 | 5 | 5 | 4 | 2 | 68 | 100 |
| 2005 | 20 | 9 | 13 | 8 | 5 | 5 | 4 | 3 | 67 | 100 |
| 2006 | 20 | 9 | 12 | 10 | 4 | 5 | 4 | 3 | 67 | 100 |
| 2007 | 19 | 9 | 12 | 12 | 4 | 5 | 4 | 2 | 67 | 100 |
| 2008 | 19 | 9 | 11 | 11 | 5 | 5 | 4 | 2 | 66 | 100 |
| 2009 | 16 | 9 | 10 | 13 | 5 | 5 | 5 | 3 | 66 | 100 |
| 2010 | 17 | 10 | 10 | 9 | 6 | 5 | 6 | 2 | 65 | 100 |
| 2011 | 18 | 9 | 10 | 9 | 6 | 5 | 6 | 2 | 65 | 100 |
| 2012 | 20 | 9 | 9 | 12 | 6 | 5 | 4 | 2 | 67 | 100 |
| 2013 | 18 | 9 | 8 | 11 | 6 | 5 | 6 | 2 | 65 | 100 |
| 2014 | 20 | 9 | 9 | 11 | 6 | 5 | 3 | 2 | 65 | 100 |
| Average | 19 | 9 | 11 | 10 | 5 | 5 | 4 | 2 | 65 | 100 |

**Source**: Computed from FAOSTAT (2017)

**Annex 2: Labour Productivity (kilogramme per capita) of Cassava and Some Food Crops in Nigeria**

| Year | Cassava | Yam | Maize | Rice |
|---|---|---|---|---|
| 1961-1970 | 197 | 156 | 7 | 6 |
| 1971-1980 | 204 | 134 | 4 | 10 |
| 1981-1990 | 213 | 106 | 6 | 28 |
| 1991-2000 | 416 | 307 | 7 | 42 |
| 2001-2010 | 462 | 372 | 7 | 41 |
| 2011-2014 | 538 | 394 | 8 | 58 |
| Average | 316 | 228 | 6 | 28 |
| Growth Rate (%) | 23.27 | 25.03 | 7.15 | 45.66 |

**Source**: Computed from FAOSTAT (2017)

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In this volume a new approach is envisaged. Based on Africa's deep routed structural problems the base for a transformative STI policy is to link the STI policies to Africa's economic transformation agenda. To address these complex issues, in a first part the general issues of introducing effective STI policies are presented, based on visions, strategic plans and the whole project cycle of implementation. In a second part country case studies highlight the new approach. Cases such as Sudan and Nigeria are analysed, as these two countries have a long experience of STI development; because of different history, size and structure they need to move in different directions towards a coherent STI policy for inclusive growth.

Complementary to Volume 20 is Volume 21 with the title "Science, Technology and Innovation Policies for Inclusive Growth in Africa - Human Skills Development and Country Cases". In the first part the role of human skills development for capacity building in STI is discussed. This is based on examples from Cameroon, Nigeria and Mauritania. In the second part the STI policies of North African countries (Egypt and Tunisia) are evaluated, to assess how they can be directed towards economic transformation and inclusive growth.

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