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Sudan's Challenges and Opportunities: A Renaissance Project for Sudan:

From Poor Agriculture to Agro-Industrial Growth and Sustainable Development

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ECONOMIC RESEARCH FORUM

منتدى البحوث الاقتصادية

Foreword

The ongoing social contestation movements in the Arab world, coming on the heels of the uprisings of 2011, the health and economic crises engendered by the Covid-19 global pandemic, and now the recent far reaching consequences of the war on Ukraine have rekindled hope that the region is again on the cusp of change. While fueled by social and economic grievances, demonstrators have been calling for political change. The challenges they face in shaping a credible political posture that can deliver a better future are enormous. In Algeria, Iraq, Lebanon, and Sudan social movements have learned from the disappointing outcomes of 2011. But unlike in 2011, they face extremely difficult economic situations, as well as regional and international opposition to change.

Against this background, ERF has launched a project that aims to empower civil society groups that are at the heart of the ongoing social movements in Sudan with the intellectual prowess to start moving from opposition to vision, and from slogans to programs: by engaging in debates on solutions that can work; envisioning the contours of a better future; reflecting on how to get there; and bargaining more effectively with political elites in the shaping of a more progressive social contract.

The main objective of this initiative is to strengthen the new social movements in Lebanon, Iraq, Algeria and Sudan by offering them an analysis of the economic, political and social conditions that could preside over a change in governance and a transformation of the practices of civility.

In Sudan, the government's response to the deteriorating economic conditions ignited deep-seated popular anger as Sudan's youth and citizens watched the unfolding 'Arab Spring'. In December 2018, youth movements took to the streets. The protests continued despite the government's ruthless suppression, and culminated in a popular uprising that ended up toppling al-Bashir's kleyptocratic regime, which ruled Sudan for 30 years. This is not the first time a popular uprising has resulted in ousting an authoritarian government in Sudan. However, the cumulative impact of failed transitions had their toll on the country's state institutions and economic development.

Change in Sudan is imbued with challenges. It is still not clear whether the ruling elites would rely on an inherently faulty approach to nation-state building, democratic governance and economic development, or – in line with the hopes of new change agents – adopt new, creative, people-led approaches. The main question then is whether the country is on the verge of a new, meaningful change, or whether the old patterns will reproduce themselves. The most recent setback due to the attempted coup and the massive popular rejection triggered by it makes this question all the more compelling for assessing the future direction of the country.

This report will focus on a Renaissance project for Sudan, and what are the best ways of taking advantage of Sudan's comparative advantage in agriculture, to move from poor agriculture to agro-Industrial growth and sustainable development. Agriculture is the backbone of the Sudan's economy and crucial for the country's exports and food security.

Foreword

The sector is not only the main source of livelihood for the majority of population, but it is also the main employer of skilled labor. Indeed, the vast agricultural potential of Sudan qualifies the country to become an agricultural powerhouse for the Arab world and Africa. However, the sector remains backward, and beset with low productivity, weak linkages to modern agro-industry, while most of the farming community continues to languish in poverty and poor access to basic services. No doubt, the initial conditions of the sector are quite dire. Notwithstanding more than six decades of several economic development plans and public policy initiatives, all centered around transforming agriculture, the country's vast agricultural potential is far from being realized.

Therefore, this reports argues that modernizing agriculture must be the centerpiece of any serious transformational project for the Sudanese economy. In this context the report presents an agricultural development strategy that combines inclusive agricultural production, tight linkages to industry, and strategies to rapidly improve productivity over time through education, new technologies, and investments in infrastructure. To achieve the envisaged development program would aim to bring about profound structural transformations in the Sudanese economy, with which it is possible to initiate rapid, sustainable and broad-based growth to provide job opportunities for youth, combat poverty and make major strides toward achieving the SDGs.

The report falls into four parts. Part 1 contains a preliminary analysis of the aggregate and sectoral value-added in Sudanese agriculture as well as the assessment of the determinants of conditional convergence of agricultural value-added by estimating an empirical agricultural growth model, using global data covering more than 120 countries. In this context, the report compares and contrasts agricultural VA in Sudan to other comparators and analyze factors associated with three pillars of productivity: policies and institution (macroeconomic environment, pricing policies …etc.); inputs and capital base of agricultural supply (fertilizers, road infrastructure, finance); human capital and empowerment. Part 2 provides detailed SWOT (strength, weakness, opportunities and threats) analysis of the three main agricultural sub-sectors (traditional rain-fed, non-gum Arabic field crops and gum Arabic; semi-mechanized; and irrigated). Building upon the SWOT analysis of the sector and the factors shaping its VA, Parts III-V address the challenging question as to how to achieve the overarching objective of "transforming Sudanese agriculture". Part 3 considers the role of institutions and empowerment of rural communities through establishing robust agricultural commodities development council, agricultural research system, seed industry, and farmers' cooperatives. Part 4 discusses the critical need to invest in agricultural supply for effecting the much-needed transformation, including by mainstreaming fertilizers use; expanding irrigation systems and renewable energy; and, considering the impending digital revolution, incrementally embracing adoption of technology and precision agriculture. Part 5, proposes a new business model for transforming agriculture by making the sector looking more like industry. The proposed business model is built around agro-industrial Growth Corridors and private sector-led contractual agriculture. Finally, Part 6 presents the key elements of the envisaged strategy for transforming Sudanese agriculture.

Foreword

I would like to take this opportunity to thank Prof. Ishac Diwan, who managed the entire 'Hirak' project for the four countries, including Sudan, and the authors of the report. I am grateful to all other contributors, reviewers and discussants for patiently working through a number of revisions of the chapters to bring them to their current form. This research offers important insights on the strategy for developing Sudanese agriculture and will, I hope, ultimately contribute to shaping informed debates and policies in Sudan. Finally, I am grateful to the Canadian International Development Research Centre (IDRC) for its financial and intellectual support for the production of this important report and the other eight papers on Sudan covering political transitions, state economic capacity, health, education, environment, youth and gender issues.

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Managing Director

Acronyms & Abbreviations

ARC	Agricultural Research Corporation
ARRC	Animal Resources Research Corporation
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
ASSCO	Arab Sudanese Seed Company
CBOs	Community-Based Organizations
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	International Center for Maize and Wheat Improvement
COMESA	Common Market for Eastern and Southern Africa
CPA	Comprehensive Peace Agreement
DLRC	Dryland Research Center
FAO	Food and Agriculture Organization
FNC	Forest National Corporation
GAPA	Gum Arabic Producers Associations
GDP	Gross Domestic Product
GIS	Geographic Information Systems
KSC	Kenana Sugarcane Company
HACCP	Hazard Analysis Critical Control Point
HCENR	Higher Council for Environment and Natural Resources
HRS	Hydrology Research Station (HRS)
ICARDA	International Center for Agricultural Research in the Dry Areas
ICRISAT	International Center for Research in the Semi-arid Tropics
ICT	Information and communications technology
IFAD	International Fund for Agricultural Development
IITA	International Institute for Tropical Agriculture
IPGRI	International Plant Genetic Resources Institute
ISNAR	International Service for National Agricultural Research
MARF	Ministry of Animal Resources and Fisheries
MFNE	Ministry of Finance and National Economy
MOA	Ministry of Agriculture
MOASK	Ministry of Agriculture South Kordofan
MOU	Memorandum of Understanding
NAPA	National Adaptation Plan of Action
NARS	National Agricultural Research System
NFRC	National Food Research Center
NLC	National Land Commission
O&M	Operation & Maintenance
RFEDT	Rainfed Farming Extension Department Team
SMA	Sudanese Meteorological Authority
SMRF	Semi-mechanized rainfed farming
TAP	Technology Action Plan for Adaptation
TCR	Technical Component Research
TFC-RFR	Transitional Facilitation Commission for Rainfed Farming Reform
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
WBG	World Bank Group
WSARP	Western Sudan Agricultural Research Project

I. Introduction and Background

Agriculture is the backbone of the Sudanese economy, and it is crucial for the country's food security. Between 1960 and 2020, agriculture ranked second to services in terms of contribution to real gross domestic product (GDP), with each adding, respectively 35.2 percent and 48.7 percent. Recently, however, it generated 47.4 percent of employment, with 69 percent of own-account businesses operating in the sector.[1] Accordingly, the sector is not only the main source of livelihood for the majority of the population, but it is also the main employer of skilled labor. Around 35.7 percent of skilled workers reported operating in the agricultural sector in 2014 compared to 11 percent operating in the services sector.

Sudan's agriculture is distinguished by three crop production systems: the irrigated, mechanized rainfed, and traditional rainfed farming systems. The rainfed farming system, or dryland agriculture, includes both the traditional rainfed and mechanized rainfed subsectors, and it remains the key priority sector in the growth and poverty reduction agenda of Sudan. As seen in Table 1, dryland farming occupies around 88 percent of the national cultivated area and contributes around 75 percent to national food grains production (Osman, 2017). Furthermore, more than two-thirds of the population are engaged in or depend on dryland farming as the main economic activity and source of income and food. The productivity of the main food and cash crops in the three crop production systems is very low compared to regional, international, and national research standards (Crop Assessment Mission 2020; Osman and Ali, 2010).

In addition to the diversity of the crop production systems, Sudanese agriculture is also characterized by three diverse livestock production systems (Faisal and Khair, 2018), namely:

- *Nomadic system (Pastoral):* Characterized by high mobility and depend solely on their livestock for their livelihoods and migrate in search of water and fodder. Camels are the main livestock species, with considerable numbers of desert sheep and some goats. Holds about 16 percent of the total national livestock population (around 116 million heads).
- *Transhumant system (Ago-pastoral):* Characterized by seasonal migration routes during the rainy season following well-defined traditional grazing routes to utilize seasonal grazing opportunities in the drier regions. This system is mainly adopted by cattle-owning tribes (Baggara) who – in addition to cattle – raise considerable numbers of sheep and goats. This system is interspersed with crop production along the route. Cropping activities play a relatively minor yet important role in the system. It holds approximately 60 percent of the total livestock population.
- *Sedentary Systems:* The agriculture component is dominated by cropping activities based on traditional rainfed cultivation. Livestock and crops are integrated in different proportions. Sheep, goats, and (sometimes) cattle are used for meat and milk production and as a monetary cushion for households in the event of crop failure. These systems own 20-30 percent of the livestock population.

Crop and livestock production take place under diverse soil types (ranging from very light sandy soils to heavy cracking clays), diverse agro-climatic zones (vary from the desert region of the north to the sub-humid of the south, Table 2), producing a wide variety of crops (cereals, oilseed, legumes, industrial, fodders, and horticultural crops) and a variety of livestock species (cattle, sheep, goats, camels, donkeys, and horses). Crop and livestock production systems are interrelated through food, feed, investment, manure, fodder, labor, and transportation linkages.

Sudanese agriculture has been identified as one of the sectors most vulnerable to climate change (Sudan's first NCCC). In addition, the global adaptation index (ND-GAIN, 2015) indicated that Sudan is among the most vulnerable countries to climate change, ranking 175th out of 181 countries. Crop and livestock production is predicted to decline substantially, with adverse impacts on both local incomes and food security. Within Sudan, the traditional rainfed sector is the most vulnerable to climate change, as demonstrated by the fact that livelihood sources (livestock and crop production) are entirely dependent on rainfall and 12 states out of the country's 18 states are fully located on drylands, i.e., depending entirely on rainfall for their livelihood. Non-climatic factors that aggravate this high vulnerability include high poverty levels, low levels of infrastructural development, limited use of agricultural inputs, technology, and market, deterioration of natural resources, and conflict and civil unrest.

Despite all the aforementioned diversities in Sudanese agriculture, the huge resource potentials, and the strategic location of the country, Sudan has failed to achieve its long-awaited dream of becoming the major "breadbasket of the world." Important manifestations of

[1] Figures are obtained from the Sudan Poverty and Households Budget Survey (2014/2015).

Table 1: Average share of the different farming sectors in national cultivated areas and food grains production

Production System	Area (Million Hectares)	Share of Cultivated Land (%)	Contribution to Main Food Crops (%)			Overall Contribution of Main Food Crops
			Wheat	Sorghum	Millet	
Irrigated	2	12	100	23	1	25
Mechanized Rainfed	6	35	0	38	5	20
Traditional Rainfed	9	53	0	39	94	55
Total	17	100	100	100	100	100

Source: (Department of Statistics, Planning & Agriculture. Economics, Ministry of Agriculture & Forestry, 2014)

Table 2. Agro-climatic zones of Sudan: General characteristics and occupying land area

Agro-ecological zone	Annual rainfall (mm)	Humid months (#)	Growing season length (days)	Area (%)
Desert	<100	≤1	≤30	34
Semi-desert	100-250	1-2	30-60	21
Arid	250-350	2-3	60-75	10
Semi-arid				
Semi-arid (a)	350-450	3-4	75-90	13
Semi-arid (b)	450-750	3-4	90-120	14
Sub-humid	≤750	4-5	≤120	8

Source: adopted from: Osman, A.K.2015.

this failure include, but are not limited to:

- Low value addition by the sector, including the challenges of missing key markets.
- Rural exodus to the urban centers, namely Khartoum, to the rush to gold mine fields and immigrations to other countries.
- Decline of productivity of land and labor.
- Deterioration of social services, namely health and education.
- Deterioration of infrastructure.

The main reason behind the dismal performance of the agricultural sector is the low priority that has been assigned to agriculture for decades in the allocation of resources. Recognizing the neglect of agriculture in their countries as the main reason behind the prevalence of poverty and food insecurity, the African heads of state issued the Maputo Declaration in 2008, according to which each country committed itself to allocating at least 10 percent of its public expenditure to agriculture. According to the Ministry of Finance and National Planning, public investment in agriculture and related sectors accounted for one percent of GDP during 2012-2014. If expenditure on related sectors is excluded, the share of agriculture in public investment is estimated at 0.3 percent. Therefore, a substantial increase of public expenditure on agriculture and ago-industries is required, at least for the next two decades, to turn agriculture into an important engine of growth.

Although the Sudanese agricultural sector is home to more than 60 percent of the population and the source of almost all non-oil and mineral exports, it remains backward and beset with low productivity with weak linkages to the modern agro-industry, while most of the farming community continues to languish in poverty and poor access to basic services. The initial conditions of the sector are undoubtedly quite dire. Notwithstanding more than six decades of several economic development plans and public policy initiatives all centered around transforming agriculture, the country's vast agricultural potential is far from being realized. Therefore, modernizing agriculture must be the centerpiece of any serious transformational project for the Sudanese economy.

This report, therefore, would argue for a model that combines inclusive agricultural production, tight linkages to industry, and strategies to rapidly improve productivity over time through education, new technologies, and investments in infrastructure. Achieving the envisaged development program would aim to bring about profound structural transformations in the Sudanese economy, with which it is possible to initiate rapid, sustainable, and broad-based growth to provide job opportunities for youth, combat poverty, and make major strides toward achieving the sustainable development goals (SDGs). This calls for attracting institutional and private investments to develop the infrastructure and manufacture Sudan's raw products and thus maximize the added value of exports and establish growth poles around productive cities as platforms for the meat and leather, horticulture, and manufacturing industries in the sectors of gum arabic, oilseeds and other food industries. This strategy hinges on the three main comparative advantages of the Sudanese economy: a young labor force, with more than 67 percent of the population below 30 years of age; a diversified agricultural sector; and a favorable geographical location, where the Sudanese coast could be developed and transformed into a regional trading and industrial hub linked to other regions in the country as well as neighboring countries through a network of interstate railways and highways.

Against this backdrop, we first ask a fundamental question as to what went wrong with the Sudanese agricultural development model. The Sudanese agricultural development plans have basically followed a 'top-down' model, almost solely driven by the public sector. Like many African governments, under these plans, the public sector undertook the responsibilities of funding and managing agricultural research and extension, importing and distributing subsidized fertilizers, allocating lands for large-scale mechanized agriculture, providing farm credits and price stabilization funds, supporting the formation of agricultural cooperatives, investing in infrastructure, and supporting agro-based industrialization. Despite the good intentions, this unfettered, all-encompassing agenda has placed a rather heavy burden on a public sector that has been systematically degraded over the last 30 years of the 'Ingaz' regime.[2] Perhaps the most challenging task has been effective coordination across the wide myriad of policies and institutions involved. For example, access to cheap land for mechanized agriculture provided incentives for land-intensive, large-scale farming by well-connected entrepreneurs, but limited the use of biological technology, leading to poor productivity and long-term damage to the environment. Furthermore, the lack of collateral and land registry for most farmers meant that most of the agricultural credits provided by the Sudan Agricultural Bank and other private lending institutions went to big urban capitalists, who dominate the large-scale, low-productivity mechanized farming.

Moreover, the agricultural development model has also been lopsided, with virtually all capital stock, agricultural technology, and extension concentrated in the irrigated sub-sector, leaving the vast rainfed agriculture at near subsistence levels of productivity. However, over the past 30 years of the Ingaz regime, the agricultural sector overall became capital-poor, where the infrastructure in the two million-plus acres Gezira scheme, among other irrigated farmlands, was run down or lost to shady privatization programs. Moreover, agriculture has been subjected to heavy taxation both at the sectoral and macroeconomic policy levels. The sector became the tax base of choice for the predatory practices of cash-poor states that were created under the new federal system since the early 1990s. Perhaps even more damaging to the sector were the macroeconomic policies that produced long episodes of hyperinflation during the early 1990s and, more recently, since the last two years of the former regime. Moreover, the competitiveness of the highly tradable agricultural sector has been severely damaged by the real exchange rate appreciation associated with the oil decade (2000-2011) and the subsequent gold boom.

The above critical assessment of the Sudanese agricultural development model is not meant to suggest that success requires less government; rather, it would require an intensive but selective government role. Moreover, for the state to be an effective 'developmental' state, it should also strive to be an effective 'regulatory' state. A competent regulatory state should be able to leverage the private sector as a complementary or leading actor in some activities along the value chain in the agricultural sector. In this context, we will argue in this report that the design of development plans for transforming Sudanese agriculture should be based on three guiding principles: (i) the implication for the role of the state from the insight of modern growth literature; (ii) the critical importance of empowering small farmers through the formation of cooperative and producers associations, access to basic services, and direct cash transfers; and (iii) the emerging new business models for commercializing agriculture as a means for enhancing productivity and forward linkages to agro-industries.

First, the insight from the modern growth literature about the process of catch-up growth in the economy at large, and the contrast between the growth processes of industry and agriculture. This literature suggests that poor countries with initially low productivity could grow faster and catch up with richer countries, provided that they adopt growth-promoting policies and build the right institutions to allow them to absorb knowledge and learn from the technological frontier. Therefore, the overall growth processes of countries are conditional on the capacity of these countries to build robust growth 'fundamentals.' Instead, recent empirical evidence suggests that productivity in manufacturing tends to converge unconditionally, regardless of the prevailing institutions or policy environment (Rodrik, 2011 and 2013). On the other hand, the agricultural growth process is actually divergent but, like countries, it tends to converge conditionally (Diwan et al., 2011). These contrasting processes between the two sectors might be explained by the different nature of the technology in the two sectors (more detailed discussion follows in Chapter III).

Rodrik disaggregates growth into two components: "fundamental" growth and structural transformation growth. He argues that fundamental growth is likely to take time because it is conditional upon building robust growth fundamentals. However, growth without such fundamentals is likely to be episodic and short-lived.

[2] The Arabic word "Ingaz" means "salvation." The "Ingaz Regime" was the name adopted by the leaders of the 30 June 1989 coup to justify their coup against the third Sudanese democratic government.

On the other hand, structural transformation growth could be engineered in relatively short order through a targeted industrial policy that allows for the transfer of labor and other factors of production from low to higher productivity sectors. The moral of this insight is that the strategy for developing agriculture should task the public sector with selectively building a few critical growth fundamentals that squarely fall within its competency, such as building competent public institutions for providing health and education services, collecting taxes, controlling inflation, and engineering competitive real exchange rates. Such focus on critical key areas would allow the public sector to also engineer some targeted vertical industrial policies for structural transformation growth. In this context, the public sector would build the agricultural research and extension capacity by investing in capital-intensive fertilizer and pesticides industries, irrigation systems, power generation…etc. However, with proper regulations, the private sector and cooperative associations could undertake key complementary functions, such as the distribution and marketing of seeds and fertilizers and the maintenance and management of secondary irrigation canals and facilities.

Second, the critical importance of agricultural development for empowering small farmers through cooperative associations and the provision of basic services and direct cash transfers. From a human development perspective, fighting rural poverty and making progress on other SDGs are important in their own right. Moreover, healthy and better-educated farmers are also more productive because they are more capable of absorbing new knowledge and technology. Also, better-organized farmers (through various kinds of associations) would facilitate their access to services and finance. Furthermore, well-connected small farmers are also more effective agents in the contest for public resources, which perhaps partly explains the limited public investment in the rainfed agricultural sub-sector, which is dominated by small and disarticulated farmers. Hence, although they account for most of the farming community, they have very little or no voice compared to the wealthier and better-organized farmers in the irrigated and mechanized subsectors.

As for direct cash transfers, especially through mobile money, evidence from recent experiences has shown that it promotes local development and financial inclusion. A policy study published by the Overseas Development Institute in 2016[3] analyzed the results of 165 studies covering 56 cash transfer programs in low- and middle-income countries and concluded that the majority of these studies reported that cash transfers contribute to achieving important development goals. For example, the results showed that cash transfers have strong positive effects on indicators that one might expect to see in the short or medium term, such as spending on food and other household needs, education, and health services. Moreover, cash transfers are shown to affect several of the SDGs in a coherent way simultaneously. For example, higher rates of child attendance in school are associated with lower incidences of child labor. In the Sudanese context, it should be noted that direct cash transfers can play the role of "economic insurance" for families in the event of disasters, such as the failure of the agricultural season, as it is well known that these families tend to make decisions that perpetuate the state of poverty inherited through generations, such as removing the girl or boy from school to work and help the family makes ends meet. There is also strong evidence that making cash transfers increases productive savings and investments. The results of these studies also show that cash transfers in Latin America and sub-Saharan Africa have strong positive effects on investment in livestock and agricultural inputs. Therefore, the frequent results of these studies indicate that cash transfers not only play an important role in reducing poverty by redistributing resources to the poor, but they can also support production in general and enhance the economic independence and self-sufficiency of vulnerable families.

Third, recent country experiences suggest that agriculture could be developed as an industry along with a variety of emerging business models for commercializing agriculture and strengthening forward linkages to agro-industries, such as building growth corridors centered around productive cities, contractual agriculture in the form of partnerships between farmers' associations and modern private sector entities, marketing boards…etc. (Diwan et al., 2019).

The rest of the report falls into four parts. Part 1 contains a preliminary analysis of the aggregate and sectoral value-added (VA) in Sudanese agriculture as well as an assessment of the determinants of conditional convergence of agricultural VA by estimating an empirical agricultural growth model using global data covering more than 120 countries. In this context, we compare and contrast agricultural VA in Sudan to other comparators and analyze factors associated with the three pillars of productivity as discussed above: policies and institution (macroeconomic environment, pricing policies…etc.); inputs and capital base of agricultural supply (fertilizers, road infrastructure, finance); and human capital and empowerment. Part 2 provides a detailed SWOT (strengths, weaknesses, opportunities, and threats) analysis of the three main

[3] https://www.odi.org/sites/odi.org.uk/files/resource-documents/10748.pdf

agricultural sub-sectors (traditional rainfed, non-gum arabic and gum arabic field crops; semi-mechanized; and irrigated). Building upon the SWOT analysis of the sector and the factors shaping its VA, parts 3 and 4 address the challenging question as to how to achieve the overarching objective of "transforming Sudanese agriculture." In Part 3, we consider the role of institutions and the empowerment of rural communities through the establishment of a robust agricultural commodity development council, an agricultural research system, a seed industry, and farmers' cooperatives. Part 4 discusses the critical need to invest in agricultural supply to drive the much-needed transformation by mainstreaming fertilizers use, expanding irrigation systems and renewable energy, and (considering the impending digital revolution) incrementally embracing the adoption of technology and precision agriculture. In Part 5, we propose a new business model for transforming agriculture by making the sector look more like an industry. The proposed business model is built around agro-industrial growth corridors and private sector-led contractual agriculture. Part 6 presents the key elements of the envisaged strategy for transforming Sudanese agriculture.

Part 1:
Agricultural Productivity in Sudan and other Comparator Countries

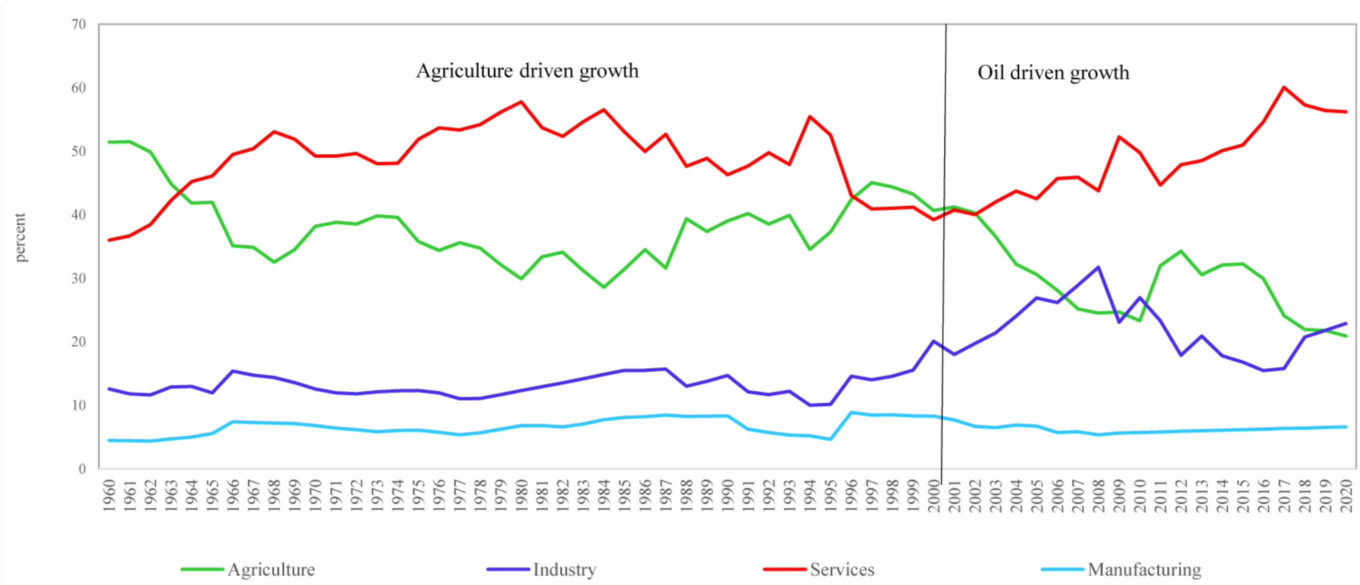
II. Value-added in Sudanese Agriculture

Between 1960 and 2020, the patterns of VA shares by major sectors in the GDP suggest that Sudan appears to have been caught in a premature deindustrialization process, where the share of services dominated that of agriculture and industry. The latter sector comprises larger scale agro-based manufacturing as well as medium- and small-scale edible oil, construction, leather tanning plants, and cottage industries (Figure 1). As seen in Figure 1, this process becomes prominent after the rise of petroleum in the economy during 2000-2011.

Table 3 compares the performance over the agricultural and oil eras. The average VA share of industry has increased by 8.9 percentage points. In addition, most of the change occurred in the VA for agriculture and manufacturing, which dropped by 8.2 and 0.4 percentage points on average, respectively. The growth of real VA in manufacturing, notwithstanding its small share in GDP, increased by about one percentage point, and is very stable as reflected by the very low coefficient of variation compared to the other sectors, which appears to be in line with the unconditional convergence that characterized manufacturing as an escalator for high and sustainable growth.

Despite the poor performance of agriculture in terms of contribution to real VA and economic growth, it generated the bulk of exports (mainly cotton, livestock, and oilseeds). Since its political independence in 1956, Sudan opted for bimodal peasant export agriculture as a main driver of real growth. Unlike the experiences of other peasant export-oriented agriculture in Africa, where the state generates rents from taxing the famers and marketing boards, Sudan continued the inherited irrigated Gezira project for cotton production, which is based on partnership with farmers, including the promotion of dry agriculture to stabilize food production and ensure a cheap rural labor supply for Gezira, (Abdelkarim, 1986).

Figure 1. Value-added shares by major sectors (percentage of GDP)



Source: Ministry of Finance and Economic Planning, Central Bank of Sudan and World Bank development indicators

*Table 3. Sectoral share in value-added (percent of GDP) **

	Agriculture	Manufacturing	Industry	Services
Period		**1960-2020**		
Mean (in percent)	35.2	6.5	16.1	48.7
Coefficient of variation	0.19	0.18	0.32	0.12
Period		**1960-1999 (the agricultural era)**		
Mean (in percent)	38.1	6.7	13.0	48.9
Coefficient of variation	0.15	0.20	0.12	0.11
Period		**2000-2020 (the oil era)**		
Mean (in percent)	29.9	6.3	21.9	48.2
Coefficient of variation	0.21	0.11	0.20	0.13
Sectoral growth of real value-added (in constant SDG)				
Period		**1960-2020**		
Mean (in percent)	2.8	5.2	5.8	4.5
Coefficient of variation	3.92	1.60	2.00	1.81
Period		**1960-1999 (the agricultural era)**		
Mean (in percent)	3.4	4.9	4.8	4.1
Coefficient of variation	3.38	2.04	1.66	1.66
Period		**2000-2020 (the oil era)**		
Mean (in percent)	1.6	5.8	7.7	5.2
Coefficient of variation	6.19	0.60	2.08	1.98

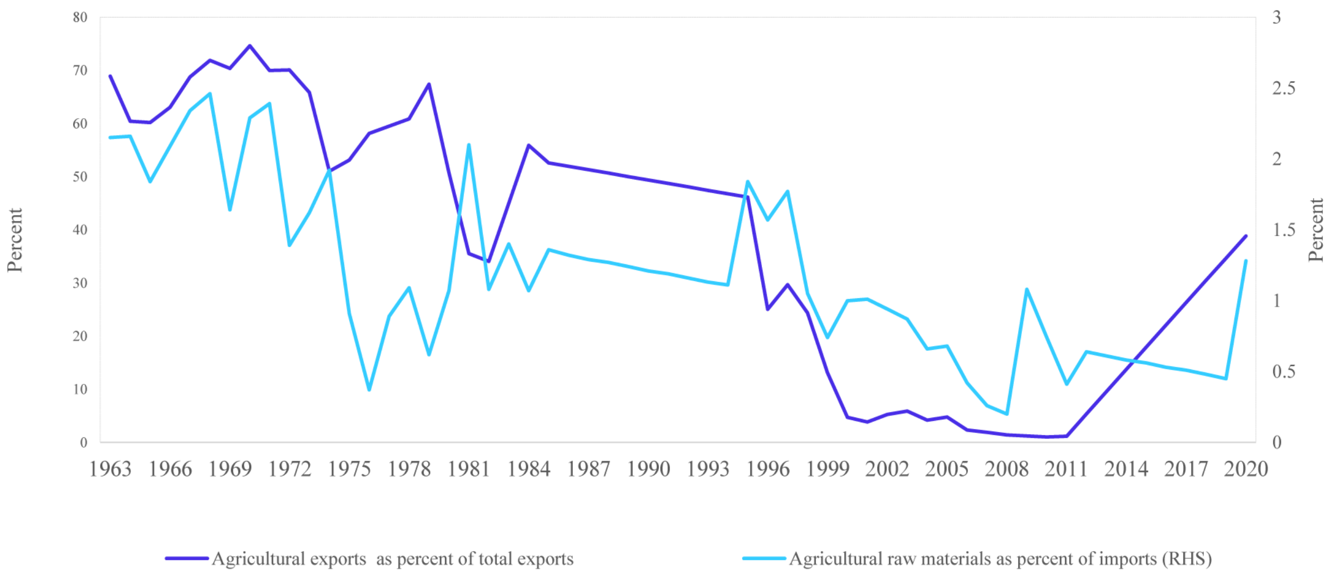
Note: Manufacturing is a sub-sector of industry; the remainder of the latter includes medium- and small-scale firms, the cottage industry, construction, public utilities, and oil.*

Interestingly, partnership in irrigated agriculture has a long history where it was introduced in the riverain northern part of Sudan as solution to the fertile lands subjected to heavy fragmentation due to the inheritance law. In dry agriculture, shifting cultivation and multi-plot systems are adopted as solutions to the vagaries of rainfall. During the colonial era, the Gezira project was institutionalized based on Al Gezira Ordinance 1925. In addition, the Dar system was introduced under the supervision of the 'Sheikh-Omda-Nazir' hierarchy to regulate land usage for shifting cultivation. Multi-plots and nomadic pastoralism were adopted as adaptation strategies by the communities in dry agriculture to reduce the risks of subsisting in rainfed lands prone to drought. It is noticeable that the decline of the share of agricultural exports began to set in after the prolonged drought of the mid-1980s – even before the advent of oil exports that boomed between 2000 and 2011 (see Figure 2).

The consequences of the drought were exacerbated by the expansion of semi-mechanized farming, especially after the introduction of the 1970 Unregistered Land Act, which favored big private businesses without due regards to the informal institution of the Dar system, which in turn fueled the brutal farmer-herder conflicts that erupted in the mid-1980s in the rainfed lands. This is in addition to the already existing arm conflict fought in South Sudan (El Shazli, 2002). In 2005, the Gezira Ordinance was repealed by the 2005 Gezira Act, which signified a complete change in the institutions underpinning the inherited peasant export agriculture, the earners of foreign exchange, and the growth driver of the economy.

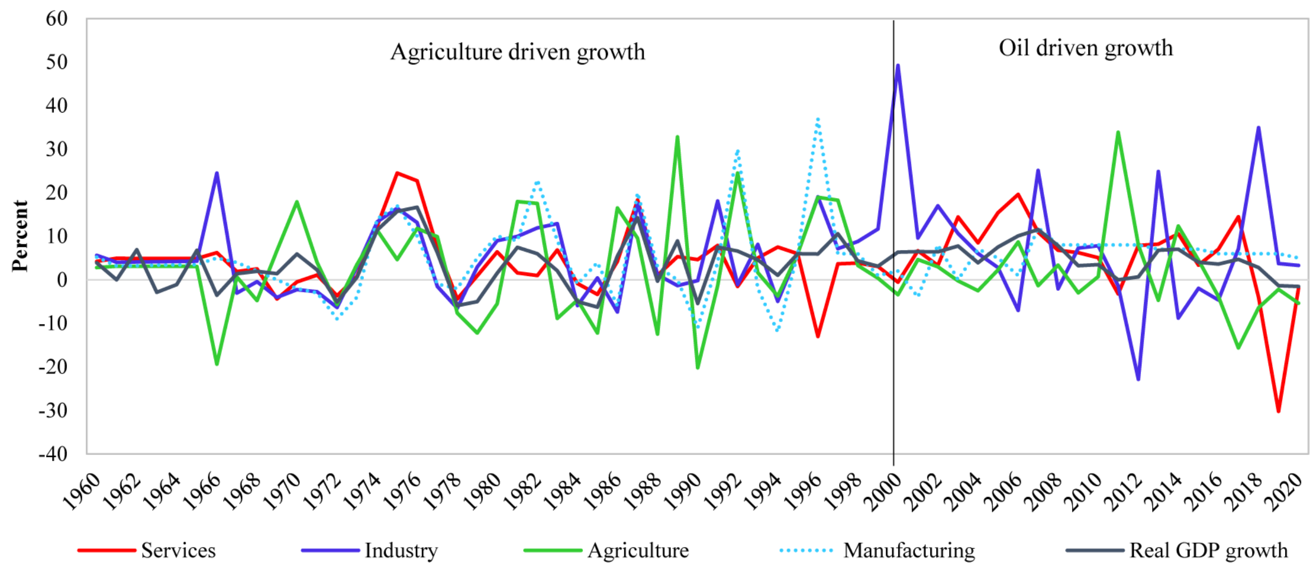
An informal deal for the commercial exploitation of oil (discovered in 1974) was made in 1987, and the first shipment of crude oil started in 2000 (see Ahmed, 1995). Following the rise of oil in the economy, the share of agricultural exports dropped by 50 percentage points on average over the sub-period 2000-2011 compared to 1961-1999. Also, as seen in Figure 3, the contribution of agriculture to the growth of real VA dropped, respectively, by one third and one half between these respective periods. Notwithstanding the inflows of substantial oil income, the share of imported agricultural inputs (excluding fuel, which is subsidized) to total imports dropped by 0.8 percentage points down to 0.7 percent; confirming the complete loss of interest by the Ingaz elite in the bimodal export-oriented agricultural model.

Figure 2. Agricultural exports and the share of imported agricultural inputs in total imports



Source: World Bank development indicators

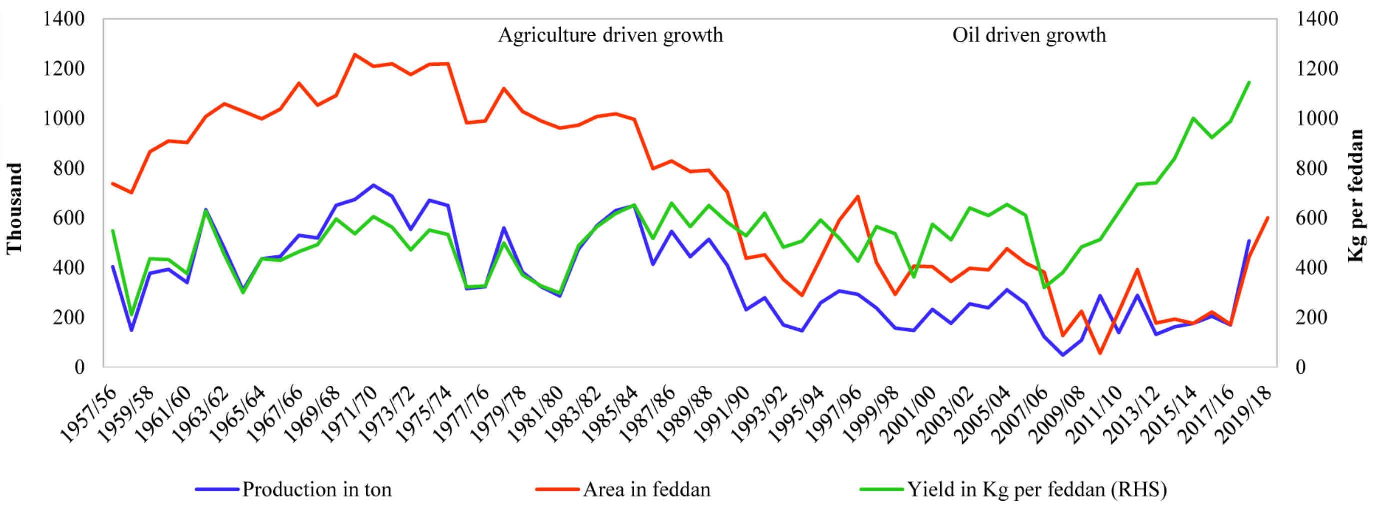
Figure 3. Real GDP growth and real value-added growth by major sectors



Source: Ministry of Finance and Economic Planning, Central Bank of Sudan and World Bank development indicators

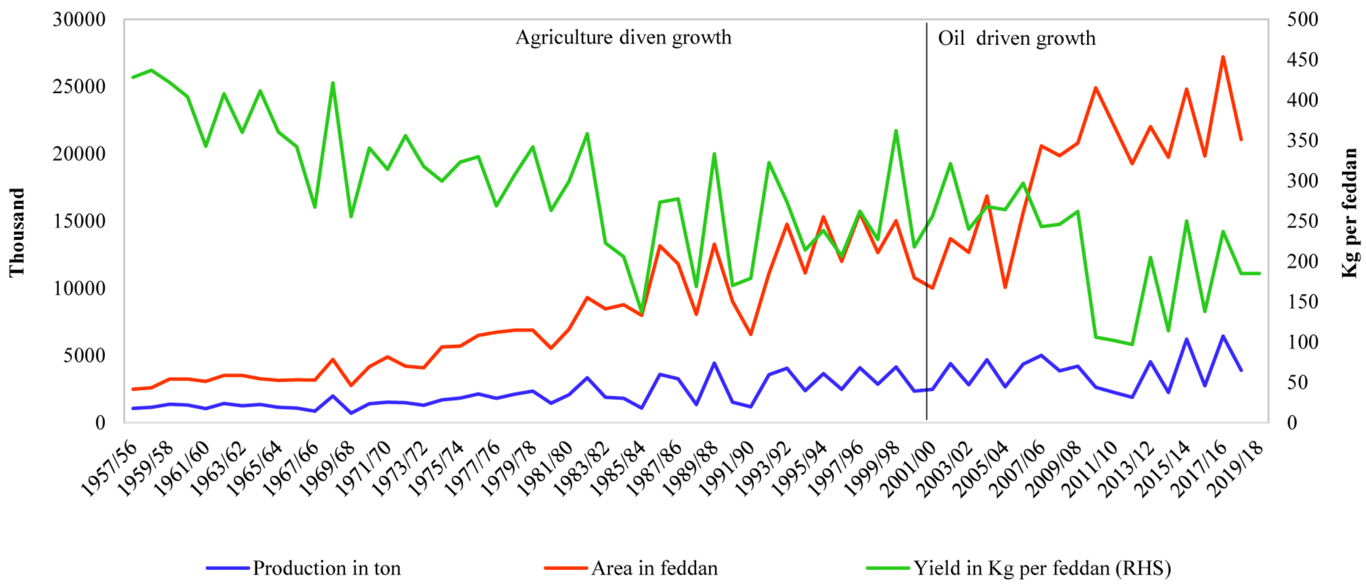
During the oil boom, the agricultural sector appeared to suffer from the combined impacts of exchange rate overvaluation due to Dutch disease, which was associated with the substantial inflows of oil revenues and the lack of commitment by political elite to develop the sector, especially rainfed agriculture, which was dominated by diverse and politically unorganized rural communities. Figures 4 and 5 show that the response of the irrigated and rainfed subsectors to these developments has been different. For example, on the one hand, the harvested area under the irrigated cotton (the main product of the subsector) was reduced by 34 percent during the oil driven growth compared to the average before oil, but yield increased by 29 percent, reflecting investments in genetically modified cotton thanks to the contribution of private companies cum farmers contacting. On the other hand, the harvested area of sorghum, which is the key crop in the rainfed subsector, increased by 53 percent, while yield dropped by 30 percent on average over the oil-driven growth compared to the agricultural-driven growth.

Figure 4. Cotton area, production, and yield



Source: Ministry of Finance and Economic Planning and the Central Bank of Sudan annual reports

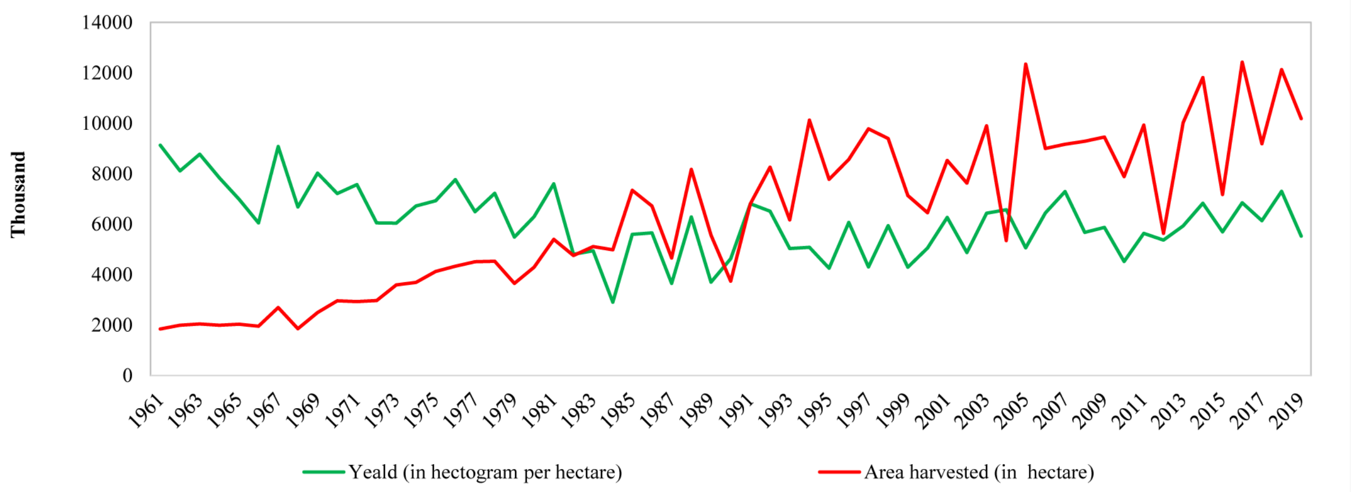
Figure 5. Sorghum area, production and yield



Source: Ministry of Finance and Economic Planning and the Central Bank of Sudan annual reports.

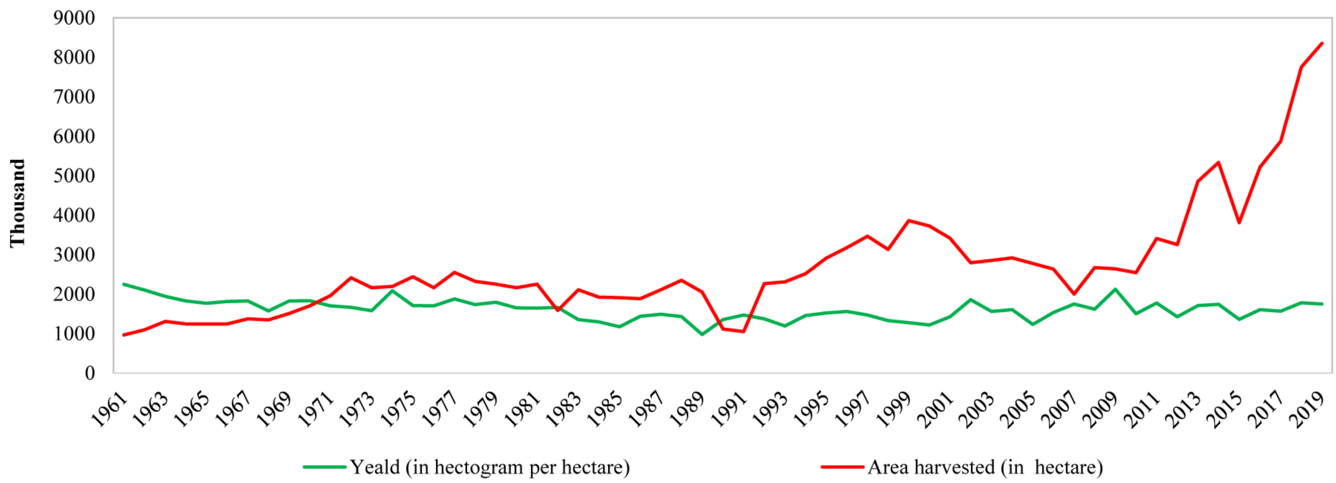
In addition, Figure 6 and Figure 7 indicate similar patterns for cereals and oil crops, confirming the increasing pressure on marginal arable land in order to compensate for the declining yield due the poor quality of agricultural inputs. In the case of the yield of cereals, Figure 8 reflects that Sudan is lagging far behind its comparators in East Africa.

Figure 6. Cereals yield and area harvested



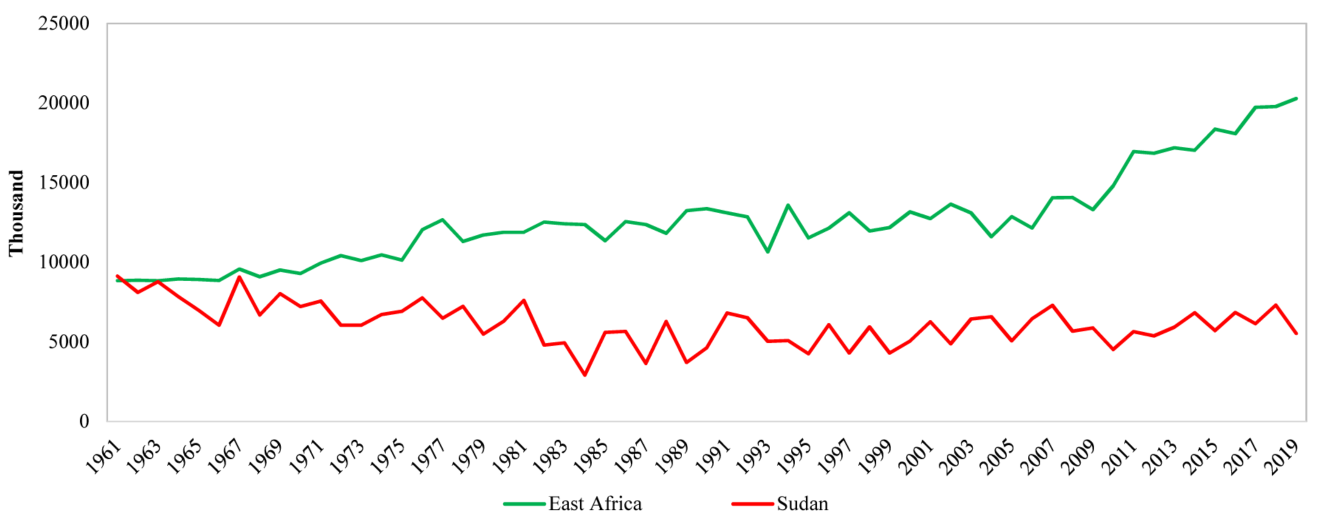
Source: Food and Agriculture Organization FAOSTAT

Figure 7. Oil crops (oil equivalent), yield and area harvested



Source: Food and Agriculture Organization FAOSTAT

Figure 8. Cereals yield in Sudan and East Africa (in hectogram per hectare)



Source: Food and Agriculture Organization FAOSTAT

This evidence clearly indicates that the prevailing patterns of land use, particularly in the rainfed subsector, are inconsistent with the long-run goal of sustainable growth in the country's food production. Hence, there is an overwhelming need for a "national industrial policy" intervention to enhance agricultural inputs (fertilizers and improved seeds), including augmentation of the capital base of agricultural supply in order to increase value addition and the sector's contribution to the GDP. Such policy is expected not only to minimize the hazards of crop losses and raise yield, but also to reduce pressures on land and mitigate the risks of climatic change emanating from soil degradation and desertification.

Information on the sectoral contribution to total real VA, employment generation, and labor productivity is inevitable for an industrial policy targeting agro-manufacturing, which is the easiest stage of import-substitution industrialization. However, as country experiences have shown, irrespective of the orientation of the industrialization plan, import-substituting or export-oriented overall productivity has been the main driver of growth-enhancing structural change (see Rodrik 2011, for example). Figure 9 and Figure 10 contain information on the evolutions of the sectoral output per worker (labor productivity) and the sectoral shares in total employment and real VA (in constant 1982 SDG). The results are obtained following the decomposition of output per worker into intrasectoral changes in labor productivity and structural changes using the Shapley decomposition method.[4] Eight sectors are included in the analysis to shed light on the sectoral real VA, employment, and labor productivity trends over the period 1990-2012, which is covered by available data. Information on sectoral employment is drawn from surveys conducted in 1990, 1996, 2009, and 2012, and the sectoral real VA is obtained from Sudan's Central Bureau of Statistics. Accordingly, a comparative analysis of the trends of these key indicators is conducted over the sub-periods 1990-1996, 1996-2009, and 2009-2012, which provides snapshots representing the agriculture-driven growth; the oil-driven growth, and the recess of the oil boom.[5]

Figure 9 plots the results of the end-of-period decomposition of output per worker into intrasectoral changes in productivity and the structural changes. The following key features stand out from the figure: (i) There are stark differences between the three subperiods compared to the overall performance with respect to the major drivers of productivity growth, real VA, and employment, within and between sectors; (ii) agriculture strongly contributed to productivity growth during the subperiod 1990-1996 followed by the substantial contribution to productivity from intersectoral shifts of labor from low to high productivity sectors, implying a progressive move into structural transformation. However, labor seems to have moved out of services and construction rather than from agriculture; (iii) the oil boom raised productivity in all sectors dominated by contributions from mining, manufacturing, and agriculture, but the structural changes moved in an opposite direction; and (iv) total productivity significantly dropped between 2009 and 2012, reflecting the recess of the oil boom and the major losses that occurred in mining, services, and manufacturing, while construction, government services, and the structural changes moved in the opposite direction.

Figure 10 further probes into productivity and the structural change linkages by running a correlation between the sectoral labor productivity growth and sectoral share in total employment. The following features stand out: (i) over the whole period, Sudan seems to have experienced growth-enhancing structural change in line with the classic path of catching-up through manufacturing. However, performance during the subperiods confirm that such progressive structural change is not sustained; (ii) except for the subperiod 1990-1996 representing the agriculture-driven growth and the other sub-periods representing the oil-driven growth. The aftermath of the collapse of oil exports has experienced growth-reducing structural change for different reasons. Services, which are non-tradable, burgeoned after the collapse of the oil-boom. Finally, (iii) employment share in manufacturing, which is the escalator for high and sustainable growth, remained low over the whole review period.

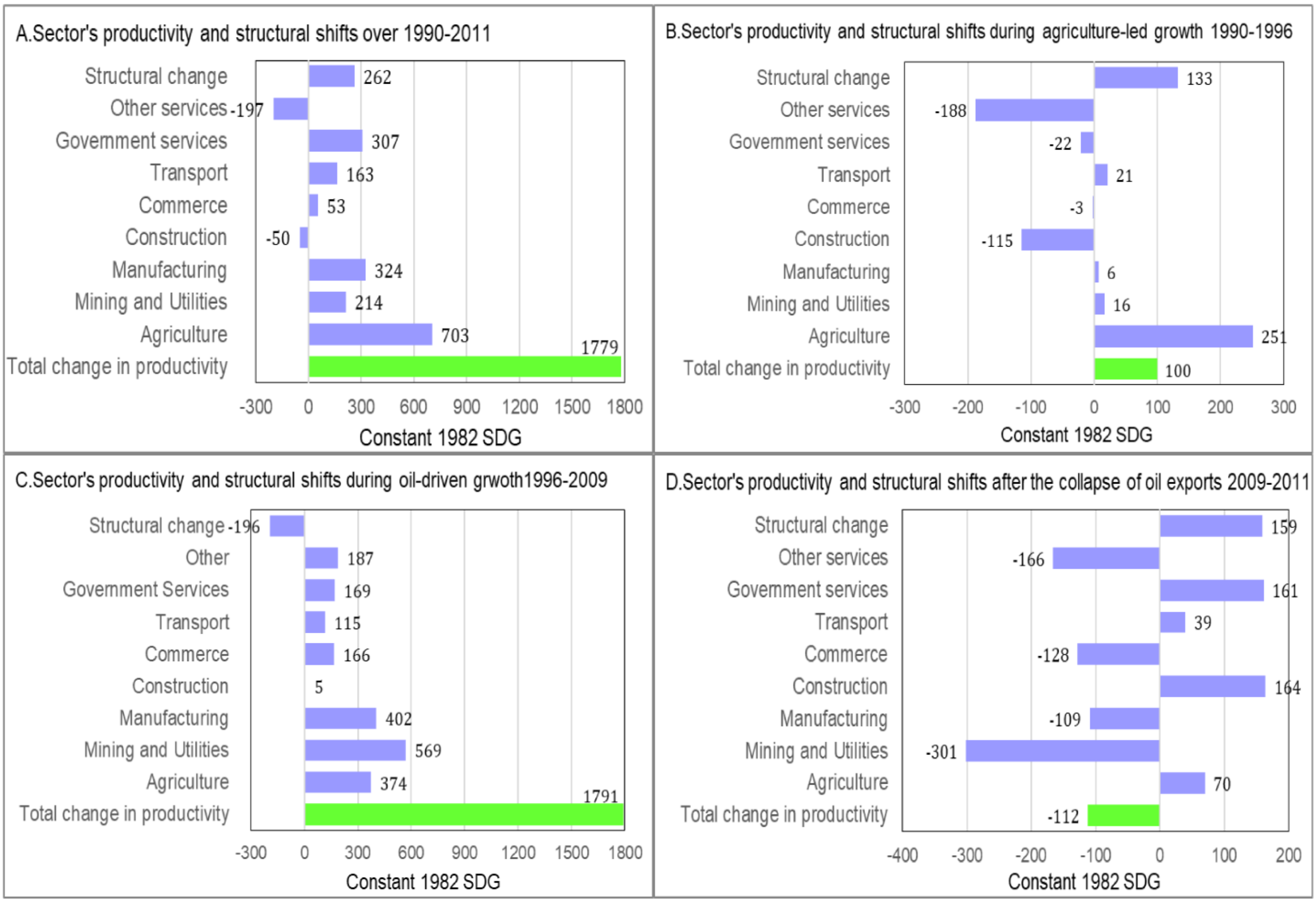
Moreover, Elbadawi and Suliman (2018) showed that productivity-intensive growth is found to reduce poverty across all sectors of the economy, while employment-intensive growth increases poverty in the largest sectors, especially agriculture and services that are mostly informal.

Overall, the evolutionary patterns of sectoral labor productivity growth as well as the sectoral shares in total employment and real VA suggest that Sudan seems to have been caught in a premature deindustrialization process, where the share of the low-productivity services dominated that of agriculture and industry. Indeed, an industrial policy targeting agro-manufacturing in the country should be based on enhancing the intrasectoral productivity growth and structural change. As shown by the experience of the

[4] See World Bank (2010) for the discussions of Shapley decomposition method and the description of the Job Generation and Growth (JoGGs) Decomposition Tool used in the estimation.

[5] See Ibrahim and Suliman (2018) for the organization of the data further analyses.

Figure 9. Decomposition of output per worker (productivity) into own-sector changes in productivity and structural changes

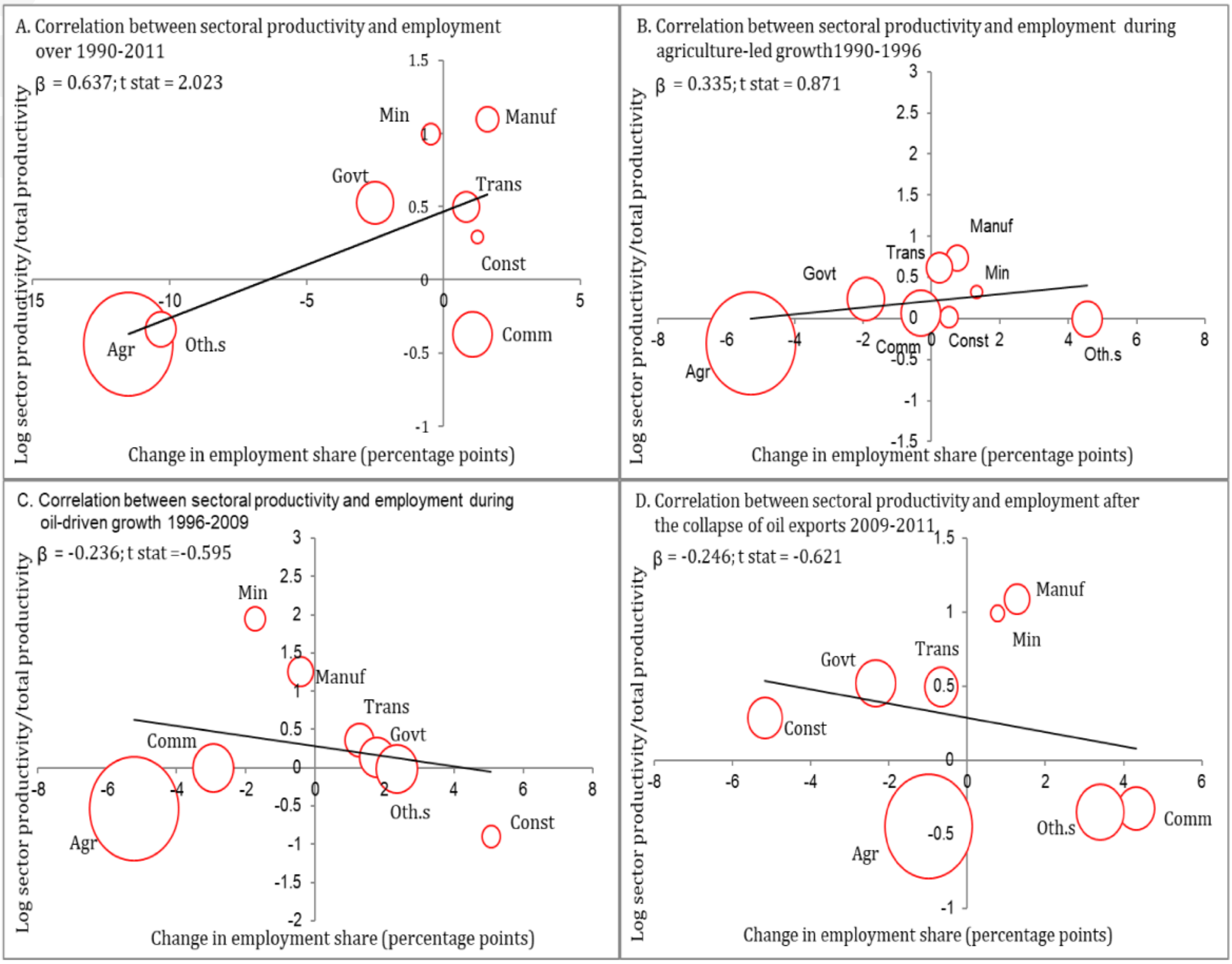


Source: Elbadawi and Suliman (2018).

Sudan National Agriculture Investment Plan (SNAIP 2016-2020, see Box 1), raising budget allocation to agriculture, while crucial, is not sufficient to raise labor productivity and VA in the sector. Deep institutional reform is needed to redress the land tenures system, land usufruct rights, and the demarcation of communal lands. Progress in this groundwork is key to an economic development strategy based on raising labor productivity, which is the main driver of the sustainable growth-enhancing structural change. In addition, contractual agriculture should be institutionalized to provide a durable integrated solution to finance, markets and link up with high value-chain markets, including with leading companies in the agro-manufacturing sector.

The success of a private sector-led integrated markets solution to the major challenges in agriculture requires the government to commit credibly to macroeconomic stability. Ensuring a stable price system is of critical importance in the current contract farming model. If the government inflates prices between the dates of committing the contract and delivering the crops, farmers would be at grave disadvantage. Since this risk is predictable, the contract price should be inflation-adjusted and the government should pay the difference.

Figure 10. The correlation between sectoral productivity and change in employment shares for various periods



Notes: The abbreviations represent the following: (Agr) Agriculture; (Cont) Construction, (Comm) commerce; (Govt) Government and community services, (Min) Mining, electricity and water, (Manuf) manufacturing, (Trans) Transport and Communications, (Oth.s) Other Services, including finance and insurance services, real estate, professional services as well as the diversified activities of the households.
Source: Elbadawi and Suliman (2018).

Box 1. The National Agriculture Investment Plan (SNAIP) 2016-2020

After the extensive efforts made since 2013, Sudan developed SNAIP with the help of its development partners. The plan is a key component for the country's participation in the Comprehensive Africa Agriculture Development Program (CAADP), which is a pan-African initiative signed by Sudan in 2013 that commits it to increase government spending on agriculture to 10 percent of GDP by 2020 to achieve an annual growth of six percent for agricultural real VA.

As stated, the SNAIP's key objectives include: promoting exports of crops and livestock, increasing the productivity and efficiency of Sudan's agricultural sector; improving national food security and nutrition; reducing rural poverty by 50 percent by 2020 and generating job opportunities (especially for youth and women); encouraging settlement in the rural areas to achieve balanced economic growth; and developing and protecting natural resources to ensure their renewal and sustainability (FAO in Sudan).

As indicated earlier (Part 1), the direct share of agriculture in public investment was estimated at a minute 0.3 percent in 2012-2014. During the period 2017-2018, budget allocation to agriculture amounted to 1.3 percent of total public spending, which was far away from the announced commitment to the 10 percent CAADP goal. Between 2017 and 2018, public spending focused on the irrigated subsector, which attracted, respectively, 39 percent and 67 percent of the overall agricultural budget. Overall, the achieved real growth of the agricultural real VA was -6.7 on average during SNAIP 2016-2020, which is 12.7 percentage points away than what was planned for 2020 (see Figure 3).

III. Conditional Convergence In Agriculture: Lessons for Transforming Sudanese Agriculture[6]

Sudan has great and diversified agricultural potential. To say that the sector has been the main stay of the economy is a factual statement, but it isn't very informative. Moreover, from the perspective of development and public policy debates, it can be quite misleading. This is because the productivity of Sudanese agriculture is very low, which explains the poverty and deprivation of rural communities as well as the limited capacity of the sector to facilitate a meaningful structural transformation in the Sudanese economy. The recent household budget surveys show that poverty headcount rates in Sudan have been rising over time and that they vary geographically.

Figure 11.A shows that the poverty rate has almost doubled between 2009 and 2014/15, rising to 83.2 percent and mainly driven by inflation. In addition, Figure 11.B reveals that the poverty rate significantly diverges spatially and that the rate of divergence increases with the distance from the core region. This outcome indicates that poverty predominates in the western parts of the country, particularly in the regions of Darfur, Kordofan, and the East. These regions are inhabited by communities of farmers, herders, and nomads largely engaged in traditional rainfed agriculture and animal husbandry. Although the share of agriculture in GDP and labor has precipitously declined over the years, as opposed to Kenya, for example, it nonetheless contributed around 20 percent of GDP and accounted for 45 percent of aggregate employment in 2019. These shares are much higher than those of Egypt, where agriculture contributed only 11 and 20 percent of GDP and employment, respectively, in the same year (Figure 13).

However, once we consider the comparative country experiences in terms of agricultural productivity, it becomes clear that the higher share of agriculture in the economy for Sudan is more a reflection of the poverty of its economy than the vitality of its agricultural sector. Figure 12 shows the evolution of labor productivity in the agricultural sector, measured as agricultural VA per worker. Panel A shows productivity in Sudan in comparison to low-income countries as well as other countries with relatively low productivity, such as Kenya and Mauritania. Unlike Kenya and Sudan, Mauritania has one of the poorest agricultural lands in the world. The area of arable land in Mauritania is not more than two percent of that in Sudan. While Mauritania's labor productivity was much higher than that of Sudan in the 1990s, it has been on a continuous decline since then. Although the gap was much narrower in 2019, Sudan's agricultural productivity is still lagging despite its natural endowments of ample arable lands. Kenya, on the other hand, is a country with a more tropical climate and higher agricultural potential than Mauritania. Yet, its labor productivity is still remarkably low compared to Sudan. This is despite the fact that Kenya's agricultural sector has been gaining more importance in the later years. In 2019, agriculture accounted for 34.1 percent of GDP and 54.3 percent of employment, both of which are higher than Sudan. While Sudan's agricultural productivity exceeds the median of low-income countries, it is still lower than that of middle-income countries.

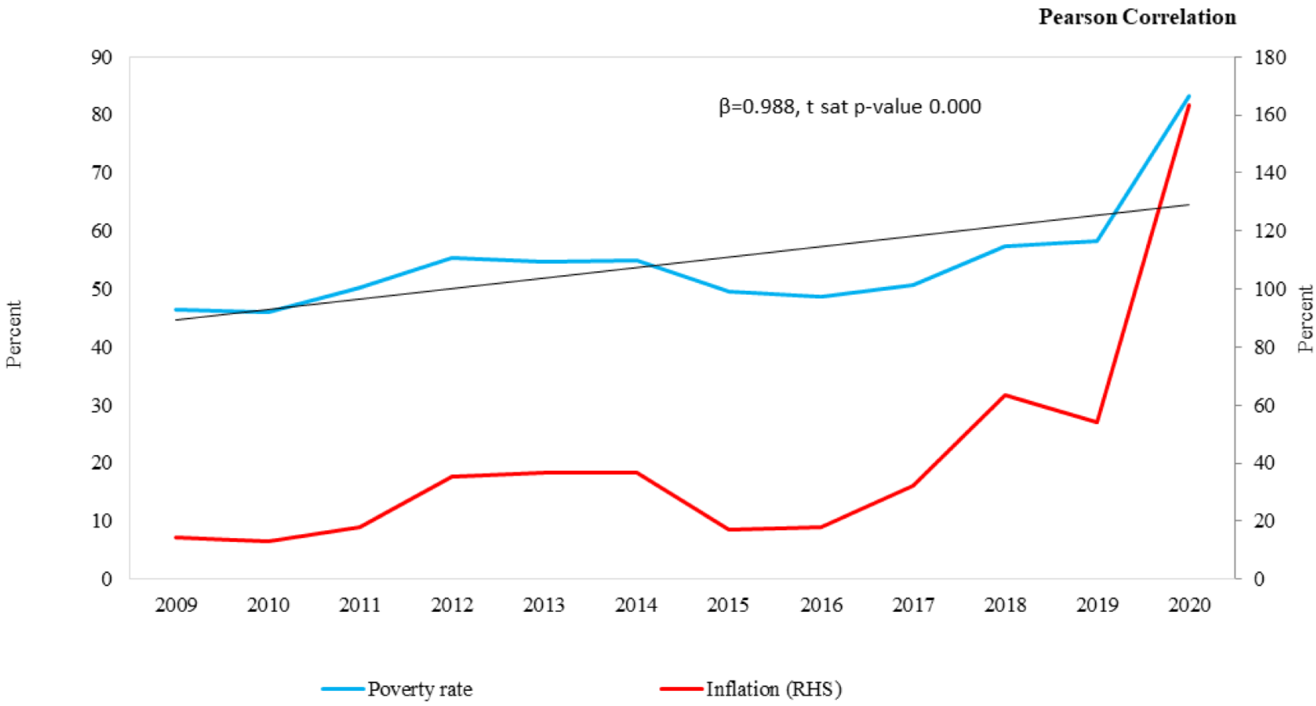
Panel B of Figure 13 shows the evolution of agricultural productivity for some middle-income countries with relatively higher productivity levels. Egypt's labor productivity is slightly above the median of middle-income countries and has shown a remarkable increase in recent years. Between 2000 and 2019, agricultural productivity in Egypt increased by around 80 percent compared to 19 percent in Sudan. Yet, Egypt is still a country with many challenges and many potential areas for improvement. South Africa is a country that could represent the next level for both Egypt and Sudan. Agricultural productivity has shown remarkable improvement over time. Between 1995 and 2014, agricultural productivity in South Africa grew by around 190 percent, before it slightly declined in the wake of the 2016 South African crisis. Despite that, South Africa's labor productivity was almost 2.4 times that of Egypt and the middle-income median in 2019, and 4.2 times that of Sudan.

1. The challenges of productivity convergence in agriculture

As shown by Figure 12, the gap in agricultural productivity in Sudan on the one hand and Egypt and South Africa on the other hand has been widening over the years. Figure 13 confirms the existence of considerable differences in

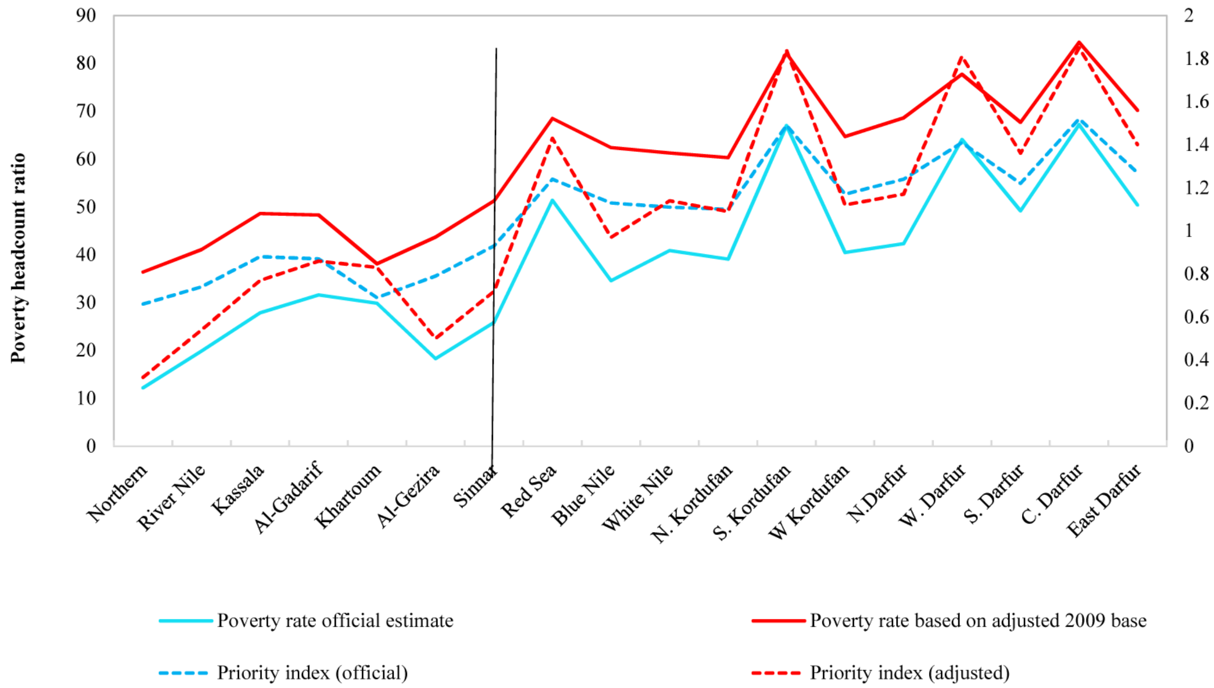
[6] This chapter draws heavily from Elbadawi and Ismail (2021).

Figure 11.A. Pearson correlation between poverty rate and inflation



Note: Poverty headcount ratio is extrapolate based on the results of the 2009 households survey. Firstly, the extrapolation uses the elasticity of poverty headcount ratio with respect to real household income per capita (RHIPC) estimated by the World Bank (2018), which is -0.67, implying that a one percent increase in RHIPC will reduce poverty by 0.67. Secondly, the final effect of RHIPC growth on poverty is adjusted for the impact of inflation. The standard quantity of money identity (MV=PY) is used to represent the aggregate demand side of the economy; the result of cointegration and error-correction estimates shows that a one percent increase in inflation tends to reduce RHIPC by around 0.29 percent both in the short and long term. Similar results are documented in Bittencourt (2012) from a panel time series analysis for Latin America. It is assumed that these elasticities remain constant between 2009 and 2020 and that RHIPC distribution has neutral effect on poverty. The data is obtained from the Central Bureau of Statistics.

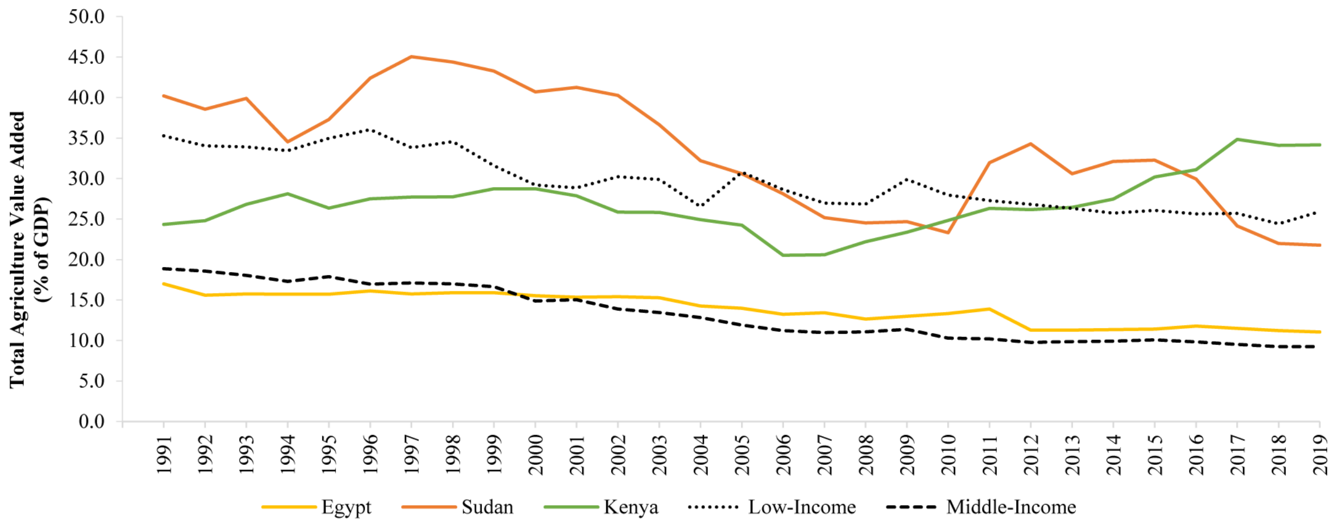
Figure 11.B. The geographical disparities of poverty and the priority index



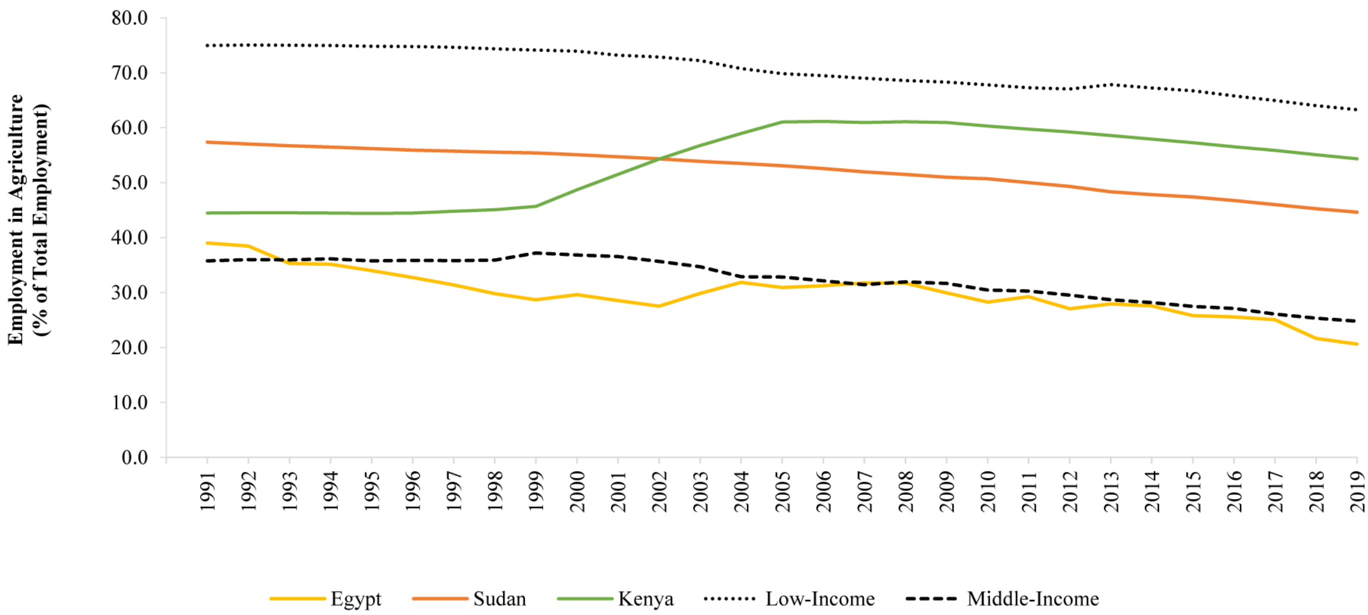
Note: The official estimates are based on the Poverty and Budget Households Survey conducted in 2014-2015.The global poverty line is estimated, respectively, at 5,110 and 4044 SDG per person annually in the urban and rural areas, and the prevalence of global poverty in Sudan is estimated at 36.1 percent. However, the national poverty line remained assumed. Accordingly, the 2009 national poverty line (estimated as 114 SDG per person monthly) is annualized and adjusted for inflation between 2009 and 2014-2015 using the consumer price index. The data is obtained from the Central Bureau of Statistics.

Figure 12. The economic contribution of agriculture to output and employment

Panel A: Total agricultural VA (% of GDP)



Panel B: Employment in agriculture (% of total employment)

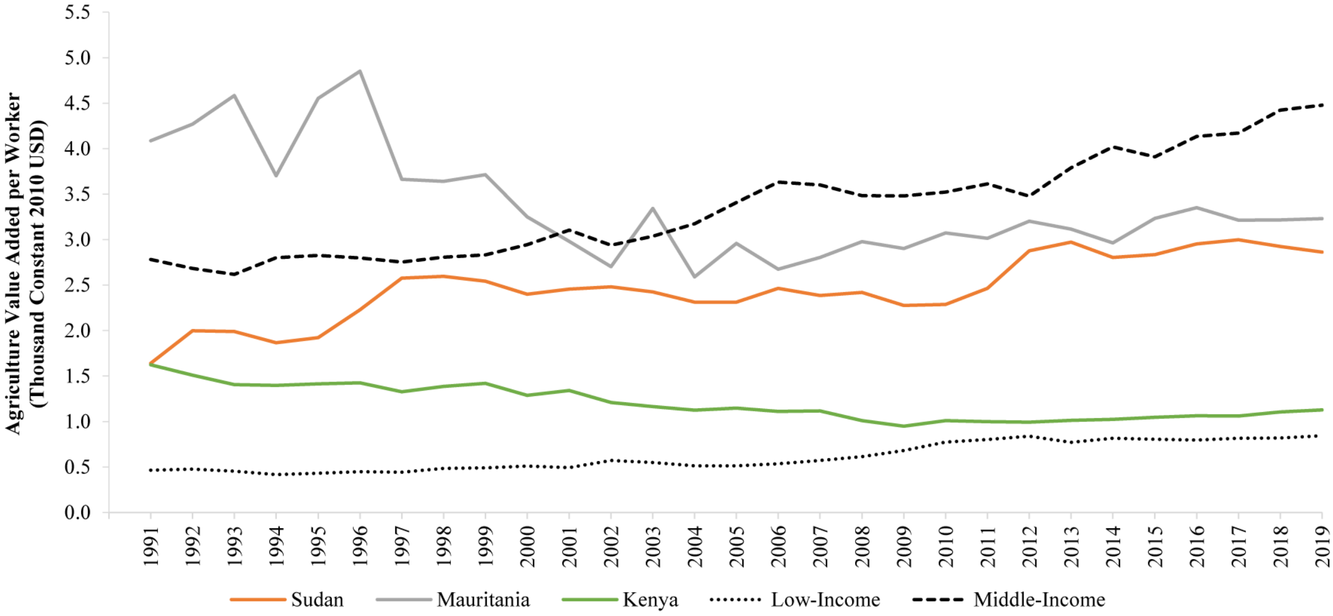


Note: This figure presents the evolution of the economic contribution of agriculture over the period 1991-2019 for Egypt, Sudan, and Kenya, in addition to the median of low- and middle-income countries as defined by the World Bank. Panel A presents total agricultural VA as a percentage of GDP. Panel B presents employment in agriculture as a percentage of total employment.

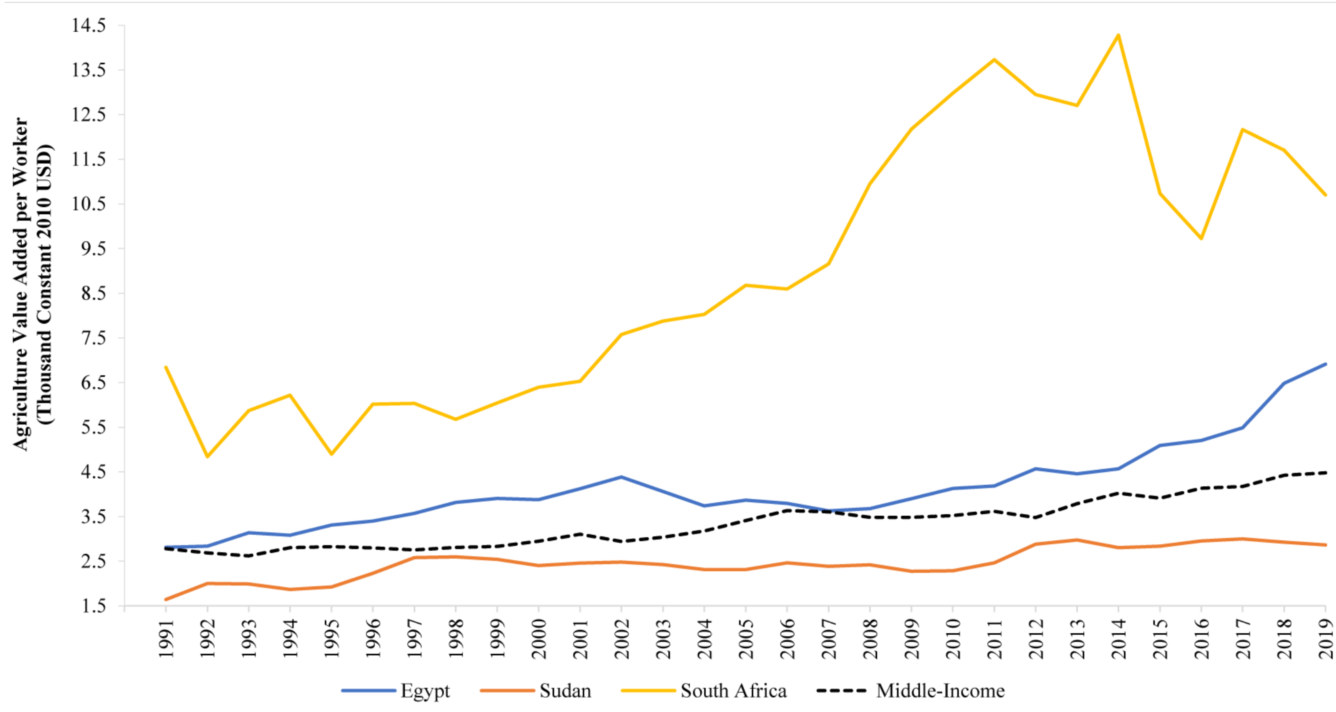
total labor productivity, reflecting the consequences of policy shifts from the agriculture-driven growth model to oil-driven growth to the management of the aftermath of the oil boom collapse. This evidence is consistent with the conditional convergence principle of growth theory, which is strongly corroborated by evidence from the empirical literature and individual country experiences. Poorer economies can only grow faster than richer economies, conditional on their endowments, policies, and institutions. Rodrik (2011), however, argues that unconditional convergence does exist in individual manufacturing industries. Once an economy starts manufacturing a given product, labor productivity in that industry should automatically follow an upward trajectory. We reproduce the results from Rodrik (2011), which shows the relationship between initial industrial labor productivity and the growth rate in industrial labor productivity between1990 and 2007. The unconditional regression (including industry and time dummies) shows a highly statistically significant and negative coefficient of -0.031, implying that countries with the lowest initial productivity in a given industry can unconditionally grow

Figure 13. Agricultural labor productivity

Panel A: Lower agricultural labor productivity



Panel B: Higher agricultural labor productivity

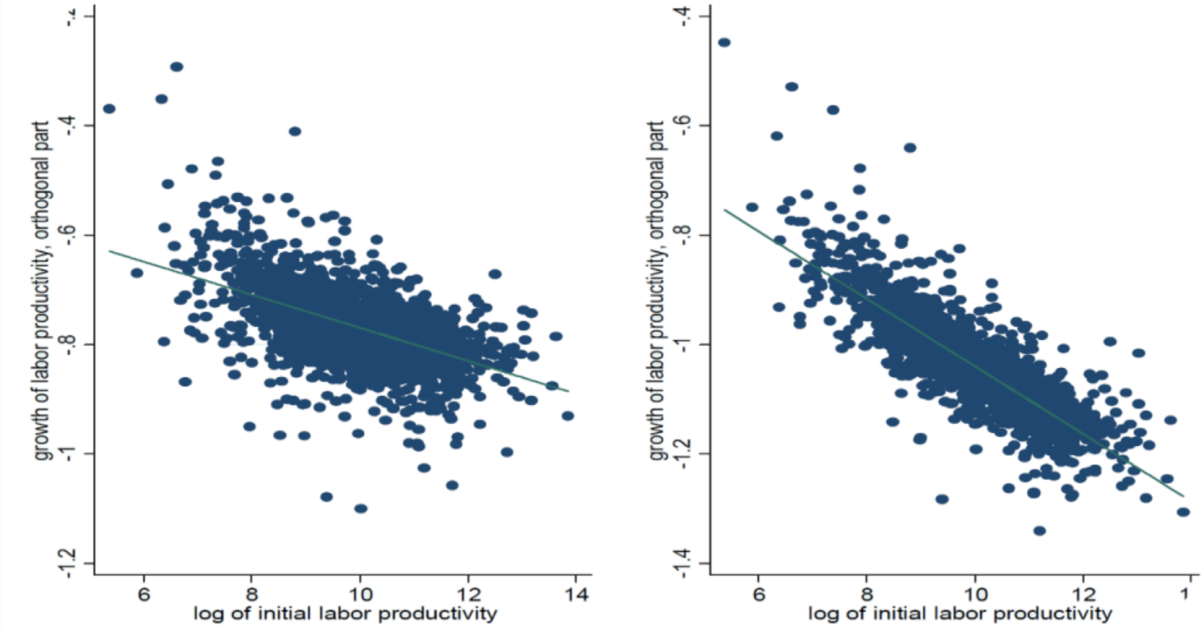


Note: This figure presents the evolution of agricultural labor productivity over the period 1991-2019 for different country groups. Panel A presents agricultural labor productivity measured as agricultural VA (in thousands of constant 2010 USD) over the number of employees in agriculture for Sudan, Mauritania, and Kenya, in addition to the low- and middle-income medians. Panel B presents agricultural labor productivity for Sudan, Egypt, South Africa, and the middle-income median. Low- and middle-income countries are defined according to the World Bank classification.

Figure 14. Unconditional and conditional convergence in industrial labor productivity

Panel A: Unconditional Convergence in Industrial Productivity (Coef. = -0.031)

Panel B: Conditional Convergence in Industrial Productivity (Coef. = -0.063)



Note: This figure presents scatter plots of the average growth rate in industrial labor productivity (on the vertical axis) against the log of initial productivity (on the horizontal axis). Data are from the United Nations Industrial Development Organization (UNIDO) industrial statistics data base (INDSTAT4). Labor productivity is computed using VA at the 4-digit level of disaggregation for the manufacturing industry. The graphs are for decadal regressions over 1990-2007. Panel A reports the unconditional relationship between the growth rate and initial value of industrial productivity. Panel B reports the conditional relationship. Unconditional convergence regressions include industry and time dummies, while conditional regressions also include country fixed effects.

and approach the frontier relatively faster (Figure 13: Panel A). Unsurprisingly, the rate of convergence is faster once controlling for country fixed effects. The coefficient for the conditional regression is almost double at -0.063 (Figure 13: Panel B).

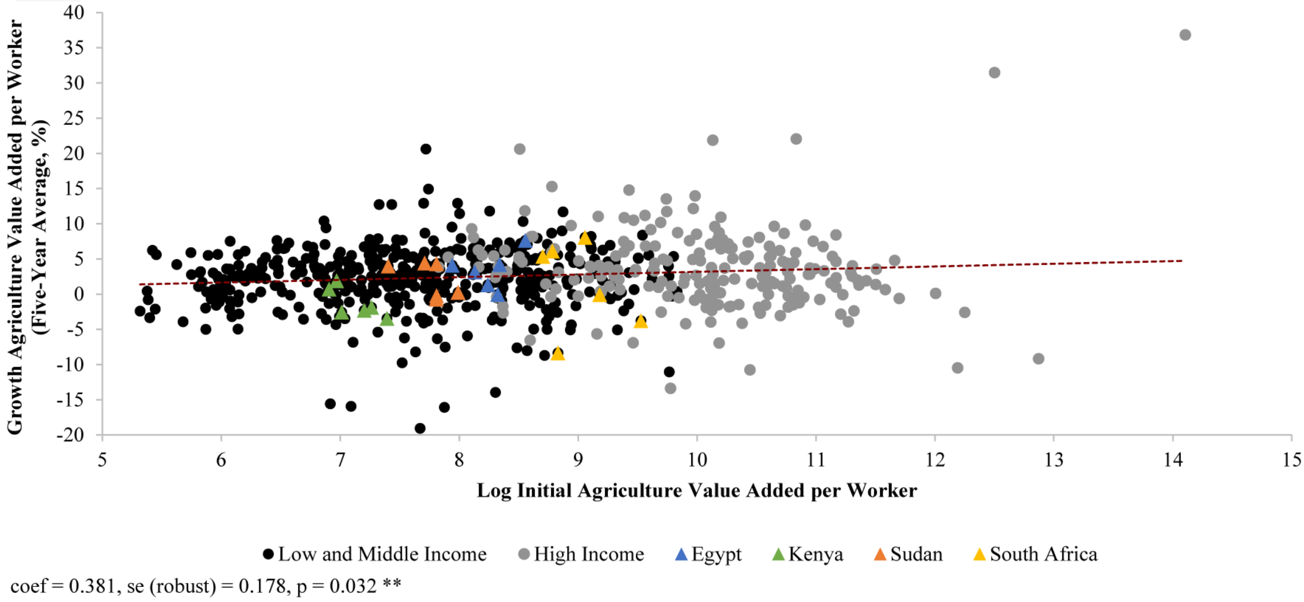
In light of the evidence from the industry, it is natural to wonder whether the unconditional convergence property also extends to the agricultural sector. In this case, the story of Figure 12 would not be a true reflection of the process of convergence in this sector. This question was originally raised by Ishac et al. (2013), who showed that there is a 'mild' unconditional divergence, not convergence, in agricultural labor productivity (Figure 14: Panel A). Therefore, when country characteristics are not controlled for, growth in labor productivity tends to grow faster for countries with higher initial productivity, therefore widening the gap[7] and corroborating the preliminary evidence of Figure 12. Once controlling for country-specific fixed effects, labor productivity does converge across countries with different initial levels (Figure 14: Panel B).

It is interesting to note that not only does industrial productivity tend to converge unconditionally, but the comparison between conditional convergence of industry (Figure 14: Panel B) and that of agriculture (Figure 15: Panel B) makes it clear that conditional convergence in the former tends to be much stronger. These contrasting processes between the two sectors might be explained by the different nature of the technology in the two sectors. The technology frontier in manufacturing is relatively standard; hence, it could easily be transplanted and adopted regardless of country or policy context, suggesting that a manufacturing production function essentially resembles Leontief production technology. On the other hand, the best practice agricultural technology frontier is conditional on the agro climatic environment. As explained by Evenson (1981: p. 1), "Most forms of agricultural technology have not been transferred from developed to developing countries. This is particularly true of technology of the biogenetic type. Plants and animals interact with the soil and climate environments in which they live. Natural selection pressures produce highly variegated species and types of plants and animals, each

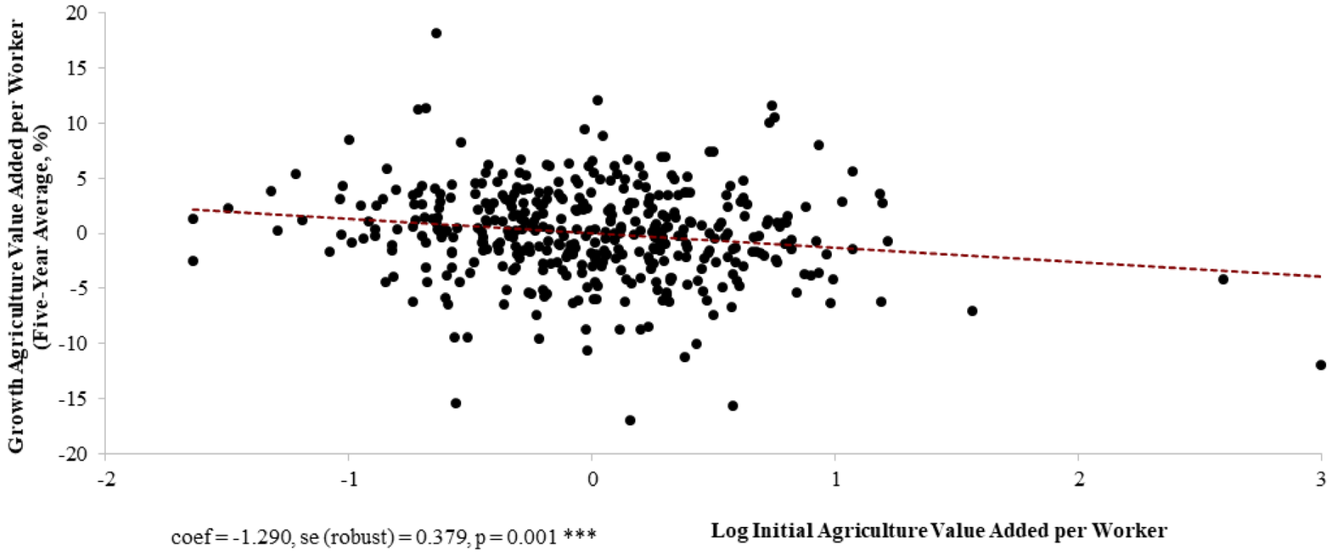
[7] Interestingly, Ishac et al. (2013) argues that this could explain why there is neither conditional convergence nor divergence in per capita income across countries. When regressing the growth rate in gross domestic product (GDP) per worker on its initial levels, the coefficient is usually not statistically different form zero. If there is unconditional convergence in industry but divergence in agriculture, then it would make sense for the overall productivity to show neither.

Figure 15. Unconditional and conditional convergence in agricultural labor productivity

Panel A: Unconditional convergence in agricultural productivity



Panel B: Conditional convergence in agricultural productivity



Note: This figure presents a scatter plot of the five-year average growth rate in agricultural labor productivity (on the vertical axis) against the log of initial productivity (on the horizontal axis). Agricultural productivity is measured as the agricultural VA per agriculture labor (in constant 2010 USD). Initial agricultural VA is the first-year value of each five-year interval. The analysis uses a panel data of 121 countries over 1991-2019 for Panel A and 1991-2010 for Panel B, in five-year intervals. Hence, a country can have between one to six points on the plot in Panel A. Highlighted in Panel A are Egypt, Sudan, Kenya, South Africa, in addition to the median of low- and middle-income countries as defined by the World Bank. Panel A presents the unconditional relationship between the growth rate and initial value of agricultural productivity (as shown in Table 2, column (1)). Panel B presents the conditional relationship, after controlling for country-specific characteristics (as shown in Table 2, column (2)).

suited or appropriate to an environmental niche. Modern plant breeding methods have only partly overcome the sensitivity of biological material to environments." Therefore, just from the agricultural technology lens, it is clear that conditional convergence would render broad-based fundamental growth in agriculture rather difficult to achieve.

2. Determinants of conditional convergence of agricultural productivity

Subscribing to the above, an important research and policy question presents itself: what are the factors that determine the convergence in agricultural productivity? We address this question by analyzing the results of cross-country panel regressions (due to Elbadawi and Ismail, 2021) of the growth in agricultural labor productivity on the log of the initial value of productivity, while controlling for factors associated with the three pillars of productivity, as discussed earlier.

2.1 Policy variables

Policy variables should pose significant effects on the growth of agricultural productivity in a country. In particular, we use three policy-related variables: the annual rate of inflation, exchange rate undervaluation, and exchange rate variability. By increasing the production costs of inputs and other factors of production, inflation is expected to have a negative effect on productivity growth. Moreover, a less stable exchange rate and a higher level of variability are expected to negatively affect the growth in productivity as they increase the difficulty and uncertainty of trade. The exchange rate is measured using the Darvas (2012) REER index, for which an increase indicates an appreciation of the home currency against the basket of trading partners' currencies. Exchange rate variability is measured as the coefficient of variation of the REER index. Exchange rate undervaluation is measured as the log of the ratio of the five-year moving average in REER to its contemporaneous value.

$$\textbf{REER\_Undervaluation}_{it} = \textbf{log (REER\_MA}_{it}\textbf{/REER}_{it}\textbf{)} \quad \textbf{(1)}$$

Where *REER_MA* is the five-year moving average of the REER index for country i in year t.[8] Accordingly, an increase in this measure would reflect a depreciation in the REER compared to its medium-term trend. REER undervaluation should be positive if the REER is below the average, indicating a relatively undervalued currency, while negative if above the average in a given year. Since a relatively undervalued exchange rate would be expected to increase international competitiveness and improve a country's trade position, exchange rate undervaluation should positively impact the growth in agricultural productivity.

The received literature suggests that maintaining the RER close to its equilibrium level is a necessary condition for sustained growth and that countries that avoided overvaluation have been associated with sustained export-led growth and substantial export diversification (e.g., Elbadawi and Helleiner, 2004). Moreover, avoiding overvaluation is not only necessary for growth, but a mild undervaluation may be good for growth (e.g., Elbadawi et al, 2012; Aguirre and Calderón, 2005). It has been argued that a depreciation of the RER has a positive effect on growth by increasing capacity utilization and raising the profitability of traded goods sectors, such as agriculture, which in turn promotes private investment. Moreover, a depreciated currency provides an economy-wide incentive to new potential exportable products that might face high entry barriers under an excessively strong currency. Further, RER depreciation avoids the necessity of selecting beneficiaries for export subsidies (i.e., "picking winners") as it promotes all exporting industries. Empirically, the evidence suggests that this positive effect of RER depreciation substantially dominates its potential negative effects associated with raising the cost of imported investment goods, which tend to be a large component of investment goods in developing economies.

Furthermore, Rodrik (2008) argues that these empirical findings are, in fact, a reflection of a deeper causal effect: countries that have managed to engineer an RER undervaluation (e.g., China, Republic of Korea, Taiwan, Uganda, and Tanzania) appear to have indirectly resolved (or provided a cushion against) deep institutional constraints. Traded goods (particularly new and non-traditional ones) are subject to a variety of market imperfections, such as information externalities (learning and cost-discovery externalities) and coordination externalities. These imperfections keep output and investment in traded sectors at sub-optimal levels. Therefore, traded goods sectors, like agriculture, are likely to be the most impacted by the types of institutional weaknesses that typically plague low-income countries. Yet, tradable economic activities are more dynamic than non-traded sectors, as would be expected in many low-income, small economies. Therefore, RER undervaluation can provide an economy-wide subsidy to tradable goods sectors, such as agriculture, and hence help alleviate the costs associated with such institutional weaknesses. Therefore, by raising the profitability of traded sectors, a RER undervaluation can be an effective strategy for increasing growth in a second-best world.

[8] The average of the variable is then computed for each five-year period τ.

Therefore, the literature reviewed above indicates the role of the RER as a growth fundamental and as a key ingredient for any successful export-oriented development strategy for low-income countries.

2.2 Infrastructure and input variables

The second set of country characteristics focuses on infrastructure development and inputs, specifically fertilizer consumption. Infrastructure is measured using the comprehensive indices developed by Donaubauer et al. (2016), which capture both the quantity and quality of infrastructure in energy, information and communications technology (ICT), finance, and transport. We use those four indices separately in the regressions as well as an overall index which captures all four aspects together. All indices range between one and 10, with higher values indicating a better level of infrastructure development. Both quantity and quality of infrastructure are expected to positively affect the growth rate in agricultural productivity. For example, better-developed road and other transport networks should reduce transportation costs for farmers and boost their productivity. Moreover, as shown by Donaubauer et al. (2016), higher infrastructure attracts more foreign direct investment (FDI) and boosts trade, both of which can contribute to higher productivity in the agricultural sector. Better access to finance should also promote investment by farmers and increase their productivity. According to Fowowe (2010), farmers are the most financially excluded group in Nigeria. Improving financial inclusion in Nigeria proves to have a positive and statistically significant effect on agricultural output and productivity. In another cross-country panel study, Lio and Liu (2006) also show that the adoption of ICT has a significantly positive effect on agricultural productivity. Higher fertilizer consumption should also positively impact productivity (Rehman et al., 2019).

It should be noted that since infrastructure development requires huge amounts of public investment, which creates an opportunity cost related to lost investments in other areas of development, one might expect the impact of infrastructure to be non-linear. This is the case here as our sample includes a large set of countries with varying levels and large disparities of infrastructure development. We expect this case to be particularly evident with finance and transport infrastructure. For example, using a country panel, Shen (2013) shows that financial development exhibits diminishing returns on the growth rate in real industrial VA. To account for such a possibility, we also include the square of finance infrastructure in the regressions. Moreover, Rodrigue (2020) suggests that there might also be diminishing returns to transport investments. When the existing infrastructure is limited, investments in transport should add capacity and connectivity and hence have a greater impact on the economy. They usually have a high impact level. In cases where decent infrastructure already exists, benefits from new investments in transport, as opposed to investing in the maintenance of existing stock of infrastructure, for example, should start to diminish. Where mature and long-established transportation systems exist, additional investments would then become means to maintain the system without adding much VA in connectivity or efficiency. To test this hypothesis, we first include a squared variable for transport infrastructure in the regression. Moreover, in a similar manner to Vandenbussche et al. (2006),[9] we define a variable of transport proximity and the log of the ratio of the transport frontier in a given time period to a country's own value of transport index in this period:

$$\textbf{Transport Proximity}_{it} = \textbf{log (Transport Frontier}_t\textbf{)/Transport Indexi}_t\textbf{)} \qquad \textbf{(2)}$$

where, *Transport Frontier$_t$* is measured as the median of the transport index for a given income group. In a given time, year t, the frontier variable can take one of two values. It is equal to the median transport index of the low- and middle-income countries for any country in those two income groups, while it is equal to the median of the high-income countries for any high-income country.[10] An increase in the transport proximity would indicate that a country is further away from its frontier; hence, it should be positively related to agricultural productivity.[11]

2.3 Human capital variables

A basic augmented Solow-Swan model predicts that human capital is a major determinant of productivity growth and its conditional convergence. In a similar manner, higher levels of human capital are expected to positively impact productivity in the agricultural sector. We measure human capital using either the HDI of the United Nations development program (UNDP), or measures of educational attainment. The HDI is a composite index, which gauges the level of human development with respect to the average achievement in three dimensions: life expectancy, education, and per capita income. The used measures of educational attainment include the mean

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[9] Vandenbussche et al. (2006) measure the proximity to the frontier of total factor productivity as the log of the ratio of a country's total productivity level to that of the frontier (taken as the US).

[10] Income groups are defined according to the World Bank classification of FY2019.

[11] The average of the variable is then computed for each five-year period τ.

years of schooling, obtained from the UNDP, as well as the mean years of primary and secondary schooling that are obtained from Barro and Lee (2013).

3. Results and discussion

The study by Elbadawi and Ismail (2021) uses data for 121 countries over the period 1991-2010. This is the longest period for which all variables are available. The panel is set over four non-overlapping five-year intervals, with the exception of the last period, which includes only four years. Accordingly, each country can have up to four periods in the panels: 1991-1996; 1996-2001; 2001-2006; and 2006-2010. Averaging data over five-year or decadal intervals is common practice in cross-country convergence regressions to eliminate cyclical factors, focus on long-term relationships, and ensure that more data are available for a bigger set of countries. Since data for agricultural productivity are available over the period 1991-2019, unconditional regressions are run for this longer period to take advantage of the greater variation in the data (A list of the countries included in the analysis is presented in Appendix Table 1. All data sources are described in Appendix Table 2. Appendix Table 4 presents the summary statistics for all the variables used in the analysis for all 121 countries, using the panel over the period 1991-2010).

As discussed above, Figure 4 shows the unconditional relationship between the growth in agricultural productivity and the log of initial agricultural productivity. The results of the unconditional regression are reported in the first column of Table 4. Unconditionally, there is divergence in agricultural productivity. The coefficient is positive at 0.38 and highly statistically significant. Although the conclusion is in line with the results from Ishac (2013), the estimated coefficient of Elbadawi and Ismail is quite smaller than that of Ishac (2013), who finds an unconditional coefficient of 1.47. Nevertheless, while our regressions use five-year panel data, theirs used decadal data. This result of unconditional divergence is robust to using different sets of countries and time spans. Columns (2) to (10) report results for the conditional regression controlling for the representative factors for the three sets of growth fundamentals of relevance to agricultural productivity. Column (2) reports the results after accounting for the three sets of fundamentals. Infrastructure is measured using the overall composite index, which accounts for the quantity and quality of energy, ICT, finance, and transport infrastructure. Human capital is measured using the HDI, accounting for life expectancy, educational attainment, and standard of living. Table 5 reports the results when using mean years of primary schooling as an alternative measure of human capital of high relevance to rural communities in developing countries. The results in Table 4 and Table 5 show a negative and highly significant coefficient for the log of initial agricultural productivity, implying conditional convergence. All other variables are highly significant and exhibit the expected signs. Growth in agricultural productivity tends to increase with a more stable and trade-oriented macroeconomic policy that exhibits relatively undervalued exchange rates as well as lower exchange rate and price volatility.

As expected, a more developed infrastructure level also promotes productivity growth. Focusing on Table 4, we find that an increase in the overall infrastructure index by one standard deviation (1.71) is associated with an increase of 0.73 percentage points in the growth rate of agricultural productivity. Moreover, on average, doubling the amount of fertilizer consumed can raise labor productivity growth by around 0.21 percentage points. The level of human development is also a significant determinant of agricultural productivity growth. On average, a 10 percent improvement in HDI is associated with productivity growth of around 0.37 percentage points. Figure 14 (Panel B) plots the conditional relationship between the growth in agricultural productivity and the log of initial agricultural productivity from this regression. As discussed above, the relationship becomes obviously negative.

Columns (3), (4), (5), and (7) of Table 4 report similar results using the separate infrastructure indices for energy, ICT, finance, and transport, respectively. The energy and finance coefficients are more significant when using the measures of educational attainment rather than the HDI to account for human capital (Table 5), where the coefficient for energy infrastructure is 0.68 and highly significant. Moreover, the coefficient for finance infrastructure is 0.42 and becomes significant at the 10 percent level.

However, the individual indices of transport and finance appear to be subject to diminishing returns. When we also add the squared values for each of the two variables (columns 6 and 8 of Table 4 and Table 5). The results show very evident cases of diminishing returns in finance and road infrastructures. The results indicate a concave relationship between finance infrastructure and agricultural productivity growth, with similar maximum values at 5.4 and 5.5 for Table 4 and Table 5, respectively. Interestingly, these values are very close to mean (5.60) and median (5.67) finance index values of high-income countries, which can be thought of as the frontier of financial development. The transport infrastructure also exhibits a concave relationship, with an estimated maximum index for transport infrastructure at 5.2 (Table 5), which, again, is exactly at the mean of high-income countries.

Table 4. Unconditional and conditional convergence in agricultural productivity

	Dependent Variable: Growth in Agriculture Productivity (%)									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Agriculture Productivity	0.381**	-1.290***	-1.341***	-1.499***	-1.186***	-1.031***	-0.944***	-0.952***	-1.252***	-1.246***
(In logs, Real Initial Value)	(0.18)	(0.38)	(0.40)	(0.38)	(0.34)	(0.33)	(0.33)	(0.33)	(0.35)	(0.35)
OnlIbx U`qi`aldr										
REER-Undervalue		9.470***	9.264**	9.074***	13.074***	12.027***	9.176**	9.330**	8.816**	8.871**
(Index)		(3.63)	(3.89)	(3.45)	(3.44)	(3.26)	(3.62)	(3.68)	(3.55)	(3.57)
REER-Variability		-8.198**	-7.725*	-7.876**	-11.683***	-10.749***	-8.251**	-8.342**	-7.567*	-7.579*
(Index)		(4.02)	(4.26)	(3.87)	(3.55)	(3.30)	(3.97)	(4.04)	(3.91)	(3.95)
Inlfation Rate		-0.005***	-0.005***	-0.005***	0.000	-0.001	-0.005***	-0.005***	-0.005***	-0.005***
(%)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Hnq`rsqt bst qd `nc Hmot s U`qi`aldr										
Overall Index		0.429**								
		(0.21)								
Energy Index			0.458							
			(0.31)							
ICT Index				0.793***						
				(0.26)						
Finance Index					0.251	3.004***				
					(0.21)	(0.83)				
(Finance Index)²						-0.280***				
						(0.08)				
Transport Index							0.098	1.177	0.642**	0.685**
							(0.17)	(0.73)	(0.27)	(0.28)
(Transport Index)²								-0.115		
								(0.08)		
Transport Proximity									3.163***	
									(1.12)	
Transport Proximity * LMIC										2.964***
										(1.13)
Transport Proximity * HIC										3.821**
										(1.75)
Fertilizer Consumption		0.214*	0.254**	0.253**	0.211*	0.181	0.228**	0.227**	0.279**	0.274**
(In logs of tonnes used)		(0.11)	(0.12)	(0.11)	(0.12)	(0.11)	(0.11)	(0.11)	(0.12)	(0.12)
GtI `mB`ok`kU`qi`aldr										
Human Development Index		3.690**	5.153***	3.420**	5.362***	4.628***	3.739***	2.910**	4.329***	4.173***
(In logs)		(1.53)	(1.93)	(1.38)	(1.55)	(1.49)	(1.40)	(1.36)	(1.40)	(1.38)
Time FE	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	678	412	378	421	392	392	422	422	422	422
R-squared	0.014	0.167	0.175	0.183	0.117	0.139	0.164	0.167	0.181	0.182

*Note: This table reports cross-country panel regressions in five-year intervals for 121 countries over 1991-2019 for column (1) and 1991-2010 for columns (2) to (10). Column (1) reports the unconditional regression of the five-year average of annual growth rate in agricultural VA per agriculture labor (in constant 2010 USD) on the log of initial VA. Columns (2) to (10) report conditional regressions, controlling for a set of policy, infrastructure, and input variables, in addition to human capital variables. REER undervaluation is the log of the ratio of the five-year moving average to the contemporaneous value of REER, whereas REER variability is its coefficient of variation. Infrastructure is proxied by the indices developed by Donaubauer et al. (2016), which capture infrastructure for energy, finance, ICT, and transport. Transport proximity is the log of the ratio of the transport frontier to own transport index, where the frontier is defined as the specific country-group median of the transport index, separately for low- and middle-income countries (LMIC) and for high-income countries (HIC). LMIC (HIC) are dummies equal to one if the country is of a low- or middle-income (high-income). Human capital is proxied by the log of the human development index. Conditional regressions also include country-specific controls (not reported for brevity) of the ratio of arable land to population, the log of yearly precipitation, the ratio of rural to total population, and a dummy variable equal to one if the country is landlocked. Initial VA is the first-year value of each five-year interval, while other control variables are computed as the five-year averages. Columns (2) to (10) include time dummies. Robust standard errors are in parentheses. *, **, and *** indicate statistical significance at the 10 percent, five percent, and one percent levels, respectively.*

Table 5. Unconditional and conditional convergence in agricultural productivity: Other measures of human capital

	Dependent Variable: Growth in Agriculture Productivity (%)									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Agriculture Productivity	0.381 **	-1.152 ***	-1.008 **	-1.330 ***	-1.004 ***	-0.883 ***	-0.730 **	-0.818 **	-0.976 ***	-0.978 ***
(In logs, Real Initial Value)	(0.18)	(0.39)	(0.40)	(0.38)	(0.34)	(0.32)	(0.35)	(0.35)	(0.36)	(0.36)
Onlibx U`qi akdr										
REER-Undervalue		7.777 *	7.624 *	7.345 *	12.428 ***	11.064 ***	7.667 *	8.162 *	7.220 *	7.468 *
(Index)		(4.18)	(4.25)	(4.03)	(3.68)	(3.42)	(4.22)	(4.17)	(4.10)	(4.07)
REER-Variability		-7.408 *	-7.392 *	-7.131 *	-11.070 ***	-9.843 ***	-7.520 *	-7.693 *	-6.866 *	-6.915 *
(Index)		(3.95)	(4.10)	(3.83)	(3.79)	(3.42)	(3.95)	(4.04)	(3.85)	(3.90)
Inlfation Rate		-0.005 **	-0.005 **	-0.005 **	0.000	0.000	-0.005 **	-0.005 **	-0.005 **	-0.005 **
(%)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Hmeq`rsqtbstqd `mc Hmot s U`qi akdr										
Overall Index		0.571 **								
		(0.23)								
Energy Index			0.675 **							
			(0.33)							
ICT Index				0.923 ***						
				(0.28)						
Finance Index					0.421 *	3.738 ***				
					(0.22)	(0.87)				
(Finance Index)²						-0.338 ***				
						(0.08)				
Transport Index							0.204	1.776 **	0.766 ***	0.845 ***
							(0.19)	(0.76)	(0.29)	(0.30)
(Transport Index)²								-0.170 **		
								(0.08)		
Transport Proximity									3.195 ***	
									(1.19)	
Transport Proximity * LMIC										2.822 **
										(1.19)
Transport Proximity * HIC										4.442 **
										(1.82)
Fertilizer Consumption		0.182	0.255 **	0.244 **	0.184	0.140	0.221 *	0.203 *	0.279 **	0.265 **
(In logs of tonnes used)		(0.12)	(0.13)	(0.11)	(0.13)	(0.12)	(0.12)	(0.12)	(0.13)	(0.13)
Gtl `mB`ohs`kU`qi akdr										
Mean Years of Pri. Schooling		0.583	0.352	0.615	1.581 **	1.475 **	0.560	0.239	0.578	0.461
(In logs)		(0.67)	(0.77)	(0.62)	(0.70)	(0.68)	(0.63)	(0.61)	(0.62)	(0.61)
Time FE	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	678	379	353	386	361	361	387	387	387	387

Note: Human capital is proxied by the log of the mean years of primary schooling.

If it is the case that transport infrastructure exhibits diminishing returns, then one would expect the positive benefits of additional infrastructure developments to be higher for countries with the lowest levels to start with. To investigate this further, we include in the regression the transport proximity variable (specified in the appendix). This variable is the log ratio of the transport frontier to the own country's transport index in a given period, and hence would be higher for countries farther away from the frontier. For both tables, column 9 adds this transport proximity variable to the regressions, while column 10 adds the variable interacted with dummies for high-income and low- and middle-income countries. Interestingly, not only is the coefficient for transport proximity positive and highly significant in all specifications, but the coefficient for the absolute transport index also becomes significant. In tables 1 and 2, the transport index has a coefficient of 0.64 and 0.766, respectively, indicating that an increase in the index by a single standard deviation (1.6) is associated with an increase in agricultural productivity growth by 1 to 1.2 percentage points. The coefficient for transport proximity for both tables is 3.2, indicating that countries with the lowest transport infrastructure index will benefit the most from any marginal improvements compared to their frontier.

4. Promoting agricultural productivity: Key lessons for Sudan

Figure 5 compares to other countries, with respect to the determinants of growth in agricultural productivity, as previously analyzed in the regressions. The figures show the case of Sudan between 1991 and 2019, compared to Egypt, Kenya, and the medians of low- and middle-income countries as benchmarks.

Figure 16 shows the evolution of the REER undervaluation, while Panel B presents the evolution of the inflation rate. The Sudanese REER undervaluation seems to hover in the area below zero more often than other countries, indicating a relatively overvalued currency. In general, the inflation rate in Sudan is also high. While there seems to have been an improvement in price stability in the early 2000s, both exchange rate and inflation reflect the deterioration in macroeconomic stability since the partitioning of Sudan. The average annual inflation rate in Sudan was as high as 51 percent and its REER was almost 1.5 that of the five-year moving average.

Figure 17 indices. Since data for indices are only available until 2010, we present their data over 1991-2010. The level of infrastructure in Egypt is much higher than that of Sudan and Kenya. In 2019, the overall infrastructure index was almost 1.5 times that of Sudan and Kenya. The level of overall infrastructure in Sudan is not only lower than the middle-income median, but for the low-income median as well. The story is not much different when looking at the individual sub-indices. Kenya seems to have consistently better infrastructure than Sudan when it comes to energy. Moreover, there was a boost in transport infrastructure in Sudan after 2008. Between 2008 and 2019, the Sudanese transport index increased by around 50 percent from 2.2 to 3.3, which most probably reflects the growth in road development.

When it comes to fertilizer consumption, Egypt fares remarkably better than Sudan and Kenya. Figure 18 shows the consumption of fertilizer in absolute metric tons (Panel A) and as a ratio to total arable land (Panel B). Egypt's fertilizer consumption is also much higher than the middle-income median. Sudan's arable land area is more than six times that of Egypt, yet its total fertilizer consumption in 2010 was no more than 15 percent of Egypt's consumption. While Egypt's fertilizer consumption was around 0.47 metric tons per hectare of arable land, Sudan only consumed 0.01 metric tons per hectare.

Sudan falls behind when it comes to human capital. Figure 19 shows the evolution of the HDI (Panel A) and mean years of schooling (Panel B) between 1991 and 2019. Sudan's HDI and average school attainment are close to the median of the low-income countries, while much lower than that of Kenya, Egypt, and the middle-income median. In 2019, Sudan's HDI was 0.51 compared to 0.21 in Egypt and 0.60 in Kenya.[12] Moreover, the mean years of schooling for the population aged 25 and older was 3.8 years in Sudan, compared to 7.4 years in Egypt and 6.6 years in Kenya.

The picture of the Sudanese economy is one of many challenges and potential areas of improvement, with respect to policy indicators, infrastructure, input, and human development. Transforming Sudanese agriculture requires a robust strategy spanning the three sets of the determinant's agricultural productivity.

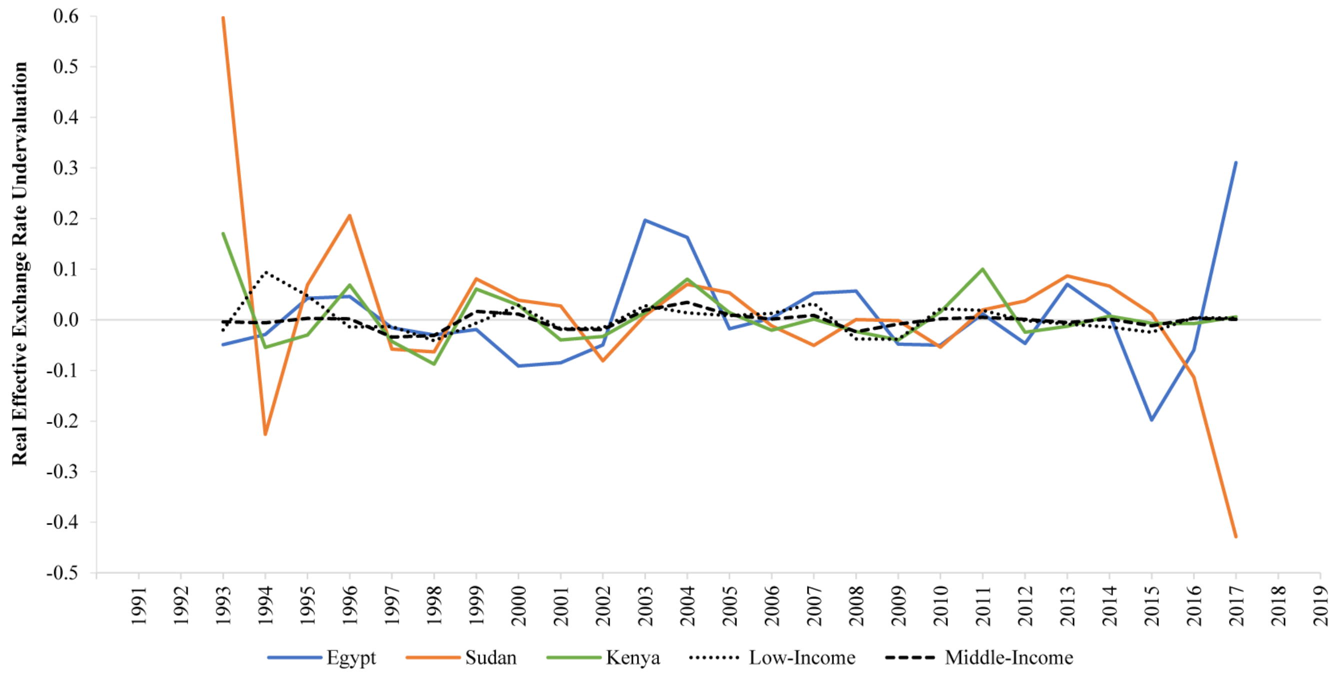
4.1 Investing in agricultural supply

Ample evidence suggests that infrastructure has considerably deteriorated following the portioning of the country in 2011 and the loss of most of the oil revenues. Therefore, infrastructure needs to be significantly developed. The value of the overall infrastructure index was 2.9 in Sudan in 2019. If Sudan were to increase its infrastructure index by 1.6 units to reach that of Egypt's (4.5), this could contribute to an increase in the growth rate of agricultural productivity by around 0.7 percentage points. Special emphasis is needed in energy and financial development, where Sudan falls behind. ICT improvements would also be of great benefits to improving productivity. Increasing fertilizer consumption could also play an important role in boosting Sudan's agricultural productivity. Although Sudan's arable land area is more than six times that of Egypt, Egypt's fertilizer consumption is almost eight times that of Sudan. This is a particularly important area of improvement for Sudanese agricultural productivity. If Sudan was to double the amount of fertilizer it uses, this could contribute an extra 0.21 percentage points to labor productivity growth. Reaching the level of Egypt's fertilizer consumption could improve the growth rate by almost 1.6 percentage points.

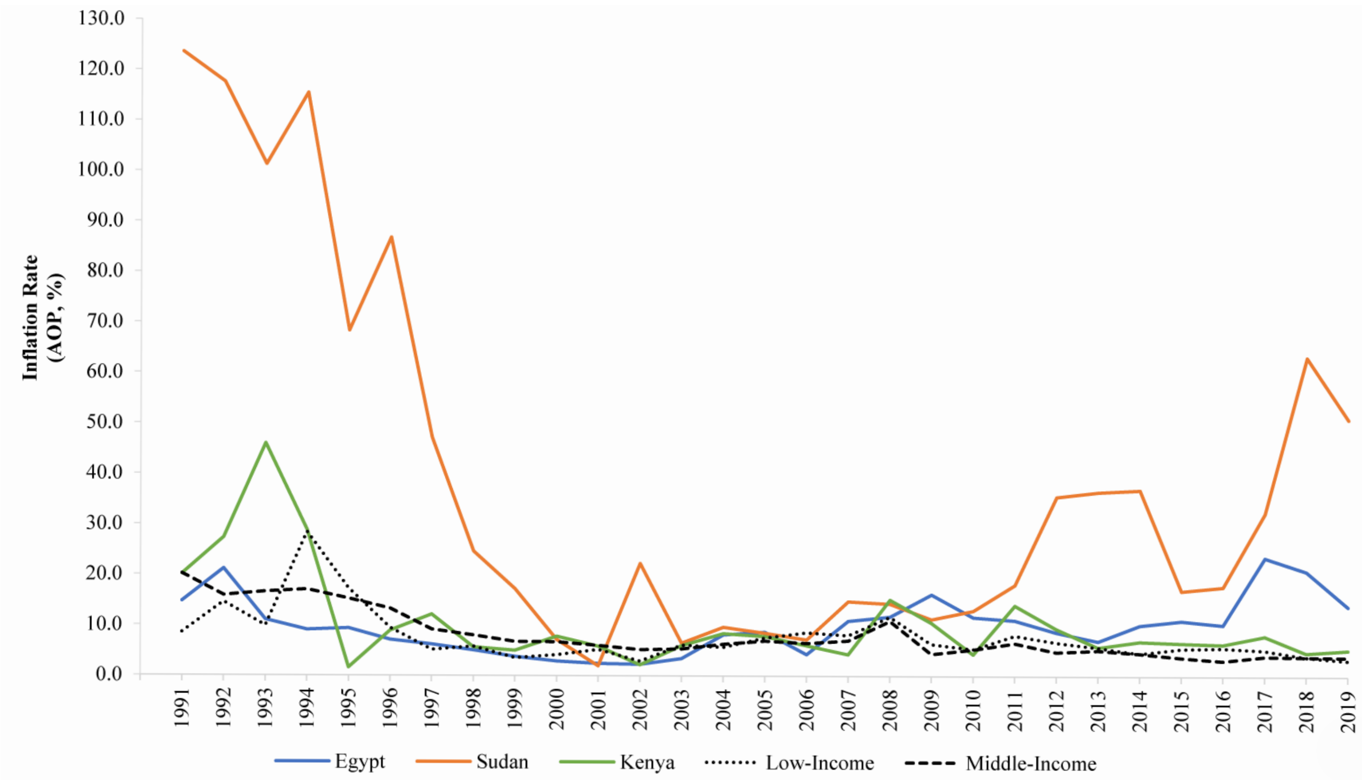
[12] The UNDP classifies a value above 0.800 to be very high, a value between 0.7 and 0.799 to be high, a value between 0.550 and 0.699 to be medium, and a value below 0.550 to be low (UNDP, 2020).

Figure 16. Policy variables: REER undervaluation and inflation rate

Panel A: REER undervaluation



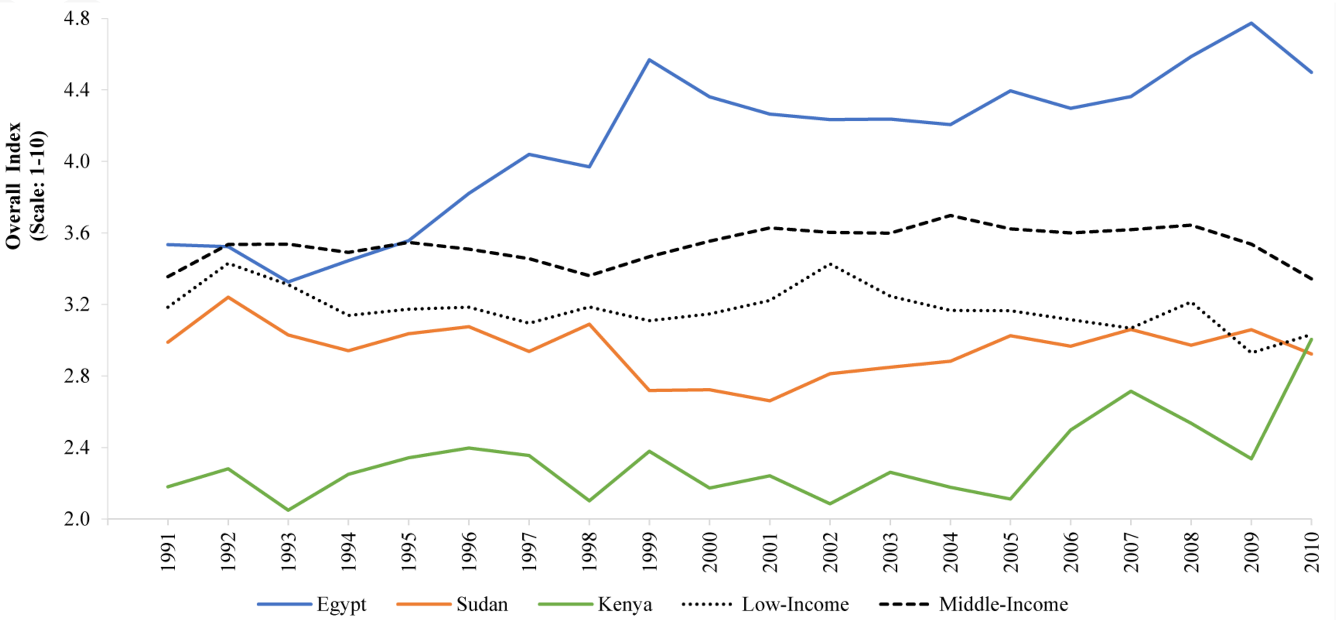
Panel B: Inflation rate



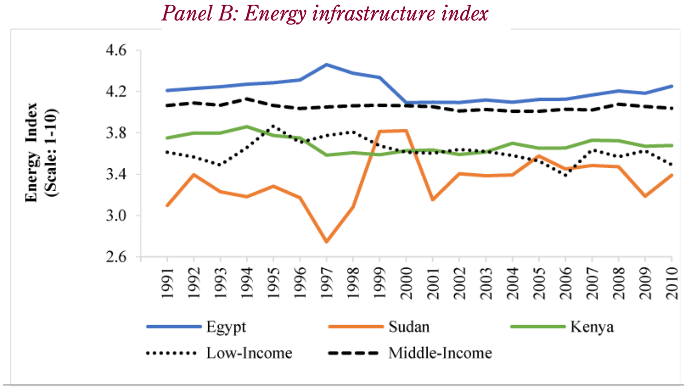
Note: This figure presents the evolution of the REER undervaluation variable and the inflation rate, over the period 1991-2019, for Egypt, Sudan, and Kenya, in addition to the median of low- and middle-income countries as defined by the World Bank. Panel A presents REER undervaluation, whereas Panel B presents the inflation rate. REER undervaluation is computed as the log of the ratio of the five-year moving average to the contemporaneous value of REER. Inflation rate is the annual consumer price index, average-of-period (AOP) value.

Figure 17. Infrastructure and input variables: Infrastructure indices

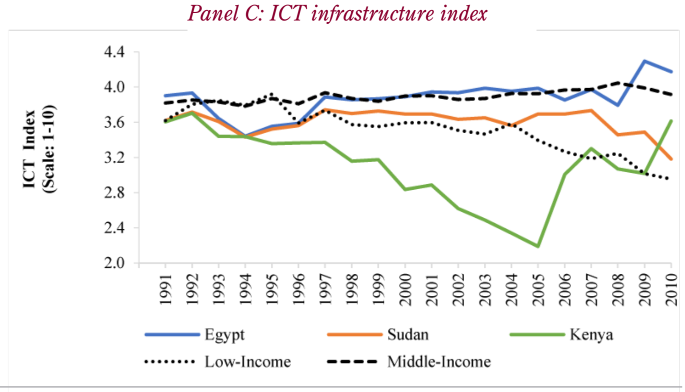
Panel A: Overall infrastructure index



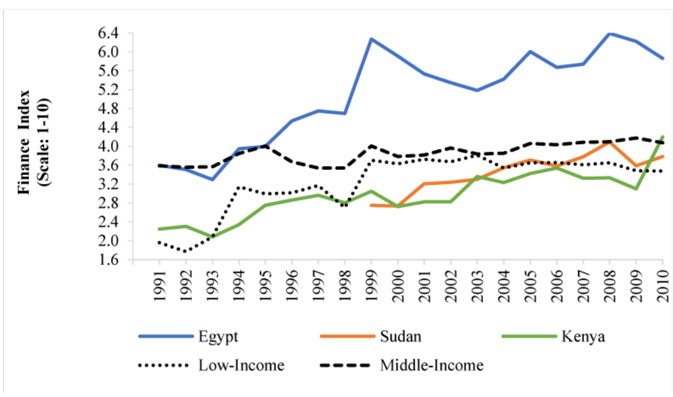
Panel B: Energy infrastructure index



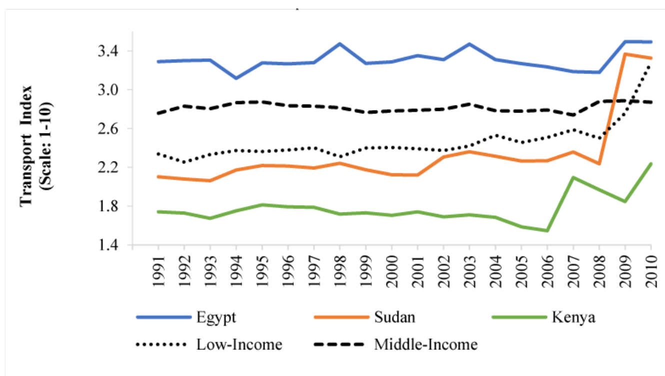
Panel C: ICT infrastructure index



Panel D: Finance infrastructure index



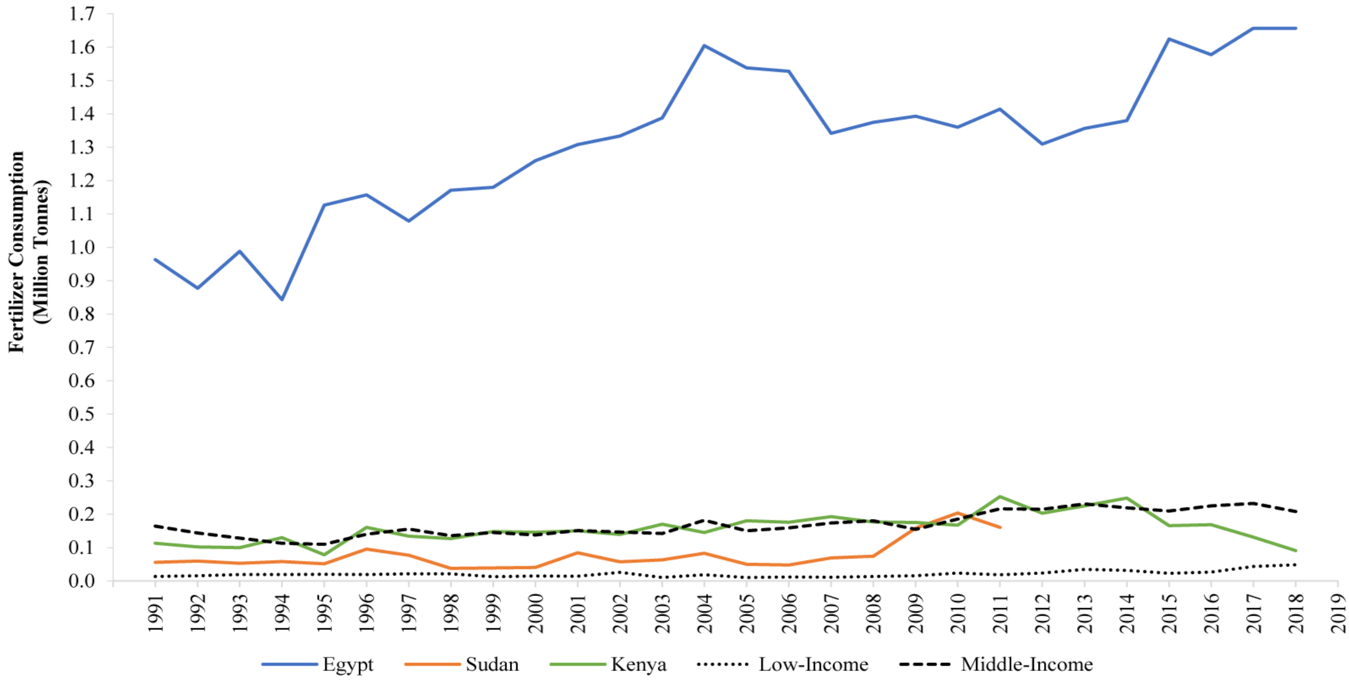
Panel E: Transport infrastructure index



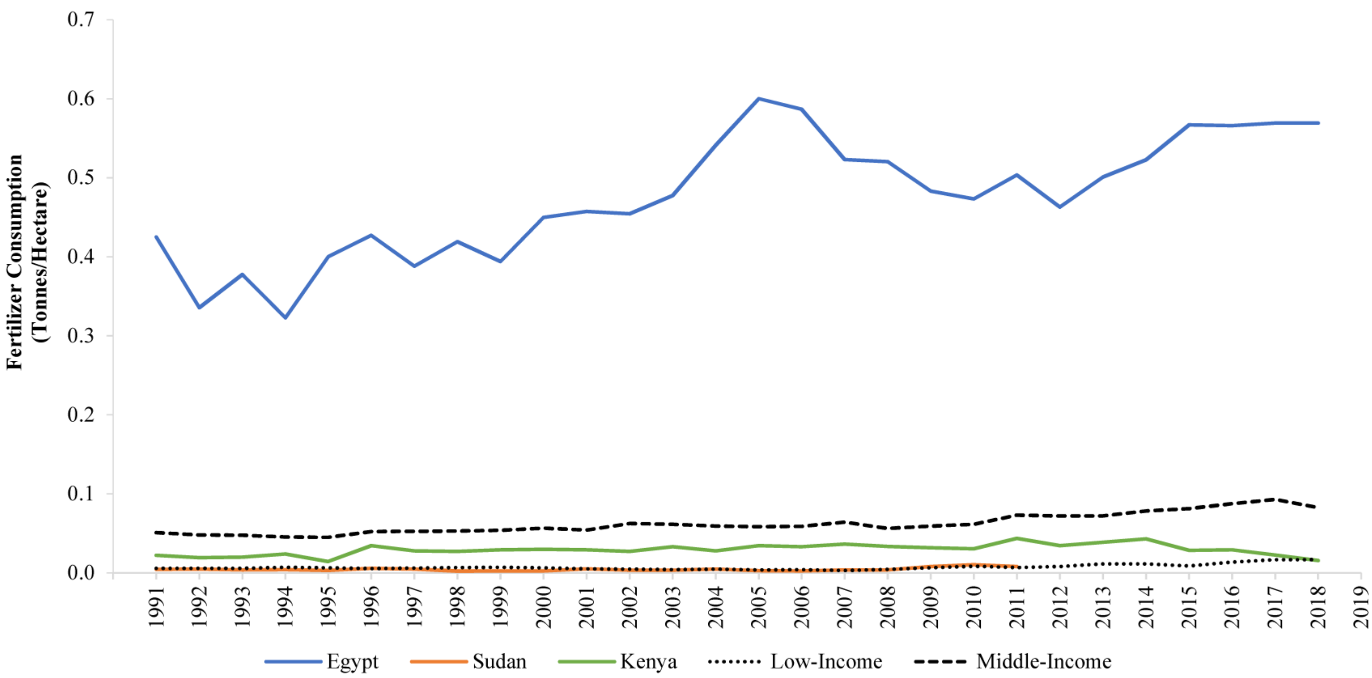
Note: This figure presents the evolution of infrastructure over the period 1991-2010 for Egypt, Sudan, and Kenya, in addition to the median of low- and middle-income countries as defined by the World Bank. Infrastructure is proxied by the indices developed by Donaubauer et al. (2016), which capture infrastructure for energy, finance, ICT, and transport. Panel A presents the level of overall infrastructure, whereas Panels B-E present the levels separately for energy, ICT, finance, and transport, respectively. All indices are scaled between one to 10 and increase with the level of infrastructure.

Figure 18. Infrastructure and input variables: Fertilizer consumption

Panel A: Fertilizer consumption



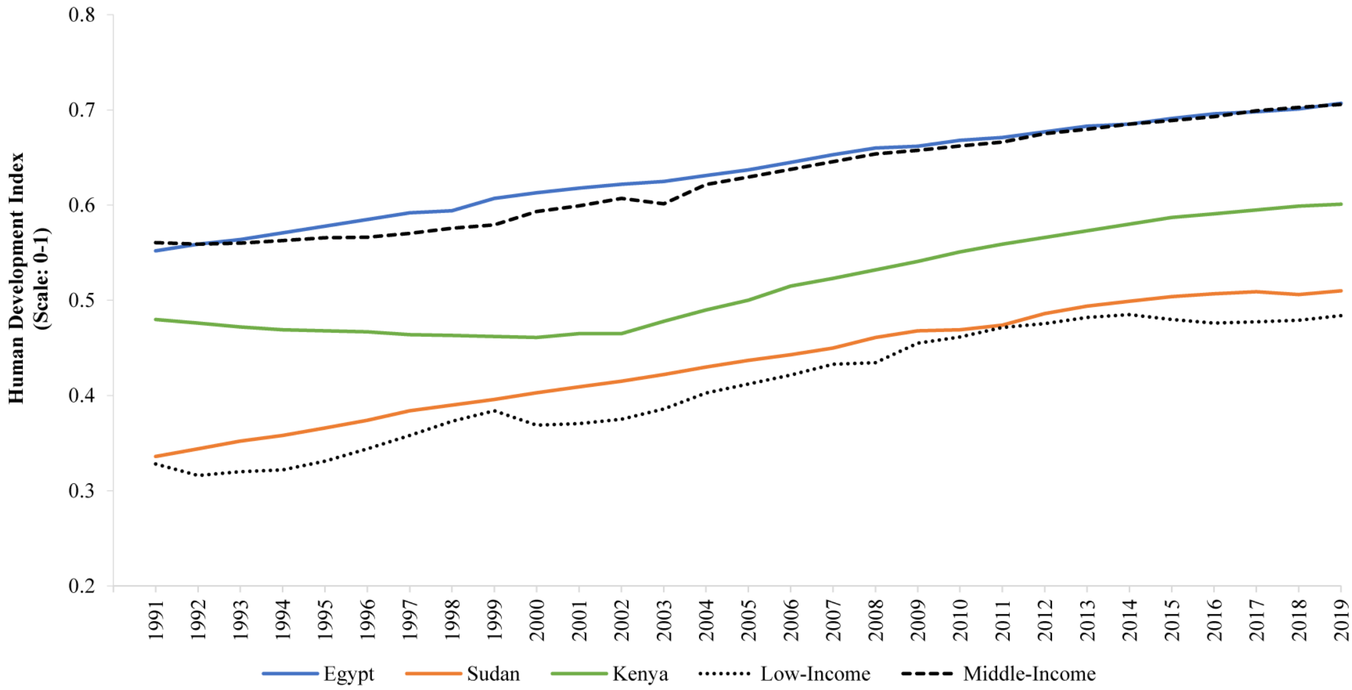
Panel B: Fertilizer consumption per arable land



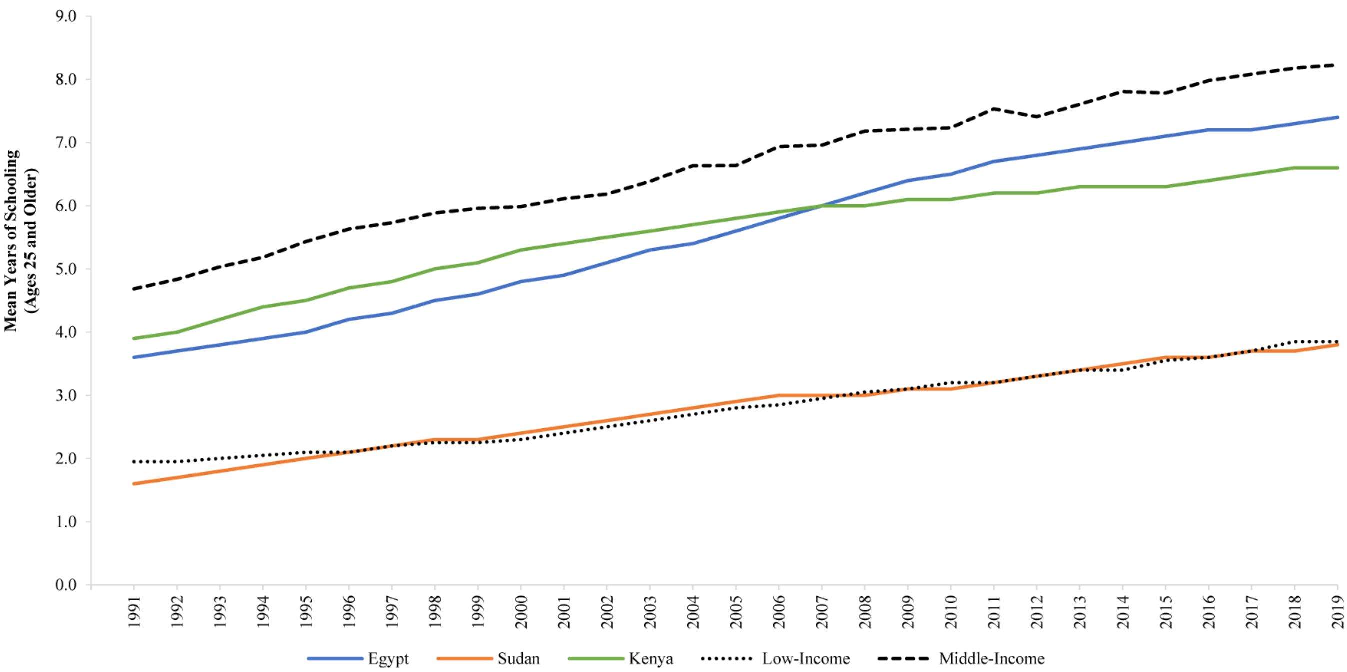
Note: This figure presents the evolution of fertilizer consumption over the period 1991-2019 for Egypt, Sudan, and Kenya, in addition to the median of low- and middle-income countries as defined by the World Bank. Panel A presents total fertilizer consumption, measured as million metric tons of nutrients used. Panel B presents fertilizer consumption per area of arable land, measured as metric tons per hectare.

Figure 19. Human capital variables: Human development index and years of schooling

Panel A: Human development index



Panel B: Mean years of schooling



Note: This figure presents the evolution of the Human Development Index (HDI) and mean years of schooling over the period 1991-2019 for Egypt, Sudan, and Kenya, in addition to the median of low- and middle-income countries as defined by the World Bank. HDI and mean years of schooling are obtained from the United Nations Development Program (UNDP). HDI is a composite index measuring average achievement in three dimensions (life expectancy, education, and standard of living). Average schooling years are for those 25 years of age or older.

4.2 Building human capital and empowering rural populations

There is no doubt that the former regime that ruled the country for some 30 years created a debilitating human development crisis. Therefore, building human capital would require a major reallocation of public spending on education and health. For example, in 2019, Sudan's HDI was 0.5 compared to 0.7 in Egypt. Working on improving the HDI to reach that of Egypt (an increase of 40 percent) could increase productivity growth by around 1.48 percentage points. However, significantly and evenly enhancing productivity in the large and diversified Sudanese agriculture would require more than operational improvements in resource allocation to the building of human capital in rural communities. As proposed by the companion paper on health, addressing the accumulated crises of the social sector in Sudan requires a transition to SDG-based budgeting.[13]

Furthermore, improved education and human capital in rural communities are the bedrock of rural empowerment, but there are other more critical instruments of direct "empowerment" that were not feasible to include in the regression, such as farmers' unions and farmers' cooperative associations. These institutions are very critical for ensuring that farmers have a voice in the society's "political market" on how public resources are mobilized and allocated among competing social groups. As indicated in Chapter I, in 2012-2014, for example, the direct share of agriculture in public investment was estimated at a minuscule 0.3 percent. This is a direct reflection of the weak political power of the disarticulated and uncoordinated rural communities in Sudan, especially the communities (more than 60% percent) that are based in the rainfed traditional sub-sector. In the same vein, the lack of political weight by the rural communities could also be attributed to the heavy burden of direct and indirect taxation of Sudanese agriculture, which we will discuss below. Finally, a robust organization of farmers in cooperatives can be an effective institutional societal instrument for efficiency of service delivery in health, education, seeds, fertilizers, and marketing of produce as well as facilitating the formation of new business models in agriculture (see Part 5 for more details on this).

[13] Despite the challenges of the political transition following the December 2018 revolution and the subsequent shocks associated with the COVID-19 pandemic, the 2020 budget espoused SDG-based budgeting, whereby the allocation for education and health was increased by almost three times. A detailed conceptual and operational exposition of SDG-based budgeting for low-income countries is provided in Sachs and Others (2019).

4.3 Ending the legacy of excessive direct and indirect taxation of agriculture

The evidence in Table 4 and Table 5 corroborates a large body of literature on the positive association between RER undervaluation and economic growth, including agricultural productivity growth. Instead (and as expected), inflation is a regressive tax on consumers and producers, most notably poor farmers, while RER volatility is an indicator of macroeconomic instability. Hence, as expected, both factors were found to be negatively associated with productivity. Therefore, throughout the Ingaz regime (1989-2019), macroeconomic policy had exacted huge costs on agriculture, due to hyperinflation and overvalued RER associated with recourse to massive deficit financing during the first 10 years of the Ingaz regime (1989-1999) and the post-oil era (2011-2019). Even during the oil era (2000-2011), the anti-developmental and kleptocratic nature of the regime meant that substantial oil resources were wasted without building the required infrastructure and the capital base for economic transformation, especially in agriculture. Indeed, the little infrastructure that existed was significantly degraded due to a lack of maintenance and new investment (more discussion in Part 2).

Furthermore, during the oil era, the sector substantially declined due to the Dutch Disease effects associated with the rising role of oil and gold in the Sudanese economy. The key factor behind the RER overvaluation is the structure of fiscal policy, which is heavily skewed toward public consumption. In fact, the country had experienced an extreme form of a Dutch Disease, which has been shown in the literature to be associated with certain symptoms: urban agglomeration associated with resource-dominated public expenditure (the case of Khartoum); the tendency of the public sector to engage in domestic and foreign debt with the implicit use of the resource base (oil) as collateral (the so-called voracity effect); the near collapse of the non-resource tradable sectors (agriculture and industry), the manifestation of which is massive rural-urban migration (the so-called "ruralization" of cities); and the meager contribution of non-oil exports. Unfortunately, even after the end of the oil era, the economy is still languishing from this disastrous legacy.

Agriculture in developing countries has been subjected to two types of taxes. First, agricultural prices are generally suppressed through marketing boards, forced procurement, export taxation…etc. This is a direct form of taxation that creates a wedge between farmgate and border prices. The second is indirect but no less impactful. This impinges through overvalued RERs, associated with unsustainable macroeconomic policies in general, especially excessive deficit financing. It is pertinent to mention that some governments have attempted to affect or partly neutralize the effects on agriculture of these interventions by investing in agricultural supply, such as irrigation, research, and extension by subsidizing input prices or extending cheap credit to farmers. However, successful agricultural transformation has been largely confined to developing Asian countries that avoided overvalued RERs and indirect taxation on the one hand and combined modest direct taxation with investment in agricultural supply on the other hand.

Elbadawi (1992) provides evidence of the direct and indirect taxation of Sudanese agriculture (reproduced in Table 6). The numbers on direct taxation provide estimates of the percentage by which domestic producers' prices diverge from those that would have prevailed in an environment with no taxes on agricultural tradables (given the actual exchange rate and the degree of industrial protection). This measure is equivalent to the rate of nominal protection (Krueger, Schiff, and Valdes, 1988). The results reveal that direct interventions have been rather substantial over the first half of the 1970s with an annual average exceeding 20 percent. For the following period, however, the direct taxation of agriculture declined considerably to average less than 10 percent per year, and in 1987 and 1988 it even dropped to less than four percent. This evidence is partially explained by the fact that the Sudanese government is apparently pursuing a policy of self-sufficiency in food grains based on extending sector-specific price protection.

The table also contains the estimates of indirect interventions, which include both the effects of trade and macroeconomic policies on the RERs, and the extent of protection afforded to non-agricultural commodities. As the numbers show, the most devastating impact on agriculture is provided by this economy-wide intervention. Since 1975, the cost of indirect intervention to Sudanese agriculture has accounted for about five times that of direct taxation. The extent of indirect taxation increased steadily from an annual average of less than 20 percent for 1970-73, to 40 percent for 1974-76, before jumping to an annual average of 55 percent during 1977-80. The cost of indirect intervention only partially declined to an average of 42 percent per annual during 1981-82, before rising to an annual average of more than 55 percent for the following years. This brief decline in NPR could not match the reductions in RER overvaluation over the first half of the 1980s. As can be seen from Figure 20, real overvaluation is transmitted into agriculture with a magnification effect.

Other and more recent contributions to the literature lend further support to the evidence provided by Elbadawi (e.g., Hag Elamin, and El Mak, 1997; Faki and Taha, 2007). Though there is no more recent evidence we are aware of, all indications show that the legacy of excessive taxation of Sudanese agriculture continues, especially during the last decade of the Ingaz regime, following the loss of more than 75 percent of the oil revenues. This period witnessed a considerable deterioration of the country's macroeconomy, while ad hoc and uncoordinated taxation of agriculture by the cash-starved states and localities reached unprecedented levels.[14]

The main lesson from this analysis for the design of macroeconomic policy from the perspective of agricultural transformation is that we need to benefit from the experience of the historical Asian state. These countries managed stable macroeconomic environments and competitive RERs while modestly taxing agriculture at the sectoral level in order to finance investment in agricultural supply (research and extensions, infrastructure, provision of finance and fertilizers…etc.). These Asian states, therefore, managed to achieve robust structural transformation within agriculture and between agriculture and industry by avoiding indirect taxation and measuredly taxing agriculture at the sectoral level to resolve market coordination failures[15] and finance much-needed investment in agricultural supply.

[14] A key associated decree to the budget of 2020 forbids the state and municipalities from taxing agricultural exports and replaced all local taxes and surcharges by a two percent federal tax.

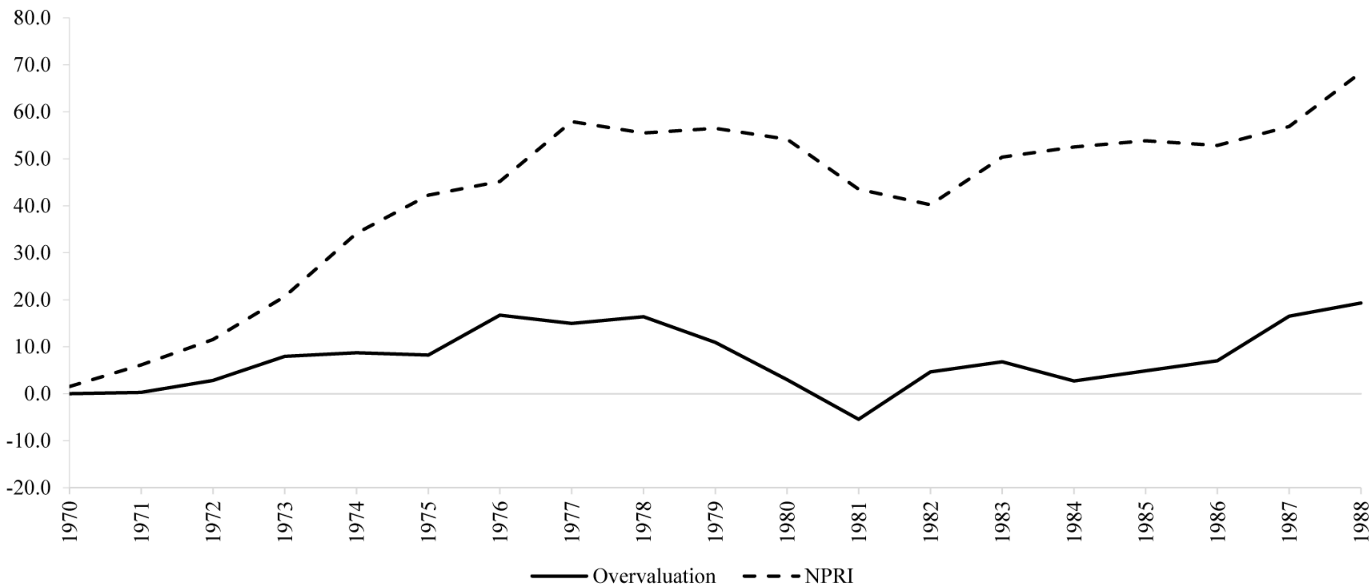
[15] This is because, left to their own devices, private farmers are not likely to invest in non-excludable public goods, such as roads, agricultural research…etc.

Table 6. Taxation of Sudanese agriculture (percent)

Year	NPRI	NPRD	NPRT
1970	1.54	20.94	22.48
1971	6.15	21.03	27.18
1972	1.53	28.39	29.92
1973	20.72	16.95	37.67
1974	34.17	15.85	50.02
1975	42.24	13.14	55.39
1976	45.17	11.32	56.49
1977	57.91	8.99	66.90
1978	55.49	8.95	64.43
1979	56.51	8.58	65.09
1980	54.17	10.08	64.25
1981	43.55	11.92	55.47
1982	40.22	12.07	52.29
1983	50.37	9.22	59.59
1984	52.51	9.67	62.18
1985	53.83	8.68	62.51
1986	52.87	5.51	58.38
1987	56.86	3.37	60.23
1988	68.37	3.76	72.12

Notes: Source: Elbadawi (1992: Table 4.2), NPRI = index of indirect rate of taxation on agriculture, NPRD = index of direct rate of taxation on agriculture, NPRT = NPRI + NPRD

Figure 20. Real overvaluation and indirect taxation of agriculture in Sudan, 1970-1988



Note: This figure presents the evolution of the RER overvaluation and the index of the indirect rate of taxation (NPRI) in agriculture in Sudan between 1970 and 1988. Data is obtained from Elbadawi (1992).

Part 2:
The Structure of Sudanese Agriculture

IV.
The Traditional Rainfed Sector

Traditional rainfed agriculture is a major production system in Sudan, representing more than 50 percent of the total national cultivated land and accommodating more than two-thirds of the country's livestock population. This sector contributes about 85 percent of Sudan's millet, 52 percent of sesame, 90 percent of groundnut, 17 percent of sorghum, and 90 percent of gum arabic, and an estimated 45 percent of cattle, 37 percent of sheep, 32 percent of goas and 65 percent of the camels are raised in this sector (El-Hag et al., 2014 and Abdalla et al., 2020). The farming systems are based on traditional systems of mixed cropping and animal husbandry systems, i.e., crop and livestock production systems that are interrelated through food, feed, investment, manure, fodder, labor, and transportation linkages.

Livestock are raised in three agro-pastoral production systems, namely: nomadic pastoralists, transhumant agro-pastoralists, and sedentary. The bulk of the livestock are primarily owned by migratory pastoralist groups. Communal range land grazing is the main source of feeding and nutrition for livestock and provides more than 75 percent of the feed needed in the nomadic systems. Due to several climatic and economic factors – such as environmental changes, drought, deterioration of natural resources, increasing settlement, expansion in farming, limited water resources, overgrazing, and blocking of the stocking routes – the traditional pastoral systems have become under pressure and the quality and quantity of feed in the ranges are deteriorating (Fadlalla and Ahmed, 1997); El-Hag et al., 2014; Osman, 2011 and 2017).

Crop production in this sector is characterized by small holdings, manual farming operations, little or no external inputs used, and farmers' limited resources. Further, farming is carried out under risky environmental conditions. This sector has been contributing considerably to the national total production and is vital to the country's food security and export revenues from the export of groundnut, sesame, rainfed cotton, and desert sheep (Osman and Ali, 2010).

Agro-industrial development in this sector is weak and still in the growing stage, and it is concentrated in limited big towns and certain states. Principal crops that have been considered promising products for agro-industrial development include groundnuts, sesame, gum arabic, hibiscus, and meat. The current industry is related to oil pressing, and small-scale oil pressing is expanding. The obsolete conditions of the current oil pressing machinery and equipment, power shortage and prices, financing, and shortages of skilled labor force remain the main challenges facing this industry.

1. Farming system components in the traditional rainfed sector

The traditional rainfed farming system is composed of the following five components: cropping system, animal system, consumption pattern, and marketing and off-farm activities. These components are interrelated and closely influenced by each other.

Traditional farming system components

Feature	Component
1. Cropping system	Based on the cropping pattern, traditional rainfed agriculture can be divided into two distinct cropping patterns developed under different climatic conditions and soil types: (a) Millet-based cropping pattern (millet is the preferred staple food crop). (b) Sorghum-based cropping pattern (sorghum is the preferred staple food crop). Groundnut, sesame, gum arabic, and roselle are the main cash crops. Other crops include cowpea, maize, and field watermelon.
2. Livestock system	The nomadic (pastoral) system is practiced by two groups: camel herders and cattle herders, with sizable numbers of desert sheep and goats. The nomads' livelihoods depend on their livestock and migrating long distances (related to the wet and dry long distances) in search of water and forage in communal grazing resources and extensive use of vast areas of rangelands. The pastoral (nomadic) system holds around 16 percent of total livestock.
	The transhumant (agro-pastoral) system. Transhumant migrate seasonally during the rainy season following traditional grazing routes to utilize seasonal grazing opportunities in the drier regions to the north and west away from biting fly and heavy mud (wet season). This system is mainly adopted by cattle-owning tribes (Baggara), who, in addition to cattle, raise considerable numbers of sheep and goats. This system is interspersed with crop production where millet, sesame, watermelon, and groundnut are cultivated along the route. Cropping activities play a relatively minor role in the system. Mechanized farms as well as traditional farming are established across or too close to many stock routes and result in frictions between several groups and disturbance of the whole migration pattern. The system holds around 60 percent of the total livestock population in the Sudan.
	The sedentary system includes both agronomic and livestock components and is dominated by cropping activities based on the bush-fallow cultivation system and intensive use of areas around settlements. Sheep, goats, and (sometimes) cattle are used for meat and milk production and as a cushion in case of crop failure. This system owns 20-30 percent of the livestock population.
3. Consumption pattern	Consumption involves both food intake by the household as well as material goods consumption. The consumption pattern influences the cropping pattern. Hence, the crops grown in the area are either used partially or totally as food or feed.
4. Marketing	Marketing consists of all sales made by farmers of agricultural products (both crops and animals) and all purchases of consumption goods by farm households (food and material goods).
5. Off-farm (off-season) activities	Off-farm economic activities are complementary and supportive to the income generated by their own farms. Off-season activities include gum tapping (off-rainy season), oil pressing, charcoal making, and dry season migration for wage labor, and others, which act as small income-generating activities, where they (one way or another) influence the cropping pattern through the purchase of agricultural inputs like seeds, tools…etc.

Osman (2018, 2020) and Elawad and Osman (1986).

2. SWOT analysis of traditional rainfed farming

Opportunities	Threats
• Main livelihood source for the majority of the rural population in the country. • Vast agricultural lands cultivation and high contribution to national food production and export proceeds. • Based on cropping and animal husbandry. production systems, which are well inter-related. • Traditional indigenous knowledge in raising livestock and producing food and cash crops. • Cooperative relations and community collective practices traditionally exist among the community to ease access to services. • Women actively participate in the production process, which mitigates the effect of males' migration. • Presence of several agricultural research stations and agricultural colleges distributed across the drylands farming sector area.	• Expansion-weak research, financial and extension services, and weak linkages among stakeholders: extension, farmers, research, private sector and financial institutions…etc. • Dominance of traditional production practices resulting in low yields and low labor and capital productivity. Some of the farmers are still operating little above subsistence level. • Limited use of improved technologies and external inputs, such as improved seeds and agrochemicals. • Poor key physical infrastructure affected access to services and inputs/inputs markets. • Complete dependence on fluctuating rain in terms of quantity, distribution, and timing. • Absent or ineffective producers' organizations weakened their decision-making power. • Shortage of labor and a high cost of labor because of the migration and the emergence of gold mining. • Limited knowledge about climate change and climate-smart agricultural practices. • Low processing activities/cleaning, packaging, storage (poor value chain development). • Conflict between individual ownership of livestock and communal land use. The seasonal movement of livestock owners inhabit the utilization of resources, including range and water.
Strengths	**Weaknesses**
• Increased awareness of the fact that agriculture is the main source of rapid and balanced economic growth. • Recently, more attention is given to this sector (political commitment). • Financial institutions started to establish services across the sector. • Mobile phone services are spreading across the sector. • Research has developed several climate smart practices for crops and livestock.	• Insecurity and social conflicts among stakeholders due to conflict over deteriorated natural resources (land, water, pastures, and forests). • Failure to reform land tenure, land use, and conflict resolution among resource users. • Climatic change and variability. • Failure to implement risk management and agricultural insurance policies to reduce risks and uncertainties. • Taxes and levies on producers levied by state and local government. • Declining interest in agriculture and the tendency of the labor force to move to gold mining.

Source: Author' analysis and Osman (2017).

3. Productivity and constraints to rainfed agriculture

The productivity of crops and livestock in this sector is very low compared to that of the world average and that obtained in the research plots (Table 7). This is due to a variety of abiotic, biotic, natural, socio-economic, and institutional factors. The most important are:

1. Ecological constraints (climatic change and variability): high evaporation, recurring droughts, degradation of natural resources (land, water range, and forest), low soil fertility, management practices, limited access to water, conflicts and over-cultivation and expansion of agriculture into traditional grazing and marginal lands, and high numbers of stock.
2. Biotic constraints: Poor genetic stock, use of traditional livestock and crop husbandry practices from land preparation to harvest, seasonal nutritional deficiencies, high cost of animal feeds (commercial concentrates) and weed, diseases, and pest infestation (crop and livestock).
3. Socio-economic constraints: poor infrastructure (such as roads, education, health services, credit, pricing, marketing bottlenecks, unavailability of inputs, conflicts among groups, communal land use), and absence of producers' cooperatives or organizations
4. Institutional constraints: lack of (or limited) research and extension (technical advisory systems), lack of (or limited) rural saving and credit institutions and livestock and crops marketing services, and poor veterinary services.
5. Policy constraints: Lack of policies for traditional rainfed agriculture in terms of credit, subsidies, pricing incentive, marketing, value chain development, lack of processing of feeds and export of by-products, and insufficiency of funds allocated to range rehabilitation.

Table 7. Average yields of the main food and cash crops by sector compared to some regional, international, and national research standards

Country/Location	Sorghum (ton/ha)	Wheat (ton/ha)	Millet (ton/ha)	Groundnut (ton/ha)	Sesame (ton/ha)
World	1.57	2.6	0.79	2.60	0.52
Africa	0.87	0.85	0.67	0.96	0.42
USA	3.31	2.7	-	4.59	-
India	0.97	2.6	0.96	1.34	0.41
Sudan (national)	0.65	2.36	0.47	0.90	0.28
Sudan (traditional)	0.59	-	0.37	0.95	0.27
Sudan (mechanized)	0.41	-	0.47	-	0.30
Sudan (irrigated)	2.16	2.40	0.81	2.82	-
Research yield (traditional)	1.29	-	0.83	1.42	0.43
Research (mechanized - Blue Nile)	1.40	-	-	-	0.88
Research yield (irrigated)	3.57	2.6	-	4.14	-
Some global recorded high yields	6.0	3.30	1.26	6.39	0.96

Assessment mission 2020, Osman and Ali (2010).

Table 8. Loss (%) in livestock productivity under traditional systems

Parameter	Desert Sheep	Nubian Goats
Breeding age	30.00%	30.00%
Offspring per lifetime	50.00%	28.60%
Calving/lambing/kidding rate (%)	36.00%	31.00%
Pre-weaning mortality rate (%)	43.00%	9.00%
Adult mortality rate (%)	15.00%	12.00%
Milk yield (liter)	-	72.00%
Milking period	-	50.00%

Source: Eco-farm research project, Report No. 71(2012).

4. Traditional rainfed agriculture transformation

The agriculture transformation in the traditional rainfed sector cannot be brought about by technology transfer alone; it must also include institutional innovations in delivering different farm inputs and producing marketing and associated services.

Interventions to enhance productivity and drive transformation in traditional rainfed agriculture by improving inputs and services delivery

The most important agricultural inputs needed to be accessed and used to enhance crops and livestock productivity include a range of materials: improved seeds, agro-chemicals (pesticides, fungicides, fertilizers, and herbicides), animal feeds, tools and implements, drugs and vaccines.

The most important services needed by small-scale farmers and livestock producers include research, extension financial, insurance, weather forecasts and climate information, animal vaccination, and market information services. Actions, constraints to be removed, and interventions to improve service delivery and enhance producers' access to inputs are presented in the table below.

Inputs and services supply chain: Main actors, constraints, and potential interventions needed to improve input delivery system and services in the traditional rainfed sector

Actors	Constraints	Priority needs and potential interventions
Small-scale farmers	• Low incomes cannot afford to buy inputs. • Input purchasing sites are far often situated in major trading centers. • Poor access to new improved varieties; farmers mainly get their seeds from the informal local seed supply system. • The size of the seed market is comparatively small, since the use of certified seeds is at best estimated at 11 percent of total requirements. • Lack knowledge and awareness of the potential benefits and market. • Lack of access to credit institutions and strict collateral requirements. • Drought and climatic risks. • Low organizational development.	• Support access to financial services by organizing farmers in groups/associations and expanding microfinance services. • Support the establishment of private input supply at the village level. • Support access to high yielding, disease and drought tolerant varieties and other climate-smart practices through linkages to extension and the establishment of demonstration plots. • Establish agricultural and livestock producers' organizations and develop a law which governs formation, organizational, legal, mandate and governance
Livestock owners	• Spread over vast remote areas with a large animal population. • Narrowing of migratory routes and sporadic conflict with sedentary farmers. • Deteriorating range land and feed resources. • Poor access to inputs and veterinary institutions and services. • Water scarcity. • Drought and climatic risks. • Low organizational development.	• Traditional migratory routes are maintained, opened all year around, and provided with water points. • Develop full and comprehensive health services at the village and pastoral camp level to further reduce the productivity problems associated with the feed supply. • Improve rural services (domestic water supplies, sanitation, primary healthcare, and basic education). • Develop the animal feed industry to make use of the crop residues and agro-industrial byproducts. • Capacity building and training of producers in disease preventative measures, rural dairy processing, and hygiene. • Strengthen the role of local institutions.
Seeds companies (including branches and agents)	• Lack of company branches across the sector; they are often situated in major trading centers. • Lack of bulk demand and perception of the market as small in size and split. • Some traders are distributing low quality seeds and not abiding by quality standards (commercial and not certified). • Very few are working on seed production and distribution inside. • Very small investment in seed production. • High cost of production of certified seeds makes it relatively costly for producers compared to traditional seeds. • No policy or legal frameworks that regulate the relationship between seed companies and breeders, research institutions, and the public seed council.	• Seed programs: rapid seed multiplication, timely supply, assured high quality of seeds at reasonable prices. • Support the establishment of seed supply at the village level and support the informal seed system • Demand in bulk through farmers' organization groups/associations. • Strict seed regulation arrangements (policies). • Develop formal community-based seed multiplication.
Livestock owners	• Spread over vast remote areas with a large animal population. • Narrowing of migratory routes and sporadic conflict with sedentary farmers. • Deteriorating range land and feed resources. • Poor access to inputs and veterinary institutions and services. • Water scarcity. • Drought and climatic risks. • Low organizational development.	• Traditional migratory routes are maintained, opened all year around, and provided with water points. • Develop full and comprehensive health services at the village and pastoral camp level to further reduce the productivity problems associated with the feed supply. • Improve rural services (domestic water supplies, sanitation, primary healthcare, and basic education). • Develop the animal feed industry to make use of the crop residues and agro-industrial byproducts. • Capacity building and training of producers in disease preventative measures, rural dairy processing, and hygiene. • Strengthen the role of local institutions.
Input providers (including retail suppliers in urban centers, dealers of animal drugs, and large-scale input firms)	• Limited capacity (e.g., mobility, budget, and training). • Limited presence of the animal wealth research corporation weakens the technical capacity of vet extension. • Inadequate transportation facilities to reach out for pastoralists and agro-pastoralists in rural areas.	• Support extension resource provision and capacity building. • Establish farmer field schools in rural communities as an effective approach to disseminating information on appropriate technologies. • Promote and disseminate climate-smart practices for crops and livestock with the participation of farmers • Promotion, knowledge, and awareness about inputs and their potential benefits and market information. • Technical support provided by research stations and universities located in target states. • With the recent expansion in the use of mobile phones in rural areas, one promising area for agricultural extension and availing market information is the use of ICTs. It facilitates the dissemination of knowledge and information to reach large numbers of farmers.

Actors	Constraints	Priority needs and potential interventions
Research stations	• Limited capacity (e.g., mobility and budget). • Inadequate number of breeders and technicians to undertake both breeding and the extra seed production. • Insufficient financial resources to cover both breeding and seed production. • Limited presence of the animal wealth research corporation.	• Resource provision. • Pilot demonstration plots (innovation platforms) in farmers' fields under farmer management and extension participation. • Private sector and university breeders and foreign companies' agents must cooperate with scientists from ASSCO.
Financial institutions	• Small-scale farmers are geographically dispersed, can be difficult to reach, and lack proper organizations. • Perceived high risk and limited focus on smallholders. • Farmers usually don't utilize financial services offered by banks because they cannot meet the conditions (collaterals, guarantees…etc.). • High transaction costs associated with small loans, farmers are geographically distributed, and smallholders carry high levels of risks (climatic, commercial). • Linkage between smallholder farmers and financial services are very weak and credit service is insufficient.	• Increase the outreach of financial institutions. • Establish formal MOUs between farmers organizations, the bank, and input suppliers. • Increase farmer access to purchased inputs. • Provide incentives for private and public sectors investors for local production and scale up mechanization and the use of small farm technology.
Farmer organizations	• Lack of established legal functioning organizations. • Lack of awareness and training about organizations and their role. • Lack of farmers' voice and influence.	• Help communities form and register their organizations to increase farmers' voice. • Farmer organizations, such as cooperatives, farmers' associations, and producer groups, offer smallholder farmers influence and support through collective action to secure better market opportunities and connect producers' organizations with financial and inputs dealers' centers. • It is essential to promote the formation and capacity-building of producer groups and train these associations in financial and business planning. • Create a strong relationship among relevant actors (farmers, extension, financial institutions and agro dealers) to strengthen and build sustainable supply systems for agricultural inputs. • Value chain development/value addition of selected priority commodities and enhance producers' quality control/grading, labelling, packaging skills/address post-harvest losses.
Insurance	• Smallholder rainfed farming is carried out under risky environmental conditions. • Insurance service is lacking or limited, involves high costs, and is ineffective. • Lack of full awareness about insurance.	• Crop insurance is most attractive when offered with other services, such as weather forecasts, extension services, and market information. • Awareness raising and insurance cost effectiveness.
Weather forecasts and climate information services	• Weather patterns, particularly rainfall, are becoming more unpredictable. • The Sudanese Meteorological Authority (SMA) has not yet developed effective weather service programs for disseminating relevant weather information at the farm level.	• Accessible weather information enables small-scale farmers in the target areas to improve their resilience in the face of erratic rainfall and climate change. • Strong early warning mechanism and forecast-based farming. • Use of mobile technology, radio, and television to surpass geographical and resource barriers.
Animal vaccination services	• Limited coverage of vaccination services and lack of routine vaccination. • Shortage of vaccines. • Spread of producers over vast remote areas with high animal populations. • High cost involved in vaccination campaigns.	• Vaccination services are provided at a cost. • Vaccination at the camp and herd levels for animals. • Enablement of a vaccination lab with the needed materials and mobility.
Market information services and market infrastructure	• Poor farmers' access to market of information to buy inputs or sell their produce. • Poor feeder roads linking main cities to other areas. • High transportation costs make inputs costly.	• Farmers and their organizations use available communication technology with main urban markets/extension to know about market opportunities. • Promote the formation of strong farmer-based marketing organizations. • Improve rural road networks to promote input-output market and reduce transaction costs.

Source: Osman and Ahmed (2016), revised.

Contract farming and smallholder transformation

Contract farming is a partnership between agri-business (investor) and farmers. The aim of this partnership is to improve farmers' access to inputs, services, and markets. Bijman, (2008) stated that contract farming is one of the institutional arrangements that may help solve the farming problems of smallholder farmers. In recent years, contract farming has been proposed as an engine for rural transformation, not just an outcome of the modernization of agriculture. Aminou et al. (2021) found that contract farming has a positive and significant impact on a number of different measures of rural transformation, such as scale, productivity, commercial orientation, and household income.

In Sudan, contract farming has been applied for some crops, such as groundnut and cotton. Usually, the company (contractor) provides improved seeds, fertilizer, chemicals, machinery, and other resources. At harvest, the company buys the produce at a much more reasonable price than the market. Despite the successes achieved from contract farming in production and productivity in Sudan, Burhan (2021) indicated that this farming has faced several problems that the state needs to intervene in and address through legislation and arrangements. The most important problems are:

- Wide variation in contract models between partners (investors and farmers), especially in the prices of inputs and produce at the beginning of harvest.
- Lack of enforceability of contracting agreements can result in either party breaking the contracts.
- Weak assurances for the investor that guarantee them the recovery of their cost, especially when the difference between the contractor and the produce market price widens.
- The emergence of sharp bargaining in the cotton (flower) market after the harvest by offering prices higher than those agreed upon between the farmer and the investor.
- Lack of the state's role in managing this system and the absence of legislation and laws that prevent conflict of interests between the parties involved in the contractual process.
- Entry of intermediaries (warrga/brokers) by offering higher produce prices (for export of cotton) for the benefit of some foreigners for the purpose of smuggling hard currency. As a result of this disorder in the field of cotton production and trade and the failure of many farmers to adhere to the conditions of the contract, the number of investors has shrunk.

Contract farming should be promoted by involving the private sector to accelerate technology transfer, capital influx, and assured produce marketing and by making necessary legislations and arrangements that back companies to expand contract farming to smallholder farmers across the traditional rainfed sector. The training and sensitization of communities to do contract farming is an essential promotional step.

Box 2. Services and inputs delivery centers model

These centers are intended to meet the needs of farmers through interacting with the relevant ministries, the private sector, and other service providers. They aim to link smallholder farmers to markets, extension, and other services such as agri-business and financial institutions and facilitate their access to information, training, storage, seeds, and farm inputs.

These centers are expected to increase farmers' access to inputs by providing a range of agricultural inputs (crop protection chemicals, fertilizers, and quality seeds of improved crop varieties), machinery services, veterinary services, and products. They are also supposed to carry out education programs to train farmers in new agronomic technologies, management and marketing skills, and access to credit to encourage the mass adoption of improved agricultural practices. These centers are also planned to be equipped with tractors and a range of implements, such as plows, cultivators, planters, fertilizer broadcasters, sprayers, and trailers to provide fee-based machinery services in addition to the sale of on-farm inputs.
These centers would be operated through coordination among the MOA (extension unit), inputs suppliers, financial institutions, and farmer organizations. Farmer organizations will receive and allocate inputs to the households and be responsible for record-keeping and following up on loan payments.

Agreements will be signed by the extension unit on behalf of the MOA, farmer organizations, and financial institutions, spelling out each partner's role and responsibilities. In addition, extension units will target a specific group of farmers for a participatory demonstration of the smart production technology package. This will enhance the adoption of these innovations to better cope with current climatic variability and its direct adverse effects on food security.

Services and inputs delivery system centers activities:

1. Establishing inputs provision centers in the localities and admin units in order to avail the needed inputs (seeds, fertilizers, pesticides, and implements) at the center level.
2. Facilitating the initiation of policies and measures that should be taken by the government and private sector, including:
   - The private sector should be mobilized and encouraged to supply required inputs to smallholders.
   - The government should facilitate access to credit (on easy terms and conditions) and dues reduction on the agricultural inputs so that many traders can enter the business and render inputs cheaper for farmers.
   - Farmer organizations should be empowered to enhance access to different financial institutions and commercial centers.
   - Technical training and market information.

Source: Osman and Ahmed (2016). Revised.

V.
Sudan Gum Arabic Sector

Sudan is the world's largest producer of gum arabic, providing around 80 percent of international gum production and exporting an average of 25,000 metric tons annually. It is a major export commodity and a significant source of cash income for the farming communities in the gum belt (Gaada et al., 2014).

Gum arabic production is concentrated within the small-scale traditional rainfed farming areas of western and central Sudan, covering an area of approximately 0.52 million square kilometers, roughly a quarter of Sudan's total area (map). It spans over 11 states and four main regions (Hamza and Rogia, 2014). Beside the wide spread of traditional rainfed farming, the belt accommodates extended areas of mechanized and irrigated agriculture; approximately two thirds of the national livestock herd, forestry, and vast grazing lands.

1. Gum arabic production

Gum is mostly produced in agroforestry systems, where Acacia Senegal is the main tree in the system grown with agricultural crops (Hassan et al., 2017). This system has significant environmental, economic, and social values. Large areas of the gum arabic belt are classified as one of the most vulnerable regions in terms of climate change, desertification, and land degradation, which negatively affected the gum arabic belt's production and boundaries. Gum arabic producers are estimated to constitute up to 20 percent of Sudan's population, or around six million people, and they are among the poorest and most vulnerable to climate change and food insecurity (Hamza and Rogia, 2014). The contribution to national gross gum arabic production among the different regions within the gum arabic belt varies as indicated by Abdel Razek (2017) and Ramli (2007):

- Kordofan region states: 50 percent
- Darfur region states: 18 percent
- Eastern region states: 16 percent
- Central region states: 16 percent

Production of gum arabic passes through phases; gum tapping is done at the beginning of the dry season, followed by collection, sorting, cleaning, transport to crop markets, packing, and storage. Marketing includes domestic and abroad marketing. Production is affected by a number of factors, including natural (biological) factors, and planning, organizational, and socio-economic factors (Abdel Razek, 2017). Climate is the greatest factor affecting production.

Figure 21. Spatial extent of the gum arabic belt

Source: Sudan's 3rd NCCC, 2022 (adopted).

2. SWOT analysis of the gum arabic sector in Sudan

Opportunities	Threats
• Sudan is the world's largest producer and exporter of gum arabic. • Production is from several states across the country. • The product has high marketing competitiveness at the local and international levels. • The natural, environmental, and human resources within the gum belt have enormous potential and are supported by climate and biological diversity. • Gum trees act as an environmental stabilizer within the gum belt and are a source of fodder and browsing. • Provides a conducive physical environment for crop and livestock production. • It's a seasonal complementary livelihood-generating commodity, where all community members participate in the gum arabic production process. • Producers have inherited experience and knowledge in dealing with gum. • Gum producer associations have been established in several production areas.	• There is a decline in gum productivity in terms of quantity and quality, and there has been a deterioration in the natural resource base. • Unstable policy innervations ranging from monopoly to liberalization have disrupted the commodity market at the local, regional, and international levels. • Production sites are distributed across wide geographical remote areas with poor infrastructures and services (drinking water, storage facilities, means of transportation, extension, official finance, education, and health units). • Lack and poor management of village nurseries for the traditional way of gum production and improper post-harvest techniques (drying, use of plastic sacks and bags). • Low prices gained by direct producers. • Lack of VA activities and export, mostly crude gum, while processing, manufacturing, and value addition take place outside of the country. • Limited research and poor technology transfer services. • Lack of effective producer partnerships with traders, exporters, and manufacturing companies.
Strengths	**Weaknesses**
• The extension service provided by the extension officers from FNC. • Growing global interest in Sudanese gum arabic and the lack of natural and industrial alternatives. • Awareness about the role of gum associations in raising the standard of living, facilitating credit accessibility, and providing loans. • The environmental importance of the gum arabic belt in reducing drought and desertification, reducing erosion rates, and increasing soil fertility. • Presence of qualified and trained cadres in research centers and universities.	• Climate change, drought, deforestation, and desertification in the gum belt. • Fire hazards, cutting, camel browsing, tree locust, and other pests. • Conflicts over resources in the gum production areas. • Seasonal labor migration to urban areas and gold mining during times of gum tapping and picking. • Poverty and the lack of adequate sources of income in rural areas. • Smuggling and marketing competition between Sudan and neighboring countries.

Source: Authors' analyses and the Gum Arabic Strategy, 2020.

3. Gum arabic producers' organization experience

Around 250 gum arabic associations were established across the gum belt (Ramli, 2007). The aim of these associations is to maximize the farm-gate returns to rural communities through the introduction of improved tree tapping and VA chain returns, raising farmers 'managerial skills through training, workshops, and field days. The main benefit from the establishment of these associations as indicated by farmers (Figure 22) are the provision of credit and how its accessibility abolished the role of peddlers, brokers, and the shell system, in addition to the provision of reasonable and suitable prices and access to extension services and water during times of gum tapping and picking. (Ramli 2007). 3. Gum arabic 4.

Figure 22. Perceptions of the Community About the Different Benefits the Association Achieved (%)

Village	Production of Seedlings	Extension Services	Access to Credit	Collective Marketing	Water & Other Services	Protection of Farmers	Reasonable Prices
Um Gezira	5.8	3.8	1.9	3.8	1.9	5.8	3.8
Merhbiba	17.3	17.3	23.1	9.6	15.4	11.5	19.2
Um Siriha	25	23.1	32.7	19.2	26.9	28.8	30.8
Um Elshik	15.4	17.3	21.2	13.7	11.5	11.5	17.3
Suntshrg	1.9	3.8	1.9	-	3.8	1.9	3.8
SuntGrb	1.9	3.8	1.9	1.9	1.9	-	3.8
Total	67.3	69.2	82.7	48.1	61.5	59.6	78.8

Source: F. Ramli (2007).

4. Recommended interventions

Constraints	Recommended Interventions
• Poor infrastructure	• Improving infrastructure and services (storage facilities, transportation, and feeder roads) at the gum arabic production areas. • Improving the availability of clean drinking water for workers during harvest season by providing and/or establishing drinking water points and supporting water harvesting and conservation practices.
• Traditional management practices • Low productivity and deterioration of the gum belt • Low regeneration capacity of hashab trees	• Encouraging the development of intermediate technologies to design suitable tools for gum arabic tapping collection and primary processing. • Adopting good practices concerning nursery operations, land preparation, and tapping techniques. • Rehabilitating the hashab forests and encouraging farmers to return to gum arabic production, • Supporting rural communities to establish community-based Hashab stands, produce seedlings, transplant seedlings, and follow up. • Providing suitable extension services: improved technology transfer and reforestation, and training on seedling nurseries establishment. • Promoting gum research and supporting relevant research institutions. • Supporting climate change adaptation and resilience through the development and dissemination of climate adaptation and resilience practices.
• Conflicts over resources and deterioration of the resource base	• Resolving conflicts on land tenure systems and resource users between different stakeholders through support and capacity building of local governance (local administration and conflict resolutions mechanisms).
• Lack of VA activities	Strengthening the gum arabic value chain through: • Enabling and encouraging the local processing and manufacturing of gum to maximize VA to exports. • Producing spray-dried gum in Sudan. • Building the capacity of gum producers on gum drying cleaning, sorting, and packing.
• Socio-economic constraints	• Setting and executing a prompt marketing strategy to develop the gum arabic sector, including the participation of local communities and stakeholders in preparing policies and strategies on the crop's production and marketing. • Developing market and information systems and improving access to information via media, mobile, SMS…etc. • Providing rural gum producers with long-term credit offers. • Promoting FNC extension services. • Developing the capacity/marketing of farmer organizations and cooperatives.

VI. Semi-Mechanized Rainfed Farming (SMRF)

According to data extracted from satellite imagery in 2007, the large-scale semi-mechanized rainfed crop production system covers an area of about 9.964 million ha. This area extends across six states: Kassala, Gedarif, Blue Nile, White Nile, South Kordofan and South Darfur, with rainfall ranging between 500 and 800 mm. The production is characterized by the use of machinery in land preparation and threshing, but it also depends on seasonal labor. Mechanized farming accounts for around 65 percent of sorghum, 53 percent of sesame, five percent of millet and almost 100 percent of sunflower production (Ali and Elasha, 2009). The major constraints in this sector include poor infrastructure, poor untimely finance, poor services, and lack of drinking water, which limits the permanent settlement of farmers.

1. SWOT analysis of mechanized farming

Newtech Consultancy, Hunting Technical Services, and P-International firms undertook the Study of the Sustainable Development of Semi-Mechanized Rainfed Farming requested by the Government (2009). The analysis of the current situation and the comprehensive recommendations for improvements are summarized below:

- The system involves the use of both agricultural machinery and labor.
- The Central Government, the state's ministries of agriculture, and traditional local authorities are all engaged in the allocation and management of land. There are thus several forms of land tenure in use. Traditional land-use and land rights, including those of livestock owners, are not respected by current laws. Sudan does not currently have a law on land use planning to guide land allocations.
- The sector suffers from extremely low yields. Smaller

Strengths	Weaknesses
• Rapid and continuing horizontal expansion. • Political intention and will to develop this sector. • Public and private agricultural research activities oriented to develop improved production technologies to this sector. • Different environments to produce different crops • Benefiting from the experiences of countries with similar sectors (Australia, Brazil, and South Africa). • Studies and preparation of land use maps for the different states. • The presence of satellite technologies and electronic digital mapping. • Legal recognition of the historical rights of families and indigenous citizens in mechanized rain lands.	• Absence of a central body responsible for land allocation, left to the authorities at their different levels (central, state, and local) with their various conditions and laws. • Extensive cultivation and expansion of un-demarcated holdings at the expense of forest and range land resulted in increased deforestation and conflicts between pastoralists and farmers. • Withdrawal of several investing companies for technical, security, and administrative reasons, and sectoral policies. • Weak agricultural finance. • Low productivity and fluctuation in cultivated areas and production from year to year. • Use of poor traditional production practices. • Weak deteriorating infrastructure. • Failure to provide effective marketing systems. • Job opportunities for most of the population end with harvest.
Opportunities	**Threats**
• Setting conditions and raising the ceiling of seasonal and medium-term financing. • Spreading ABS services through its branches in the various regions of mechanized farming to provide inputs and distribute machines and spare parts. • Encouraging the production of promising crops that have proven successful and have a rewarding financial return, such as (guar, soybean, and maize). • Expanding and diversifying Sudan's markets abroad for exports and imports, which create diversification and price competition in imports.	• Expansion of un-demarcated holdings (unplanned). • Risky environmental conditions (climate change, outbreak of pests and diseases). • Weak infrastructure and financing, poor technology, and low productivity. • Insecurity and social conflicts.

farmers get slightly better yields than larger farmers and the largest farms appear to be the least efficient, most probably due to:

- Diseconomies of scale (rising cost of production per metric ton of product due to increasing management and supervision costs of large farms and lack of good roads).
- All farmers make very low cash returns, and most schemes operate at a loss.
- Most impacts of the operation of the SMRF have been negative. These included the loss of traditional lands, and associated landlessness, degradation of water supplies, intimidation, and insecurity. Increased completion with livestock owners, conflicts resulting in loss of life, injury and destruction of property, and declining incomes and assets.

- The effects on pastoralists have been harmful. They have lost traditional grazing lands and livestock movement routes, suffer from a loss of water supplies, low productivity, and have experienced a reduction in herd sizes due to a shortage of good quality pasture.
- There are large areas of forest and rangeland which have been destroyed through the encroachment and expansion of mechanized farming. All soil resources used are degraded through the exhaustion of nutrients and compaction, severely limiting their ability to absorb moisture and respond to rainfall. The degradation has also damaged water catchments and led to the siltation of Hafirs.

In summary, the SMRF farming sector is in serious disarray, with attendant major public and private costs and negative implications for all stakeholders.

2. Main contributing factors to the current situation

- Policy: Governments have supported increases in area under cultivation rather than increases in productivity per unit of cultivated land. The areas under un-demarcated or legally undocumented holdings have increased substantially.
- A succession of laws since colonial periods have reduced the rights of traditional users of land, in favor of mechanized farming schemes.
- Sectoral management has been poor over a long period, with a lack of coherent sector-wide policy and confusion over the roles of different levels of government. There has been a lack of capacity in providing services and administration.
- Farmers have extremely low levels of investments in plant, equipment, and farm improvements.
- The capacity for the provision of effective extension services by federal and state governments is very weak.
- Finance provided by the Agricultural Bank of Sudan and other commercial banks is limited and late.
- Marketing is poorly organized, and markets lack liquidity and absorptive capacity.
- The SMRF sector is constrained by extremely poor rural roads, with no all-weather access available to most farming areas. There is little rural electrification, and poor water supplies for humans, animals, and agricultural use. Good telecommunications are available only in big towns and main roads. Most areas lack public facilities for the storage of grains.
- The method of levying and collecting Zakat on production by rainfed farmers needs revision because it is levied as a flat 10 percent charge on gross revenue, rather than on net returns or profit.
- The imposition of various levies and charges is a burden on cash flows. Contractors and service providers are also obliged to charge 15 percent VAT, which mainly affects small producers.
- Strategy for land use: very large improvements in crop yields per ha are possible within the scope of known technology and practices. The strategy will be to encourage the realization of such potential through a combination of technology promotion, applied research, targeted financing, and intuitional reforms. The higher yields will free up space for the use by currently disadvantaged smallholders and livestock owners and allow for the generation of natural resources. In general, support should be provided to small farmers, medium-scaled enterprises of less than 1,000 feddans, as well as to scheme owners with up to 5,000 feddans. While larger corporate farms would not be disallowed, they would not be encouraged because they have proven to be inefficient users of natural resources, are not financially or technically sustainable, and their size precludes land-use by other potential users such as new farmers and pastoralists.

3. Recommendations for action: Immediate actions

Domain	Recommended Action
• Institution arrangement for reform	• A Transitional Facilitation Commission for Rainfed Farming Reform (TFC-RFR) should be formed. This would be a temporary institution, designed to enable the rapid and effective reform of the sector. • The TFC-RFR would support the revival of institutions for rainfed agriculture, particularly at the state level, relating to land tenure, refinancing of farmers and contractors, targeted rural infrastructure investment, demonstration and application of improved technology, revival of applied research, development of viable markets, and development of complementary relationships between rainfed farmers and pastoralists.
• Institution arrangement for reform	• The National Land Commission (NLC) proposed as part of the Comprehensive Peace Agreement (CPA) should be made fully operational without delay. There should be an audit of land in each state to establish the current status of land tenure and use. A standardized system of leaseholds for rainfed farming offering sufficient security for investment would be established.
• Establish a technology transfer system	• Resolving a technology transfer system would be established as soon as possible. Demonstration farms would be established on existing operating semi-mechanized farms. The Rainfed Farming Extension Department Team (RFEDT) would be provided by a contractor to support implementation.
• Technology	• The central feature would be moisture management. There would be emphasis on: • Timeliness of operations. • Improved use of existing machinery. • Improved use of purchased inputs. • Improved cultural practices. • This would be accompanied by the introduction of modern machinery and technology for sustainable impact. Conventional "tillage" and the more innovative "zero tillage" would be used. Different rotations would be applied for different agro-ecological zones, but a leguminous crop would be included in all rotations. Fodder production would be encouraged where appropriate to the farming system. Gum arabic on 10 percent of the area would be a feature in suitable areas for the crop. Development of a viable inter-relationship between rainfed farmers and livestock producers would be a priority for extension.
• Taxation and zakat reform	• VAT should be abolished on the provision of agricultural services. • There should be an immediate reform of the methodology for collecting zakat.
• Marketing	• A study should be carried out to outline a framework for successful marketing.
• Agricultural finance	• A study should be carried out to recommend necessary reforms.
• Investment in infrastructure	• A study was recommended to come up with detailed recommendations.
• Large farms	• A rationalization strategy needs to be made to revitalize public sector mechanized enterprises.SMS…etc.

4. Recommendations for Action: Medium- and Long-Term Actions

Domain	Recommended Action
• Agricultural financing – loan finance	• Provision of loan finance for low-input farming should stop immediately. Strict lending criteria should include improved technology and use of financial planning methods.
• Recapitalization of matching grants	• These would complement loans for innovation. Grants would be for specified investments for machinery, which would allow the adoption of new technology (e.g., planting, tillage, and spraying equipment).
• Revitalization of research	• Long-term sustainable development of the sector should be supported by research results. Three research stations would be established, one in each major agro-ecological zone (low, medium, and high rainfall zones). Research would include livestock production integrated into rainfed farming systems.
• Marketing	• Federal government requirements concerning the import of agricultural chemicals, seeds, and machinery should be rationalized and streamlined. • The government should facilitate the cross-border trade in sorghum and agricultural produce. • Gum arabic marketing should be liberalized. • Contract farming should be encouraged.
• Investment in infrastructure	• The Infrastructure Needs and Assessment and Prioritization study should orient the necessary investment in infrastructure. This will include feeder and access roads, clean water supply, and sanitation.

VII. Toward a New Irrigated Subsector Model

Sudan's irrigated farming is concentrated mainly along the Nile Riverbed and its tributaries, which is the source of water for more than 90 percent of irrigated agriculture. Based on the irrigation water source and the size of the irrigated holding, farming includes:

1. Public production schemes (Gezira and Managil, Rahad, Suki, New Halfa): Gravity flow is the main form of irrigation. The main crops grown are sorghum, wheat, cotton, groundnut, and vegetables.
2. Pump schemes: private and public, large and small, and rely on pumping water from the Nile and its tributaries (scattered in the White Nile, Blue Nile, and the main Nile). Crops grown include cotton, groundnut, sorghum, wheat, sugar cane, fruits, vegetables, and grain legumes.
3. Flood irrigated schemes (Abu-Habil, Tokar, Gash Deltas): these rely on seasonal streams. The main crops grown are sorghum and cotton.
4. Small-scale irrigated cultivation along the riverain lands of the northern and Nile states, relying on diesel pumping water from River Nile. Land is scarce and cultivation is year-round and has a strong horticultural base. Main crops grown are wheat and winter legumes.
5. Large-scale investment farming: this farming extends in the northern and Nile states, occupying vast areas of the plains. Lucerne and Rhodes fodder are the principal export crops grown using center pivot sprinkler irrigation water of the Nile or underground water. Land deals for this farming have increased considerably in recent years. Large-scale land acquisitions for agricultural investments are characterized by purchases and/or long-term leases by wealthier private investors (individuals or companies, mostly foreign, from Arab countries).

1. SWOT analysis of the irrigated sector: Public production schemes

Strengths	Weaknesses
• Availability of a good natural resources base (land, water). • Spread in 11 states. • Use of different irrigation systems (gravity-sprinkler-flood (recession)). • Well-established infrastructure (irrigation system and some agro-industry structures). • Experienced and trained human resources. • Distinctive geographical locations. • Diversity in crop production (food, cash, forage and horticultural crops). • Food security guarantee in case of partial or total failure of the rainy season. • Potential for introducing promising crops and modern agriculture technologies.	• Deterioration of irrigation infrastructure. • Differences in irrigation network management between agriculture and irrigation authorities. • Weak supportive agricultural services (funding, marketing, training, and access to inputs and modern technologies). • Low productivity and poor value chain development. • Difficulties in applying modern agricultural technologies.
Opportunities	**Threats**
• Political will and government priorities to promote the agricultural sector. • Openness to the outside world facilitates the process of attracting investments. • Promising agricultural research technologies and existence of research stations and universities. • Availability of raw materials and opportunities for agro-industry. • Presence of untapped ready infrastructure and facilities. • The National Road and some agricultural roads linking the states. • Distribution of faculties of agriculture provide trained manpower in all areas of specialization.	• Political instability. • Climate changes and natural factors (desert encroachment, receding Nile). • Accelerated inflation rates and their impact on agricultural inputs, production costs, investment opportunities, rehabilitation programs...etc. • State and local fees and taxes. • Displacement of a large number of farmers and agricultural labor to cities and migration to gold mining areas. • The complexities of land acquisition.

Source: A.M. Eltaieb: revised and translated

2. SWOT analysis of the small-scale irrigated cultivation along the Nile

Strengths	Weaknesses
• Fertile, renewable land. • Very direct access to irrigation water source. • Relatively higher yields. • Diversified, high-value winter crops. • Close to market and service centers.	• Smallholdings subject to splitting (inheritance). • High dependency on fuel (high production cost). • Low level of mechanization and dependency on manual labor. • One cropping season. • Limited financial capital and access to financial institutions. • Fluctuating market.
Opportunities	**Threats**
• Accessible and close to main roads. • Potential for renewable energy use (solar, wind) and electrification.	• Sand movement threatening Nile bank. • Climate change (short winter season and frequent flooding). • Trend among youth to move to gold mining.

3. SWOT analysis of the flood irrigated schemes

Strengths	Weaknesses
• Good geographical locations. • Renewable soil fertility (silting). • Rainfall, surface, and flood water sources. • Established water infrastructure (irrigation canals, water flow regulator-admin facilities). • Presence of some agricultural research stations and agricultural colleges. • Employment opportunity during the season.	• Deterioration of infrastructure (roads, canals silting-regulators breakdown) and lack of routine maintenance. • Unstable or unsettled land use rights. • Unclear laws and regulations regarding production relations. • Traditional production practices and reduced productivity. • Seasonality of production. • Weak research, financial, and extension services. • Weakness/lack of linkages among stakeholders. • Limited use of improved technologies and external inputs and access to inputs-outputs markets. • Lack of processing and poor value chain development.
Opportunities	**Threats**
• Financial institutions started to establish services. • Presence of several NGOs and projects working in agricultural development.	• Entire dependence on seasonal streams and flood water. • Environmental degradation, drought, and climate change. • Expanded invasion by mesquite trees in agricultural lands. • Conflict between pastoralist and sedentary farmers. • Tendency of labor force to move to gold mining.

4. Current situation

The total area under irrigation is estimated at 1.681 million ha, which accounts for around 10 percent of the total cultivated land. However, this sector produces important crops, including sugarcane, cotton, sorghum, groundnuts, wheat, vegetables, fruits, and green fodders. The irrigated schemes, and in particular Gezira, Rahad, and New Halfa, have witnessed a rapid deterioration in infrastructure and productive capacity. This deterioration is manifested in the following:

1. Deteriorating operation and management conditions as a result of underfunding of O&M activities.
2. Heavy silting of minor canals in need of cleaning to enable effective and efficient water distribution.
3. System operation suffers from insufficient staff, inadequate and inaccurate measurement, and poor communications.
4. Degraded infrastructure, and irrigation and roads need rehabilitation and modernization.
5. Loss of irrigated lands due to degraded infrastructure and changes in farming systems.
6. The wide level disc used in land preparation changed the farms or tenancies into bowl-shaped fields with deep centers suffering from excessive watering and shallow peripheries suffering from water stress.
7. High sedimentation loads leading to maintenance costs and the increasing siltation of canals.
8. Aging farming population and growing dependence on sharecropping arrangements.
9. Current land tenure arrangements are not conducive to the aggregation of farms for contract farming.
10. Holdings are generally too small to provide income for the family, so there are many part-time farmers with outside jobs.
11. Extremely low extension staff to farmers ratio.
12. Farmer unions are ineffective and are now in transition to commodity-based producer associations.

5. Modernization of the irrigated sector

Many initiatives were proposed during the last three decades aiming to rehabilitate and modernize the irrigated sector, but none of them were implemented due to a lack of finance and political will. The latest and most promising was initiated by the Arab League. The Arab League decided to achieve food security for the Arab countries through the Sudan project. Lahmeyer International, in association with

SES consultancy (2016), prepared a study exploring the agricultural resources potential of Sudan in depth and proposed 24 projects (including the modernization of Gezira, Rahad, and New Halfa schemes, which account for about 75 percent of the total irrigated lands) intended to contribute to achieving food security for the Arab countries.

Keywords for the modernization of these schemes are:

a) GIS data to be developed.
b) Status quo assessment through rapid appraisal procedures.
c) Irrigation scheme hydraulic simulation.
d) Land tenure.
e) Institutional and management structure.
f) Technical aspects for canal modeling.
g) Cropping pattern and future production model.

Modernization of Gezira will be limited to one-fourth of the scheme in the first phase and then later replicated. This consists of 200,000 ha. The estimated costs are:

a) Off-farm costs: USD 400 million
b) On-farm costs: USD 100 million
c) Central pivot development: USD 600 million
d) O&M: five percent of investment costs plus one percent for desilting
e) EIRR: estimated 32 percent
f) Implementation: three years

For the Rahad Project, the modernization area is 126,000 ha. Preliminary on and off-farm costs are USD 250 million plus USD 380 million for pivot development. EIRR is 32 percent. For New Halfa, the modernization area is 126,000 ha. The preliminary on and off-farm costs are USD 328 million plus USD 380million for pivot development. EIRR is 37 percent.

The modernization of the irrigated subsector would bring multiple benefits for the national economy, the rural communities, and the private sector, including:

a) High potential for improved productivity through the recovery of irrigated lands and increases in yields.
b) Production of a range of high-value crops for export and for import substitution, including groundnuts, sunflower, wheat, sugarcane, green fodder, cotton, fruits, and vegetables. Sorghum will be excluded due to lack of competitiveness but will be compensated for elsewhere in the rainfed sector.
c) Farmers can form groups for contract farming.
d) Investors can rent land from farmer groups for contract farming.
e) Private sector companies will provide mechanization services and establish ginneries, textile factories, and oil mills.

The modernization of the irrigated subsector calls for detailed feasibility studies, huge capital investments, and robust programming and prioritization. If the requirements are provided, it may take 10 years to complete the modernization of the irrigation subsector.

Summary of the recommended interventions for the irrigated sector

Constraints	Recommended Interventions
• Deterioration of the infrastructure of irrigated schemes	• Rehabilitating and modernizing the irrigation water infrastructure (detailed feasibility studies, huge capital investments). • Developing ginning and oilseeds crops, milling, and the animal feed industry. • Reestablishing machines and agricultural engineering centers attached to irrigated schemes. • Establishing a telecommunications network between the administration and offices spread in the field and irrigation water distribution sites. • Improving infrastructure and services (storage facilities, transportation, and feeder roads) • Completing the project to restore the internal railway to transport cotton from the gins and production inputs to offices, fields, and produces to processing sites. • Rehabilitating the railway net for within and between inputs produce. • Establishing a communication system (admin-field office-irrigation water points distribution).
• Poor management practices and dependence on manual operations	• Fully mechanizing agricultural operations from planting, harvesting, and post-harvesting operations. • Providing technical management (input supply, contract farming, land tenure issues, private sector involvement…etc.). • Providing suitable extension services through improved technology transfer activities. • Promoting linkages with regional research institutions. • Reestablishing improved seed multiplication farms in the irrigated schemes.
• Lack of agro-industry VA activities	• Developing the value chain: promoting industrial crops that can be used in agro-industries such as cotton, peanuts, vegetables, juices, and others. • Enabling the processing and manufacturing of produce in order to maximize VA to exports through the rehabilitation of the irrigated schemes' agro-industry infrastructure (ginning textile, oilseed, milling, vegetables, juices, animal feed industry, and others). • Enhancing producers' quality control/grading, labeling, packaging skills, and addressing post-harvest losses.
• Socio-economic constraints	• Setting and executing a prompt marketing strategy, developing marketing and information systems, and improving access to information via media, mobile, SMS…etc. • Providing producers with long-term credit offers. • Mobilizing farmer unions and producer associations. • Developing the contract farming system (the relationship between the investor and the farmer) through the two forces and the regulations governing this relationship.

Part 3: *Transforming Sudanese Agriculture: Institutions and Empowerment*

VIII. Establishment of Agricultural Commodity Development Councils

Many countries have used commodity councils to promote their socio-economic development. This approach is particularly appropriate for commodity-dependent countries like Sudan because it facilitates the integration of all the activities along the commodity chain by linking all the stakeholders involved in the production, marketing, export, processing, and consumption of that commodity. In this study, the focus will be on certain commodities chosen based on Sudan's comparative advantage in the production of these commodities, the magnitude of the local and international demand, and the competitiveness in local and international markets. The commodities chosen are characterized by the ability to induce regional and national economic and social development.

The programs for the development of commodities include establishing a development council for each commodity or group of related commodities, implementing a package of incentives for the producers, and promoting applied research, the transfer of technology, and the improvement of marketing.

The advantages of this approach are as follows:
- The development of some commodities induces socio-economic development in wide geographical areas.
- Efficient use of resources.
- A forum for all stakeholders in the commodity supply chain improves cooperation and helps reach a common understanding of strategies and requirements for development.
- This approach ensures sustainable production of the commodity because it strengthens all the components of the commodity chain: research, production, processing, marketing, and export.
- It has a direct impact on poverty reduction and therefore it can get government and donor finance.
- It is a quick and easy-to-monitor way of achieving the objectives of development.
- The commodity focus helps maintain quality standards and upgrade the technical and business skills of producers.

1. Proposed TOR of the councils

The TOR of the councils may be summarized as follows:
- Analysis of the present situation of each commodity with respect to production, consumption, and domestic and export trade.
- Identification of the strengths, weaknesses, opportunities, and challenges.
- Exploring the opportunities for growth to meet domestic and international demand.
- Recommending a package of incentives and policy reforms to support commodity development programmers which fulfill the following objectives:
- Increase productive efficiency.
- Emphasize the rational use of resources.
- Promote fair competition and eliminate monopolistic practices.
- Strengthening agricultural support services, including applied research, credit for producers, and the adoption of a quality control system.
- Increases the share of Sudan in the markets of the traditional trading partners and access to new markets.
- Prioritize commodities that promote interdependence between the different parts of the country.
- Emphasize the processing of exports to add value.
- Promote partnerships between national and international private sectors.

2. The role of the government in the establishment and support of the commodity councils

The Ministry of Finance and Planning and other relevant ministries should initiate the establishment of these councils in consultation with stakeholders. The government has a key role at the start-up stage in terms of financial and technical assistance.

3. General guidelines for the operation of the councils

The following matrix presents a possible agenda to be considered by the councils when they draft their specific TORs:

Commodity	Topic/Intervention Area	Specific objectives/Issues
Cotton	• Promoting the cotton textile industry	• Learn from previous successful textile factories i.e., the Sudanese Textile Factory. • Learn from the Hasaheisa factory operated by Turkish investors. • Learn from Bangladesh as a successful cotton manufacturing and exporting country. • Expand rainfed cotton production. • Promote the textile industry and export textile products instead of lint.
Livestock	• Livestock and red meat	• Increase and improve livestock production in production areas through the provision of veterinary services, the improvement of pastures, and the availability of water. • Locate slaughterhouses and meat-canning industries based on socio-economic and technical feasibility studies. • Stop exporting live animals and concentrate on exporting meat to increase VA. • Adopt the Hazard Analysis Critical Control Point (HACCP) system, which ensures food safety at all points in the food chain, from the stage of production to final intake by the consumer. It is required in international markets.
Skins and hides	• Processing of skins and hides	• Improve the quality of skins and hides from production to slaughter and adopt a strict grading system. • Stop exporting raw skins and hides. • Establish special industrial areas for processing skins and hides. • Promote the shoes and leather industries, especially in regions with a comparative advantage, such as Kordofan, Darfur, and Omdurman. • Transfer leather technology from countries advanced in this area e.g., Italy, Brazil…etc.
Milk	• Milk and milk products	• Increase milk production by improving local milk breeds. • Introduce exotic, high yielding breeds. • Store, collect, and distribute milk benefiting from the Dal project and taking lessons from the Indian experience for self-sufficiency in milk.
Fish	• Fish and aquatic species	• Upscale aquaculture in fresh and marine water. • Develop pearls and shells in the Red Sea. • Utilize and develop fish resources in Lake Nuba.
Wildlife	• Wildlife and natural habitat	• Develop the natural habitat in a sustainable way. • Promote exports of wildlife products. • Promote tourism.
Wheat	• Wheat	• Realize self-sufficiency based on technical, economic, and financial feasibility, and build reserves to meet consumption needs for two years. • Increase productivity and production in existing production areas through research and extension • Expand rainfed wheat production in Jebel Mara, explore the potential of growing wheat under irrigation from valleys in Darfur and establish wheat mills locally to meet the demand of the Darfur region. • Identify constraints and problems of composite flour and propose feasible solutions leading to the substitution of sorghum for wheat.
Cereals	• Sorghum, millet maize, rice	• Emphasize sorghum production in the rainfed sector and reduce the sorghum area under irrigation. • Develop the production of maize in the rainfed sector. • Upscale rice production under flood in the White Nile and in the irrigated schemes. • Build national and local (State) strategic grain reserves.
Sugar cane	• Sugar cane	• Increase productivity in existing schemes. • Operate the White Nile sugar factory by overcoming the technical and technological constraints. • Increase the area in Blue Nile and Southern Gezira, Upper Atbara Project based on comparative advantage.
Oilseed crops	• Vegetable oils sesame, groundnuts, sunflower, cotton seed, and soybeans.	• Utilize idle capacity in local oil factories. • Stop the import of raw oils for local processing to protect locally produced oils. • Upscale soybean production. • Stop exporting oil seeds and export good quality oils.
Gum arabic	• Gum arabic and forestry products	• Rehabilitate the gum arabic belt. • Eliminate taxes and levies that distort gum arabic marketing. • Encourage the processing of gum Arabic (not just treatment crushing and granulation) and move away from export of raw gum with a view to adding value. • Review the international specification which equates between gum arabic and Talh.
Fruits and vegetables	• Fruits and vegetables	• Enhance the use of tissue culture as a method of multiplication. • Ensure the availability of fruits all year round through appropriate transport and storage. • Adopt the HAACP system to promote exports. • Emphasize processing (concentrates, juices…etc.) to add value and reduce losses.
Local manufacturing of inputs	• Local manufacturing of agricultural inputs	• Promote local manufacturing of agricultural inputs, including fertilizer pesticides, herbicides and agricultural equipment and machinery, irrigation pumps, spare parts, transport vehicles, packing materials, protected houses, fishing equipment, dairy equipment, forestry equipment…etc.

Commodity	Topic/Intervention Area	Specific objectives/Issues
Women and youth	• Women and youth	• Improve access of women and youth to factors of production, especially land and capital. • Provide training and skill development opportunities. • Upscale the program for training agricultural entrepreneurs financed by the African Development Bank. • Strengthen the information and communications program by facilitating the access of youth trained in ICT to international technology companies. • Examine the example of Bangladesh (working from home arrangements).
Strengthening producer organizations	• Strengthening producer organizations	• Examine how to organize producers to reduce transaction costs and increase bargaining power. • Study the role of producer cooperatives in negotiating with MFNE to reduce taxes and levies on gum arabic. • Use community-based organizations to promote the production and marketing of good quality seeds in South Kordofan with assistance from IFAD. • Utilize farmer field schools as a vehicle to improve the knowledge and skills of farmers and provide access to improved technology executed in two states affected by conflicts: South Kordofan and Blue Nile.

IX. Overview of Sudan's National Agricultural Research System (NARS)

1. Introduction

Sudan's National Agricultural Research System (NARS) includes several research institutions. The Agricultural Research Corporation (ARC) and the Animal Resource Research Corporation (ARRC) are the main agricultural research agencies, representing the bulk of the country's total agricultural research spending and staff numbers. Other government institutions involved in agricultural research include the National Food Research Center, Higher Education Colleges, the National Center for Research (NCR), and the Hydrology Research Station (HRS). Agricultural research performed by the private sector in Sudan is minimal and is mostly focused on sugarcane. The present structure and features of NARS and its SWOT analysis are presented below.

Research executing institutions	Affiliation	Main features	Research focus and mandate
Agricultural Research Corporation (ARC)	A semi-autonomous public organization with a legal identity under the Federal Minister of Agriculture and Forestry.	ARC is the principal research organization in Sudan, responsible for conducting most of the applied research in the different fields of agriculture. It has a network of 27 research stations and 14 specialized institutes and centers distributed throughout the 18 states in the country.	• Research on the diversity of commodities and disciplines: • Crop production and protection, biotechnology, agricultural engineering and machinery, horticulture, animal production, forestry, range, water, soil, food technology, socioeconomics, and conservation of genetic resources. • ARC has released various technologies that have significant impacts on productivity, such as improved crop varieties, improved cultural practices, soil and water management, forestry, and animal production practices.
Animal Resources Research Corporation (ARRC)	ARRC is under the Ministry of Animal Resources and Fisheries (MARF) established in 1995.	ARRC consists of the Central Veterinary Research Laboratory, the Animal Production Research Center, the Fisheries Research Center, the Wildlife Research Center, and a network of 22 regional veterinary laboratories and animal production research stations.	• Principally charged with identifying diseases and epidemics that constrain animal health, production, and export; developing disease control mechanisms; and conducting research on wildlife within their ecosystems. The central veterinary research laboratory of (ARRC) is diagnosing diseases and isolating local pathogens to produce vaccines. The laboratory currently produces more than 15 types of various vaccines, viral, bacterial, and mycoplasma.
National Center for Research (NCR)	Ministry of Higher Education and Scientific Research, and has a similar status to Sudanese universities	NFRC consists of nine research departments: animal products, canning technology, food chemistry and nutrition, food safety and biotechnology, cereal technology, oilseed technology, post-harvest physiology, food dehydration technology, and economics and marketing.	• Principally charged with different food type technology research including different aspects of food establishment, maintenance: preservation, processing, packaging, distribution, and use of safe food. Related fields include food chemistry, biotechnology, nutrition, quality control, food safety management, and marketing.
Hydrology Research Station (HRS)	Ministry of Irrigation and Water Resources located in Gezira (Wad Medani)	HRS is a pioneer center for water research activities in Sudan. Established in 1976 through help from UNDP, it lends support for sound and sustainable national water resource development and management.	• HRS conducts agricultural research activities, accounting for a combined four percent share of Sudan's total public agricultural research capacity. HRS investigates conveyance systems of irrigation water, along with issues of weed control and siltation in the irrigation canals of the Gezira Scheme. Over the years, HRS has established a reputable record of research achievements in areas like river training, sediment transport and management, irrigation engineering and management, and water resources planning and management.

Research executing institutions	Affiliation	Main features	Research focus and mandate
Faculties of: Agriculture and Natural Resources, Forestry, Veterinary Medicine, and Animal Production	Ministry of Higher Education and Scientific Research	Traditionally, some agricultural research is carried out by Khartoum and Gezira universities. With the expansion of the higher education sector in several agricultural and animal productions, natural resources institutions have been established across the 18 states of the country.	• The overall agricultural research conducted at these new faculties is generally very limited and weak and mostly confined to graduate student studies due to underfunding and a lack of research management structures and facilities. Research conducted includes crops, pastures and forages, natural resources, socioeconomics, forestry, animal health, animal production, dairy, and gum arabic
Kenana Sugarcane Company (KSC) Private Research	A private company	Research conducted by the private sector in Sudan is minimal. Many of the larger companies outsource their research to ARC, ARRC, and the universities. KSC conducts research on sugarcane improvement and production.	• Kenana Sugarcane Company (KSC) and the Guneid Sugar Company (GSC) both conduct applied research to promote and maintain high sugarcane yields and reduce production costs. These programs are well coordinated with ARC. ARC also carries out fertilizer and pesticide tests on behalf of a number of chemical companies, but these activities are limited.

Sources: authors review, ARC strategy (2007), Fadlalla and Ahmed (1997), Gert and El-Siddig (2010), Nienke et al. (1995), and Gert et al. (2013).

3. NARS SWOT Analysis

Strengths	Weaknesses
• Rich heritage of agricultural research and achievements (more than 100 years). • Well-structured research system (within institutions). • Good coverage across the country. • Qualified research staff (Masters and PhDs). • Linkages and collaboration with regional and international research centers. • A rich stock of developed and improved technological packages for main products. • Scientists are strongly oriented toward applied research. • Presence of national technical committees with representation from various stakeholders: universities, national schemes and private sector companies entrusted with the evaluation and approval of the release of agricultural technologies developed.	• Lack/poor coordination and linkages among NAR institutions and relevant stakeholders resulting in poor dissemination of research findings and feedback. • Poor link between crop and livestock research. • Weak linkage with private sector and limited private sector contribution in research. • Limited abroad training of research staff in recent years. • Deterioration of basic infrastructure. • More attention to education rather than applied research (universities), and university staff is underutilized for research purposes. • Weak financial resources and funding is almost entirely by the national government and donor funding is limited. • Research is predominantly on-station with limited participatory, adaptive on-farm and system-oriented approaches. • Loss of highly qualified and experienced researchers who were trained abroad due to accelerated retirement. • Imbalanced distribution of researchers over various research stations and centers and disciplines.
Opportunities	**Threats**
• Increased demand for improved technologies. • Intension of international research centers to collaborate with NARs. • High attention, strong official support, and recognition of research role. • Existence of externally funded projects. • Global advances in technology should improve research access to efficient research technology, such as biotechnology and genetic engineering.	• Poor allocation of budget and resources. • Deterioration of infrastructure. • Poor training of research staff. • High competition for limited resources among various domestic research institutions in light of limited coordination and optimal resource distribution. • Inactive engagement of the private sector in promoting demand-driven research and research financial capacities.

Source: Authors' analyses, ARC strategy (2007)

4. Financial resources and sources of funds

Spending on agricultural research is stagnant. Moreover, research lacks adequate operating and capital funds and relies on national government budget funds to carry out its research activities. Major sources of funding for research include the national government budget, contributions from the public sector, funds from external sources in specific fields of research, testing fees for agrochemicals, and revenues from the sale of farm products. The last two items represent a minor share of the total funds available. Available data in 2012 indicated that research spending allocation was 80 percent for salaries, eight percent for operating and program costs, and only 11 percent for capital investments. Funding sources are, 92 percent government, two percent donors, and six percent sales of goods/services (Gert-Jan Stads and Kamal El-Siddig, 2010; Gert et al., 2013).

4.1 Links

For a long time, research institutions, particularly the ARC, have developed a wide network of linkages with a variety of both regional and international organizations. Examples of such institutions are the International Center for Agricultural Research in the Dry Areas (ICARDA), the International Center for Research in the Semi-arid Tropics (ICRISAT), the International Service for National Agricultural Research (ISNAR), the International Plant Genetic Resources Institute (IPGRI), the International Center for Maize and Wheat Improvement (CIMMYT), the International Institute for Tropical Agriculture (IITA), the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), and the Food and Agriculture Organization (FAO).

For furthering the partnership with international research centers, Sudan joined the CGIAR fund in 2014. As a donor to the CGIAR fund, Sudan will benefit from the world's largest agricultural research partnership in the fields of development and dissemination of improved crop varieties, sustainable agroforestry, and integrated crop-livestock systems.

5. Research in the traditional rainfed sector

5.1 Introduction

Sudan's major export commodities i.e., gum arabic, sesame, groundnut, roselle, and sheep come from the traditional rainfed sector. Despite this, the sector has been practically ignored for a long time and most of the research in the past was directed toward solving the problems of either irrigated agriculture or the big, mechanized rainfed production schemes. Little research has been carried out in the small-scale/pastoral systems. To rectify this situation, emphasis has been put on improving production in the small-scale traditional farming sector, the leading attempt in this regard being the establishment of Western Sudan Agricultural Research Project (WSARP) in 1979. The project was funded by the United States Agency for International Development (USAID) and the World Bank. WSARP was officially placed within ARC, but the project was effectively run as an autonomous operation with its own budget and administration (WSARP Records 1979-1986).

5.2 Research approach

Agricultural development in the traditional rainfed areas has been facing a multitude of technical, biophysical, socio-economic, and institutional constraints that cannot be tackled by a single commodity research approach. Accordingly, from the start it was decided that a farming system research/extension approach, is more suitable for serving the traditional farmer who grows field crops, rears animals, and raises tree crops such as gum arabic (Acacia Senegal). ARC adopted this research approach in western Sudan, conducting both on-farm and TCR in a multi-disciplinary fashion (Winch 1984).

The farming system research/extension approach assures community involvement and participation in technology development and evaluation through on-farm research/demonstration. The outcome of the work is expected to be socially acceptable and affordable, environmentally sound, and economically feasible. Backup research to support, complement, or verify the on-farm research interventions is a must (Osman and Abuelgasim, 2004; Osman, 2020).

Interventions and achievements: during its operation in the traditional rainfed sector of western Sudan, ARC made significant contributions and impacts on agricultural development. These contributions are well recognized at various levels by beneficiaries as well as service providers (government, development projects, and nongovernmental organizations). These contributions include the development and release of improved crops, livestock, gum arabic, and forestry production technologies. Several scientific papers were published in refereed journals as well as local, regional, and international workshops. In addition, ARC stations in western Sudan have carried out several training sessions and consultancies related to development issues (DLRC, 2005).

5.3 Dryland Research Center (DLRC)

In 2005, the Agricultural Research Corporation established the DLRC to improve the production of agricultural crops, livestock, forestry, and natural resources using an integrated farming system perspective, in an environmentally sound, gender-sensitive, socially acceptable, economically feasible, and sustainable manner.

DLRC operates in Kordofan and Darfur. It has eight main research stations, in north, south, and east, west, and central Darfur and three in north, west and south Kordofan. The director of DLRC is in charge of the research and work under the responsibility of the ARC Director. The station directors resume their technical and administrative responsibilities at the station level (DLRC, 2005).

6. Grant institutions system to improve NARS effectiveness

Strengthening Sudan's agricultural research system is a key component in addressing the country's increasing food insecurity, reducing poverty, and enhancing export revenues.

Several research institutions, such as the ARC and ARRC stations and the agriculture, animal, and natural resources colleges and centers, are present in the 18 states of Sudan. Coordination among these institutions is lacking or poor. For efficient use of resources (human, financial and physical), quality multidisciplinary research, better dissemination of research results and integrated research programs, and a grant institutions system can be applied to promote the three functional pillars of the grant institutions i.e., teaching function, research, and extension. Grants to research institutions are intended to replace the fragmented research organizations in the state with a multidisciplinary approach. Grant institutions offer their resources to original agricultural research, bringing the research developed agricultural technologies to farmers through agricultural extension, analyzing agricultural value chains; thus contributing to the success of farms and rural businesses. Teaching functions are combined with all activities to train university graduates. Research institution resources plus federal and state support are combined. This act also requires that the states provide matching funds in order to receive the federal monies. Grant institutions' system requirements include:

- Setting research priorities and resource allocation and conducting research on issues of state interest.
- Participation of the different stakeholders in program formulation and implementation.
- Linkages with national, regional, and international research institutions.
- Building the capacities of researchers, technicians, and supporting staff to be trained abroad for long- and short-term training alongside short within-country training.
- Physical rehabilitation: immediate upgrading of research functions and quality and rehabilitation of the research infrastructure.
- Strengthen research on production economics marketing and human resources and integrate crop and livestock research.

X.
The Seed Industry in Sudan

1. Seed systems in Sudan

Seeds are basic agricultural input, and quality seeds of improved varieties represent the foundation for agriculture transformation. They lead to higher quality yields and high prices. More importantly, quality seeds of any preferred varieties are the basis of improved agricultural productivity. An effective seed system should guarantee the availability of quality seeds to farmers at the right time and place and at affordable prices.

The seed systems in Sudan can be divided into informal and formal systems. The characterization of each system is presented in the table below. The main stakeholders involved in the seed industry are the Ministry of Agriculture, the National Seed Council, the Agricultural Research Corporation, the Variety Release Committee, the Seed Administration, and private seed producers and farming communities.

Characterization of the seed systems

Characteristic	Informal system	Formal system
General description	• Also known as farmer, local, and traditional. • Community-based. • Farmers save from their own harvest and receive donations from friends, neighbors, and relatives, or they buy from local grain markets or traders.	• Introduced or developed by plant breeding. • Release of varieties and the subsequent multiplication and dissemination of the released varieties.
Type of varieties and crops	• Local landraces or mixed populations. • Food and subsistence crops.	• Improved varieties. released through research. • Imported and hybrid varieties. • Major food and cash crops.
Seed quality	• Variable quality (variation in purity, physical, and physiological quality).	• Standard/quality governed by regulations intended to maintain varietal identity and purity.
Seed production and distribution	• The seed production/distribution chain is community-based, short, and simple, without any regulations	• Guided by a regulatory framework. • Improved seed is produced in an organized chain of institutions of seed production and quality control. • Marketed through officially recognized outlets.

Source: Osman (2014), revised.

The majority of farmers, particularly in the traditional rainfed sector, get their seed supply from the informal seed system. In the informal system, the seed production/distribution chain is short and simple, without any regulations. As a result, this system provides almost all the local varieties of seeds.

The formal sector supplies certified, improved, and imported hybrid varieties. The average estimated national coverage of certified seeds is only around 12 percent (Baseline survey, 2011). The formal seed system in Sudan is led by the private sector after the government policy change toward the privatization of seed production activities. The government's role is now concentrated on quality control through the Seed Administration (SA) of the Ministry of Agriculture. It is the body responsible for maintaining quality control, enforcing policy and seed certification standards, conducting variety evaluation, release, and registration, and moving seeds across the country borders. According to the Baseline survey, the constraints facing the SA include:

- Lack of transport facilities necessary for field inspection. Inspectors rely on companies and common transport.
- Inability to allocate enough resources for the SA to fulfill its mandate of quality assurance and control.
- Shortage of well-trained staff. Most of the staff and members are new graduates with inadequate experience and training.

The role of private investment in the seed industry is very small due to several factors, including (Baseline survey, 2011):

- Production of improved high-quality seeds is faced with higher production risks and needs, compared to normal commercial crop production.
- The rate of returns from investment on seed production is generally lower than the rate of returns from the other industries. Therefore, the seed industry receives fewer investment funds.
- Seed production involves a set of technical steps that are tightly linked together. Failure of any of these steps would lead to total crop failure and/or rejection of the produced seeds. Hence, there is more risk and loss of investment money.

2. SWOT analysis of the seed sector

Strengths	Weaknesses
• Presence of an organized chain of institutions for maintaining quality control and enforcing policy and seed production. • Providing farmers with quality seed goes back to the 60s of last century. • Increased farmers' awareness and willingness to use new improved variety seeds. • Seed production stations were linked to research stations where the breeding programs took place. • NGO/development projects and seed aid distribute seeds of improved varieties.	• The demand and market size for improved seeds is relatively low, due to poor promotion, marketing, and high prices. • Lack of trained personnel and a limited number of breeders. • Most farmers depend on their own crops produce as a source of seeds. • Deficiency and inadequate supply of foundation seeds of the released varieties. • Lack of incentives and policies encouraging the private sector to invest in the seed industry. • Distribution difficulties in the traditional rainfed sector due to the low demand and poor purchasing and infrastructure. • SA lacks adequate funding, facilities, staffing, and training. • Seed companies prefer the importation and distribution of vegetable seeds because of the high profits, and because no risk is encountered. • Most of the companies lack the basic facilities necessary for seed production (equipment, storage facilities, graders, and packing containers required to prepare seeds).
Opportunities	**Threats**
• Prominence of the new released verities to withstand biotic and abiotic stresses. • Government and donors' intervention to improve seed industry infrastructure. • Engaging the end users in participatory variety selection.	• Unfavorable climatic conditions. • Low demand and high production cost. • Pests and diseases.

Osman and Ahmed, 2016, Mutasim (2021), revised.

3. Seed security framework

The table below outlines the fundamental elements of seed security: seeds must be available; farmers must have the means to access them, and the seed quality must be sufficient to promote good production (FAO, 2012).

Fundamental Element of Seed Security	Seed Security	Key Intervention to Promote
Availability	• Sufficient quantities of seeds for appropriate crops are available within reasonable proximity and in time for planting.	• Support the establishment of seed supplies at the village level. • Linkages with research, the Federal Seed Administration, financial Institutions, and extension. • Develop a formal community-based seed multiplication. • Pilot demonstration plots of improved varieties (innovation platforms) in farmers' fields.
Access	• People have adequate income or other resources to purchase or barter for seed.	• Local seed procurement. • Demand in bulk through farmer organization groups/associations; collective action to secure seed supply. • Support access to financial services through organizing farmers in groups/associations and expanding microfinance services.
Quality	• Seed is of acceptable quality: varieties should be 'healthy' (physiological, analytical, and sanitary) adapted, and acceptable to farmers.	• Efficient extension services and awareness campaigns. • Seed quality control and compliance with seed certification regulations.

Source: FAO (2012), adapted and revised.

4. Some major steps to accelerate the use and demand of improved varieties

Key needs for supporting sustainable seed enterprises are:

1. Educational awareness campaigns and increased promotional activities (variety demonstrations, farmer field days) by community seed producers to stimulate the demand for improved varieties.
2. Access to credit is vital to the development of seed enterprises for the purchase of inputs.
3. Develop partnerships and linkages with other services providers (research, formal seed sector, financial services, extension, federal seed administration, private seed companies…etc.).
4. The development and promotion of the seed production market for smallholders is one of the most effective measures for stimulating the development of seed enterprises.
5. Support the development of seed regulations, laws, guidelines, and protocols for quality seed production.
6. Foundation seed multiplication and processing:
7. Foundation seed, also known as basic seed, is the descendent of breeder seed and is produced under conditions that ensure maintaining genetic purity and identity. The benefits from released improved varieties can only be realized when they are grown commercially on a large scale and become available to farmers for commercial cultivation. The seed production system chain includes four basic links: ARC plant breeders, private seed companies, the Seed Certification Authority, and seed end-users (i.e., farmers). However, this chain faces one major constraint; ARC has faced difficulty in producing sufficient quantities of foundation seed for certified seed production to the private seed companies to get involved in the activities of the chain. Accordingly, maintaining adequate quantities of foundation seed of a cultivar can be promoted through:

- ARC should be supported to establish seed multiplication and processing units and sites to increase its capacity to produce a sufficient quantity of foundation seed.
- Adopt plant breeders' rights (PBR), also known as plant variety rights (PVR), as a form of intellectual property protection that gives plant breeders control over the new varieties for a number of years. With these rights, the breeder can choose to become the exclusive marketer of the variety or to license the variety to others (PVR, 2013).

XI. Strengthening Farmers' Cooperatives and Producers' Organizations

1. Introduction

Community-based organizations

The traditional rainfed production system, which is scattered throughout the country, is characterized by being unorganized and without collective actions. In fact, no communities were organized into community-based organizations (CBOs), community development committees (CDCs), or societies to meet agricultural development demands and challenges except those associated with some developmental projects devoted by the international interest to form CBOs/CDCs. Moreover, Amal Bushara (2012) noted that the lack of community organization in the agricultural rainfed sector had placed the following challenges and implications on the path of rural development:

- Communities, individuals, and poor families have no voices or power as long as they are unorganized to take decisions in their favor throughout the production cycle.
- The creation and existence of middlemen affect the market prices, which reduces farmers' benefits.
- Limited or no access to external inputs, market, credit and financial resources, and improved production technologies.
- Unbalanced gender roles are always associated with an unorganized community, as there are no opportunities for organized meetings, contacts, training, and decision-making. Organizations offer participation opportunities for women and create women leaders. Adding to this, gender balance is ensured and confirmed in the existence of gender policies, especially when it is supported by the external donors' fund.

Hence, interventions to organize communities have become crucial to face all the above challenges (A. Bushara, 2012).

Cooperatives

On a global scale, the cooperative movement is guided by the following golden principles:

- The democratic principle of one vote per man/woman.
- Profits are distributed among the members in proportion to their contributions to the capital of the society.
- Easy access by all individuals in the community irrespective of gender, ethnicity, economic status, or political affiliation.

Cooperatives were introduced in the northern part of Sudan in 1920 during the British colonial period. However, the official movement started in 1949 as the government accepted the recommendations of a British consultant (Campbell) to establish the official body of cooperation. Since then, the movement expanded geographically and across sectors. In 1989, there were 4,725 cooperatives in Sudan, 422 of which were agricultural cooperatives with 1,132,213 members (Muneer, 1989). Recently, according to the ILO, there were 3,332 primary cooperatives, 2,000 of which were in the agricultural sector. However, cooperatives have been riddled with many problems which limited their growth and impact, including:

- Lack of commitment to the basic principles resulting in exclusion, elite capture, and (sometimes) embezzlement.
- Lack of basic infrastructure of cooperatives.
- Lack of finance and inputs. The cooperative bank has been converted to AlNile Bank, which has nothing to do with cooperatives.
- Institutional issues (governance, political interventions).
- Lack of confidence and vested interests.

For these reasons, efforts have been made by the government and donors to reform the cooperative movement, benefiting from lessons learned from other countries with conditions similar to those of Sudan.

2. Roles of the revitalized cooperatives

- They are potentially useful ways of providing bundles of services to farmers, thereby connecting them with input and output markets (Diwan, I. et al.). Cooperatives could also enable farmers to coordinate planting and harvesting schedules in order to avoid saturating markets.
- They also create economies of scale; farmers can aggregate crops and sell in bulk to an exporter or processor and demand a higher price.
- Farmers could also collectively hire trucks and drivers to collect their produce at harvest time, rent a warehouse/storage space, pay for extension services, and information and technology services to determine prices and demand elsewhere…etc.
- Cooperatives could also give farmers credit to allow them to purchase farm inputs.

3. Recent examples of successful cooperative societies in Sudan

3.1 Use of productivity enhancement inputs (seeds, crop protection, animal health)

Based on evidence derived from completed and ongoing IFAD co-financed projects, the timely availability of good quality seeds is one of the critical factors for productivity increase. Historically, traditional rainfed farmers select their own seeds. So far, the percentage of certified seed used for sorghum production (the highest area cultivated using certified seed) is 15 percent.

The Ministry of Agriculture in South Kordofan experimented with two models of seed production (MOASK, 2011):

- Production by a CBO at Abbassya-Tagali
- Production in Habila State Farm

The CBOs were trained on the basics of seed production. In Habila, all production activities were carried out by graduates of agriculture.

Comparing yields of the improved sorghum variety produced under the two models, members of the CBOs in Abbassya achieved an increase of more than 200 percent over Habila State Farm. The yield of groundnuts achieved by the CBOs improved the profitability of groundnut production. The two experiments showed positive net returns for all crops in the two locations, with CBOs realizing a 300 percent increase over Habila in sorghum.

The advantages enjoyed by members of cooperatives over non-members were demonstrated by a case study of groundnut farmers in Enahud district, West Kordofan (Ali Abdelrahman and Cathy Smith, 1993). The study examined groundnut net income effects for agricultural cooperative members and non-members. The comparison between the two groups showed that members of cooperatives had higher incomes compared to non-members, strongly supporting using cooperatives as a means for agricultural development.

The good performance of the CBOs in seed production and their ability to disseminate improved seeds to the farming communities qualified them for further support and upscaling. The success of upscaling depends on the following prerequisites:

- Creating an enabling environment for the private sector, including the CBOs, to ensure the sustainability of the production of improved seeds.
- Improving the regulatory framework through the enforcement of the Seed Act and capacitating and empowering the National Seed Administration to carry out its seed quality regulatory functions effectively.
- Increasing the supply of good quality and appropriate varieties of seeds of all classes of crops and ensuring its timely delivery to the end-users.
- Developing a sustained marketing outlet by enhancing the effective demand for certified seed by farmers using microcredit facilities.
- Building the capacities of agricultural research workers to produce new high yielding varieties and the extension departments in the localities to deliver the required training and ensure carrying out the full production package by farmers.

4. Improving financial and marketing services for gum arabic producers

The Forest National Corporation (FNC) (2013) implemented a five-year USD 14 million project (2008-2013) with the objective of providing small-scale gum arabic producers with incentives. The grants offered by the project included water reservoirs, gum stores, tractors, water stations, and Hafirs. These projects were financed on the basis of matching funds and managed by Gum Arabic Producers Associations (GAPA) committees. The 20 percent financial contributions of GAPAs reflected their commitment and ensured sustainability. A later assessment of the project's impact revealed a significant increase in the total household income for the surveyed producers.

Policy reform advocated by the Gum Arabic Council and implemented by the Ministry of Finance and National Economy (MOFNE) helped GAPAs increase their share of FOB price from 10 percent to 50 percent by reducing levies and taxes on the produce.

The ingredients of success for these cooperatives were:

- The selection of beneficiary cooperatives was based on track record.
- The producers' cooperatives improve the bargaining power of producers in negotiating with the MOFNE to reduce taxes and levies.
- The cooperatives provided collateral for each member borrowing from the project fund.
- The grant provided by the project enabled cooperatives to keep their produce in stores until prices improved later in the season.
- The grant was to be used by the cooperatives as a revolving fund for financing members in subsequent seasons.

5. Prescription for strengthening and upscaling farmers' cooperatives

Building on the successes achieved by the government and donors in establishing different types of cooperatives to serve small-scale farmers, the following policies are recommended to strengthen agricultural cooperatives:

- Ensure the organization of every cooperative according to the classic principles of cooperatives.
- Injecting new skills by training cooperative committee leaders on project and financial management.
- Training of leaders and members of cooperatives should also include technical skills in the production, use, and maintenance of agricultural machinery and the need to add value to their produce through processing.
- Improving the availability and accessibility of microfinance, including simplifying borrowing procedures and accepting committee membership as collateral.
- Effective guidance by the concerned government departments to enhance cooperatives' performance, including keeping proper accounts and holding regular general meetings to inform members about the financial position of the cooperative committees and solicit their advice.

Part 4:
Transforming Sudanese Agriculture: Investing in Agricultural Supply

XII. Promoting Fertilizer Use to Increase Productivity, Stimulate Pro-Poor Growth and Enhance Environmental Sustainability

1. Introduction

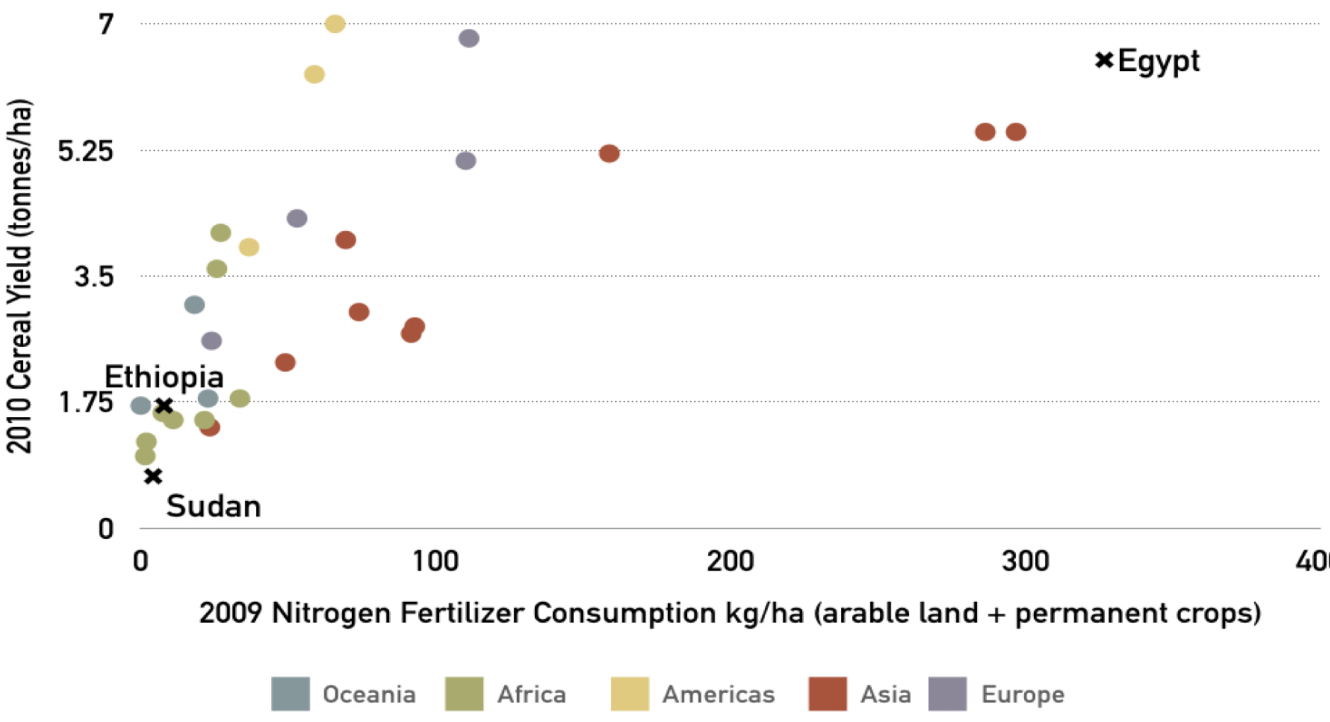
Sudan, just like many African countries, falls behind in agricultural productivity due to the lack of adoption of important agricultural technologies, such as the use of better seeds, fertilizers…etc. An initiative is needed to increase agricultural productivity in Sudan with three components:

First, it emphasizes the adoption of modern technology using better seeds, more use of targeted fertilizers, and financing for the vertical (rather than horizontal) expansion of agriculture. Soil fertility mapping and new significant investments in agricultural research infrastructure are critically needed, in addition to new investments in targeted agricultural financing and marketing.

Second, it should explore the potential for establishing a technically and economically viable Sudanese fertilizer industry to start and increase local production, specifically nitrogen fertilizers; potentially utilizing Sudanese natural gas from the few sites where it was discovered. The appropriate location of the prospective factory would be determined by the feasibility study.

Third, this initiative should encourage the industrial processing of traditional agricultural Sudanese exports, such as gum arabic, sesame, peanuts, cotton…etc., to add value before exporting them. Similarly, animal production activities should have the objective of exporting meat products instead of exporting animals or animal feed, capitalizing on the proximity to Middle Eastern markets.

Figure 23. Rates of fertilizer application and agricultural productivity



There is a great potential for increasing the productivity of agriculture in Sudan significantly with modest investments in agricultural technology (increased use of fertilizers and improved seed varieties).

The recent success of the 2019/2020 wheat season proves the potential for quick progress in this field. The large increase in productivity resulted from limited investments by the African Development Bank in a new targeted seed variety.

Average crop yields obtained in Sudan are low compared to regional and international standards. This is due to a variety of constraints. Low fertilizer use is one of the major factors explaining the low agricultural productivity in the country relative to other regions. Sudan's fertilizer consumption was 8.6 kilograms per hectare in 2018, down from 8.7 kilograms per hectare in 2017, registering a change of 1.05 percent. Increasing input use, such as the rate of fertilizers and pesticides, can increase farm productivity and thereby increase economic growth. Very few farmers use such inputs to increase yields, even though strong evidence suggests that such inputs increase productivity and are generally economically viable (WBG, 2019). The need for improvements in soil fertility and the use of inorganic fertilizer in most crops and soil types in Sudan has been appreciated for many years from the work conducted by ARC.

2. Use of fertilizer

Measured by the average consumption per ha, Sudan's use of fertilizer falls much below that of other countries in the region. For example, the World Bank Development Indicators (WDI) show that the average annual use of fertilizer of all types in kg per ha of arable land during 2007-2010 was 18.6 in Ethiopia, 33 in Kenya, and 161 in India, compared to 6.7 in Sudan (Elbashir and Faki, 2013). This explains the low productivity of crops in Sudan in comparison to other African countries. According to FAOSTAT, Sudan's average yields of sorghum, groundnut, and sesame, respectively, are 35 percent, 20 percent, and 47 percent below Africa's averages.

Reasons for the low use of fertilizer are due to demand as well as supply factors. Demand for fertilizer is often weak in Sudan because incentives to use fertilizer are undermined by the low level and high variability of crop yields on the one hand, and the high level of fertilizer prices relative to crop prices on the other hand. The demand-depressing effects of unfavorable price incentives are aggravated by many other factors, including the general lack of market information about the availability and cost of fertilizer, the inability of many farmers to raise the resources needed to purchase fertilizer, and the lack of knowledge on the part of many farmers about how to use fertilizer efficiently. These constraints on the demand side are accompanied on the supply side by factors that reduce the timely availability of affordable fertilizer in the market.

3. Supply of fertilizer

The supply of fertilizer is constrained by factors that reduce the timely availability of affordable fertilizer in the market. Mainly, these factors are:

- The high cost of finance and shortage of foreign exchange required to import fertilizer and insecticides. The Bank of Sudan makes available a limited amount of foreign exchange from the export proceeds, often too late to catch up with the season. This amount is usually used to meet the needs of the major irrigation schemes. Other farmers struggle to obtain fertilizer at a higher cost from importers who resort to the parallel market to buy foreign exchange.
- Time lost looking for finance and unloading and handling fertilizer shipments in Port Sudan result in the late arrival of fertilizer and missing of the optimum time of application on the fields.
- High transportation costs stemming from inadequate road and rail transport.
- Abundance of taxes and fees, which are reflected in the final price of fertilizer.

4. Entry points for public interventions

Public interventions that can be used to strengthen demand for fertilizer include:

- Strengthening agricultural research and extension.
- Improving farmers' ability to purchase fertilizer.
- Providing farmers with financial tools to better manage risk.
- Improving market information (for example, by increasing investment in market information systems and building capacity in the private sector to manage such systems on a commercial basis).
- Protecting farmers against low and volatile output prices (for example, by investing in measures to reduce production variability, such as irrigation, research on drought-tolerant crops, and grain storage systems).
- Empowering farmers by supporting producer organizations (for example, by increasing investment in rural education and offering farmers training in organizational management skills).
- Improving the agricultural resource base so that the use of fertilizers can be more profitable (for example, by investing in soil and water conservation measures and irrigation infrastructure).

Public interventions that can be used to strengthen the supply of fertilizer include:

- Reducing fertilizer sourcing costs (for example, by lowering trade barriers, adopting common quality standards, and harmonizing approval processes to increase the size of national and regional markets, which would allow fertilizer importers and eventually manufacturers to capture economies of size and scope).
- Reducing fertilizer distribution costs (for example, by improving road and rail infrastructure to reduce high transport costs).
- Strengthening business finance and risk management instruments (for example, by implementing credit guarantee schemes and innovative types of insurance).
- Improving supply chain coordination mechanisms (for example, by enacting and enforcing regulations relating to product grades and standards and by introducing market information systems that can help reduce information costs).
- Procuring fertilizer in bulk (by aggregating the needs of most farmers) to entertain economies of scale and get the lowest price possible.
- Prices of fertilizer in the international market are characterized by seasonal variations based on supply and demand. It is important to enter the market for procurement at a time when prices are lowest.

Policymakers and development partners who are seeking to bring about sustainable increases in fertilizer use must select combinations of these measures to ensure that demand and supply can grow in parallel, thereby providing the basis for the emergence of viable private sector–led commercial fertilizer markets.

Elements of a balanced approach:

- Policy reforms are needed to stimulate private investment and the commercial financing of the agricultural sector. Relevant options include trade policies that promote the free flow of goods.
- Institutional reforms are needed to ensure smoothly functioning commercial exchanges at all levels of the value chain.
- Investment in infrastructure is needed to reduce fertilizer costs, increase farmers' share of output prices, and improve the reliability of services.
- The strengthening of agricultural research and extension services is needed to improve their responsiveness to the needs of farmers and to allow them to adapt with greater ability to the commercial realities of the fertilizer without crowding out private investment

5. Prospects for establishing a competitive fertilizer industry in Sudan

A World Bank study concluded that the capacities of African countries to produce fertilizer are limited because fertilizer production is capital-intensive and characterized by substantial economies of scale. For instance, a modern ammonia/urea complex capable of producing 550,000 metric tons of urea per year costs more than USD 350 million to build. Factories producing other types of fertilizer such as DAP and triple phosphate must also be large enough to be competitive. Moreover, a country must have abundant supplies of raw materials needed for fertilizer production (natural gas, phosphate rock) and must have domestic demand (effective demand) large enough to make production economically feasible (Morris, M. et al.).

Attempts were made in the past to produce nitrogenous fertilizer locally when a fertilizer plant was installed in the 1970s in Elshagara (south of Khartoum), but production was never commenced. Lack of access to raw materials, natural gas (which constitutes 60 percent to 80 percent of the running costs of the factory), and the absence of a domestic market large enough to realize economies of scale and support competitive local production were the main reasons.

In short, to establish a competitive fertilizer industry, Sudan must meet two criteria:

- A large enough local market.
- Abundance of natural gas with very low opportunity cost (since natural gas has alternative uses, such as generation of electricity, which is a national priority).

5.1 Fertilizer import and expanding use

The table below illustrates the quantities of nitrogenous fertilizer imported annually, which shows fertilizer consumption.

These figures show that both the quantity and value of imports of fertilizer are increasing steadily. The annual

Table 9. Quantities and value of imported fertilizer

Year	Quantity in metric tons	Value in US dollars
2016	289,414	87034.000
2017	234,093	108393000
2018	299,408	98572000
2019	424,157	11867300

Source: compiled from Custom Department Records.

average is 311,893 metric tons, which is well below the World Bank threshold of 550,000 metric tons. However, serious efforts should be made to expand the fertilizer market through:

- Promoting local demand through the policies alluded to earlier in this paper.
- Joining COMESA member countries, such as Egypt, Ethiopia, Kenya, and Uganda, to create a regional market driven by private investors from these countries and benefitting from the lower tariffs offered by COMESA. The African Development Bank may be approached to contribute to the financing of this since it benefits several countries.
- Kenana Sugar Factory, a major fertilizer user in the country, may be solicited to be a shareholder in this project.
- On the other hand, a robust feasibility study should be carried out to ascertain the abundance of natural gas and the opportunity cost of using it to produce fertilizer.

XIII.
Irrigation Systems and Renewable Energy

1. Background and assessment of current energy access in Sudan

According to the UN, 35 percent of Sudan's population has access to electricity, while more than 25 million people have not yet been connected to the national electricity grid. International figures put electricity access figures as follows:

1. Population without electricity: 24,700,000
2. Electrification - total population: 35 percent
3. Electrification - urban areas: 63 percent
4. Electrification - rural areas: 21 percent

Sudan's primary energy supply is estimated as 14.8 million metric tons of oil equivalent (TOE), of which biomass resources account for 62 percent, fossil fuels 34 percent, and electricity four percent of the total energy supply. However, Sudan achieved improvements in the energy supply situation during the last 10 years due to the use of indigenous oil reserves and the construction of dams along the Nile. The South Sudan cession presents a huge setback in the energy supply situation in Sudan. Following the secession of South Sudan in July 2011, Sudan lost 60 percent of its biomass energy resources, 75 percent of its oil reserves, and 25 percent of its hydropower potential. This new development poses a critical energy supply situation for all primary sources due to a dwindling stock of energy resources from one side and an increased population from the other side.

Sudan meets approximately 87 percent of its energy needs with biomass, while oil supplies 12 percent, and the remaining one percent is produced from hydro and thermal power. The total energy consumed is approximately 11.7 million metric tons of TOE, with an estimated 30 percent lost in the conversion process. The heavy dependence on biomass threatens the health and future of domestic forests, and the large quantities of oil purchased abroad cause Sudan to suffer from serious trade imbalances. A shift to renewable energy would therefore help solve some of these problems while also providing the population with higher quality energy, which will, in turn, improve living standards and help reduce poverty.

2. Assessment of current and future mix of energy sources in Sudan

Re-source	Assessment	Interventions
Network (National Grid)	• Poor infrastructure and experiences frequent power outages. At present, the country's electricity-generating capacity consists of about 1,700 megawatts of thermal power and about 1,600 megawatts of hydropower capacity. Total electricity generation is around 15 billion kilowatt hours (Bow). • Electrical generation stations that operate by fuel produce around 50 percent of the total electrical supply of the country. Hydropower makes up the remainder. • 70 percent of the population currently has no access to electricity and around 92 percent use biomass for cooking purposes.	• The upper Atbara and Setit dams are expected to increase Hydro Production.

Re-source	Assessment	Interventions
Solar	• Solar energy is based upon a continuously renewable resource that cannot be depleted, and which is not subject to political control. • Solar energy applications can be divided into two main categories: solar thermal applications and photovoltaic technologies (PV). Solar thermal is a technology where the heat from solar energy is harnessed for heating purposes, while photovoltaic is a technology where arrays of cells which contain solar photovoltaic material convert the solar radiation into direct current electricity. • Sudan's average temperature ranges from 28 to 39C. Average solar insolation in the country is roughly 6.1 kWh/m2/day, indicating a high potential for solar energy use. Total potentials over the course of a year have been estimated at 10.1 GJ/m2. • A UNDP-funded project utilized PV to electrify 13 rural and peri-urban communities, with some 45,000 households in the country now using PV systems. • The Northern State has been considered one of the best parts of Sudan for exploiting solar energy. The climate in the Northern State is typical desert, where rain is infrequent and annual. • The cities with the highest solar radiation are in the northern and western parts of the country, namely Dongola, 6.7 kWh per meter squared per day, and El Fasher, 6.4 kWh per meter squared per day.	• The government should encourage wind energy and solar systems in view of the environmental problem. • Encourage the private sector to assemble, install, repair, and manufacture wind pumps and solar cells via investment encouragement.
Re-source	**Assessment**	**Interventions**
Wind	• Wind energy has considerable resources in Sudan where the annual average wind speeds exceed 5 ms-1 in most northern parts (latitude 12° N) and along the Nile valley. • Southern regions have the poorest potential because of the prevailing low wind speeds. • The extractable energy ranges from 400- 600 kWm-2 year-1. • Experience in wind energy in Sudan began in the 1950s when 250 wind pumps from the Australian government, were installed in El Gezira Agricultural Scheme for water pumping. However, due to difficulties in obtaining spare parts and the availability of diesel pumps, these machines are not currently working. • The Energy Research Institute (ERI) installed 5,000 15 CWD wind pumps around Khartoum and the northern and eastern states. • ERI, in cooperation with the Sudanese Agricultural Bank (SAB), introduced 60 wind pumps to be used for water pumping in agricultural schemes, but they have not yet manufactured them due to a lack of financial support. • The development of mechanical wind pumps has been ongoing in Sudan for several years. It is based on a multi-bladed rotor with high efficiency. The aim has been to develop a wind pump that needs limited service and maintenance and meets mass production needs. • Average wind speeds are estimated at 3-6 m/s; higher speeds have been recorded along the Red Sea coast. The average wind density in Sudan is estimated at 400 W/m2. • Wind energy is currently used for pumping water from both deep and shallow wells to provide drinking water and irrigation through the use of wind pumps. • Mean wind speeds of 4.5 ms-1 are available over 50 percent of Sudan, which are well suited for water lifting and intermittent power requirements. • One region in the eastern part of Sudan has a wind speed of 6 ms-1 which is suitable for power production.	• Encourage the water pumping wind machines program as an infrastructure building program • Encourage village cooperatives or set up cooperation for installing and maintaining wind pumps. • In areas where there is wind energy potential but no connection to the electric grid, develop wind pumps with simple design, and high efficiency. • Local production of wind machines should be encouraged in both public and private sectors. • Research and development in the field of wind machines should be directed towards utilizing local skills and local available materials.

Re-source	Assessment	Interventions
Biomass	• Biomass includes solid biomass (organic, non-fossil material of biological origins), biogas (principally methane and carbon dioxide produced by anaerobic digestion of biomass and combusted to produce heat and/or power), liquid biofuels (bio-based liquid fuel from biomass transformation, mainly used in transportation applications), and municipal waste (wastes produced by the residential, commercial and public services sectors and incinerated in specific installations to produce heat and/or power). • There is a vibrant co-generation industry in Sudan, with an installed capacity estimated at 55.5 MW in sugar factories, mainly for own use.	• An estimated 41.4 million hectares of forest resources are present, with an allowable cut of approximately 15.1 million cubic meters. • Significant potential exists for the utilization of agricultural residues, particularly crop residues and animal waste. • Add significant bioethanol and biodiesel production capacity in the coming years, in the region of 60 million liters/year and 50 million liters/year, respectively.
Geothermal	• Geothermal potential is estimated at 400 MW of power generation capacity. • Potential geothermal fields have been identified near the Jabel-Marra volcano, the Tagbo and Meidob hills, the Bayud volcanic field, and the Red Sea coast. Hot spring temperatures in the Red Sea region range from 56oC to 85oC.	• Two sites of particular interest in the region are the Suakin-1 and Bashayer-1A wells, which both have temperature gradients of over 70oC. • Sudan was collaborating with KenGen, the Kenyan national utility, to further build capacity and assess potentials in the region.
Hydropower	• The total potential for hydropower in the country is estimated at 4,860 MW, with an annual production of 24,132 GWh. • Small-hydro also offers significant potential, with more than 200 suitable sites for in-stream turbines. • Sudan has five hydropower plants with a total capacity of 1,593 MW. • The Sinnar power plant consists of two units with a total capacity of 15 MW (1962). • The Elgria power plant consists of three Turbine pumps and two units with a total capacity of 17.8 MW (1964). • The Roseires power plant consists of seven units with a total ge capacity of 280 MW (1971). • The JabelAwlia power plant consists of 80 units with a total capacity of 30.4 MW (2005). • The Merowe Dam power plant: its recent and bigger dams were erected in 2009, and it consists of 10 units with a total capacity of 1,250 MW.	• Total hydro generation 1,593 MW. • Due to the growth in electrical energy demand, the Ministry of Water Resources and Electricity plans to increase the generation capacities with different sources as well as conventional and renewable energy. • Use available hydro potential for the following projects.

3. Challenges facing the utilization of renewable energy in Sudan

Challenge	Description	Mitigation
Planning location sites	• One of the biggest issues in renewable power utilization is the selection of a proper location for the installation of selected renewable power plants. • The selected location should enhance and improve the reliability and security of the national network. • The trend of decentralization and distributed generation drive the power system planners to select remote areas to install renewable energy power plants. • The national electricity network transmission capacity is overloaded and cannot withstand any additional capacity.	• Place the renewable power plants close to load centers in Khartoum and areas out of the national electricity network.
Finance	• The Ministry of Water Resources, Irrigation, and Electricity (MWRIE) is the primary body responsible for the generation, transmission, and distribution of electric power in Sudan. • There are no independent power producers (IPPs) in the country, though initiatives are underway to promote private investment in power generation. • The financing of renewable power plants needs cooperation between the government, the private sector, and international bodies.	• The government must encourage the private sector to invest in the installation of renewable power. • The renewable energy project must be financially supported by the Global Environment Facility (GEF) and the UNDP. • The fund must be used in research in renewable energy by universities and institutes, improving renewable power technologies, and the installation of projects in selected areas
Technology	• Utilizing and converting renewable energy requires effective and economical technologies. • The developed technologies must possess excellent technical characteristics at reasonable costs. • It's economically critical that the cost of generated power competes with the cost of power generated by fossil energy. • It is well known that the prices of fossil fuel and conventional power technologies are low in the energy market.	• Rigorous methods are needed to accelerate the development and utilization of renewable energy technologies and to increase their contribution to the current energy supply mixes.
Integration of renewable power into the main grid	• The variation of generated power from renewable sources is due to weather conditions. • The variation of injected power would influence the main grid in terms of frequency, voltage, and system stability. • In some cases, variable renewable energy sources should complement each other at different times (e.g., solar power during the day, wind power overnight) and/or in different regions (South, North). • The integration of a significant share of variable renewable energy into power grids requires a substantial transformation of the existing networks	• Allow for a bi-directional flow of energy; that is top-down (from generators to users) and bottom-up (with end-users contributing the electricity supply) aimed at ensuring grid stability when installing distributed generation. • Establish an efficient electricity-demand and grid management mechanism aimed at reducing peak loads and improving grid flexibility, responsiveness, and security of supply in order to deal with increased systemic variability. • Improve the interconnection of grids at the regional, national, and international levels to increase grid balancing capabilities, reliability, and stability. • Introduce technologies and procedures to ensure proper grid operation stability and control (e.g., frequency, voltage, power balance) in the presence of a significant share of variable renewables. • Introduce energy storage capacity to store electricity from variable renewable sources when power supply exceeds demand to increase system flexibility and the security of supply. • Modern, high-voltage, direct-current (HVDC) transmission lines for long distances are highly efficient though their implementation takes time and involves significant upfront investment. • Grid interconnection also requires full integration of the grid management systems.

4. Renewable energy for 21st century agriculture, and irrigation systems in Sudan

Renewable energy has multiple uses in agriculture and could be an important vehicle for developing the agricultural sector in Sudan. These uses include:

- Pumping water for irrigation.
- Reducing the huge losses in agricultural products through refrigeration, hence extending the marketing seasons of perishable commodities such as fruits, vegetables, milk, meat, and fish.
- Promoting mechanical workshops and small-scale rural industries in support of agricultural activities.
- Electrification of the rural sector to improve the quality of life of farmers, especially rural hospitals Dissemination of information using communication technology, including mobile phones and the Internet, to support agricultural activities.
- Support of education and training at all levels.

Traditionally, irrigation in Sudan relied on either a gravity-driven flow of water in channels or water pumps powered by diesel/electricity. The emergence of renewable energy sources, especially solar energy, offers Sudan a great opportunity for the modernization of its irrigation systems. This is especially true given the abundance of solar energy in Sudan due to its geographical location and its cloud-free climate for most of the year. The access and availability of electricity and diesel are quite limited and are likely to remain so for some time. Under these conditions and given the recent decline in the cost of solar technology, solar-powered pumps present an attractive solution that is economically efficient and environmentally friendly. The distributed nature of solar energy ensures access to this vital resource in all regions of the country.

Solar-powered pumps can be introduced at a large scale in Sudan for use across the country. These pumps can be used to fuel primary or supplementary irrigation within large-scale irrigation schemes. As primary irrigation systems, solar pumps can be used to supply water from the Nile and its tributaries, from aquifers connected to the Nile system, or from renewable groundwater sources associated with aquifers that are not connected to the Nile in Kordofan and Darfur. As sources of supplementary irrigation, solar pumps can be used to recycle water from aquifers beneath the main irrigation schemes in Sudan.

The successful introduction of solar systems in Sudan at a vast scale requires investments by the central government in solar technology by building new manufacturing facilities, preferably in partnership with the private sector. Training engineers and technicians on this new technology is needed to prepare the human resources needed to maintain a vast, distributed network of solar-powered irrigation systems.

XIV. Disruptive Technology in Agriculture

here are global megatrends that are creating major challenges for the global agriculture industry: population growth, which is projected to reach 10 billion by 2050; arable and acreage shrinkage; climate change; soil degradation; water availability; and greenhouse gas (GHG) emissions are presenting the agriculture industry with food security, food safety, sustainability, and efficiency challenges.

Disruptive technologies have the potential to help address many of the aforementioned challenges. Disruptive technologies in agriculture consist of digital and technical innovations that enable farmers and agribusiness entrepreneurs to leapfrog current methods to increase their productivity, efficiency, and competitiveness, thereby facilitating access to markets, improving nutritional outcomes, and enhancing resilience to climate change. Agri-tech solutions range from mobile phone applications to solar applications, portable agriculture devices, and bio-fortified foods. Disruptive agricultural technologies (DATs) differ from other agri-technology solutions in that they empower farmers by accelerating agri-food outcomes three- to fivefold or by circumventing the conventions of the value chain to achieve the same or better results but with a more efficient agri-food outcome.

The technology and agricultural industries are responding by adapting three technology-centric themes: (i) digital agronomy to digitally collect, store, analyze, and share electronic data or information along the agricultural value chain using Precision Agriculture (PA), IoT Sensors, Predictive Analytics (PI), Artificial Intelligence (AI) and Machine learning (ML), Unmanned Aerial Vehicles (UAV), and other emerging technologies; (ii) sustainable food systems to produce healthy food while also providing sustainable impacts on environmental, economic, and social systems; and (iii) supply chain optimization processes and tools to ensure the optimal operation of a manufacturing and distribution supply chain. In this section, we will focus on the first theme with respect to how Sudan's agricultural sector can benefit from the technology application.

Precision agriculture (PA) can be defined as the collection of real-time data from farm variables combined with the use of predictive analytics to make smart decisions that enable farmers to maximize yields, minimize environmental impact, and reduce cost. PA relies on various technologies, such as sensors and big data, to achieve improved crop yield. The smart decision derived from the data analytics also results in less resource waste, such as water in irrigation systems, fertilizer, pesticides…etc. With PA, farmers can locate the exact location and map sites with several data variables, which are then used by variable rate technology to optimally perform seeding, spraying, and other services. Although PA technology can improve yield, it is essential to provide solutions that are user-friendly to farmers and provide training to enable small- and medium-scale farmers to exploit the technology.

Challenge Framework	Agricultural Challenges	Standard Agricultural Solutions	DAT Solutions
Agricultural productivity	Insufficient advisory and climate-smart services	Insufficient advisory and climate-smart services	Insufficient advisory and climate-smart services
	Limited access to inputs (tractors) for land preparation	Limited access to inputs (tractors) for land preparation	Limited access to inputs (tractors) for land preparation
	No systematic pest and disease management	No systematic pest and disease management	No systematic pest and disease management
Market links	Poor market access	Poor market access	Poor market access
Farmer financial inclusion	Insufficient or unfair access to credit and financial products	Insufficient or unfair access to credit and financial products	Insufficient or unfair access to credit and financial products
Data analytics and agricultural intelligence	No or inadequate access to data for informed decision-making	No or inadequate access to data for informed decision-making	No or inadequate access to data for informed decision-making
Energy for agriculture	Poor irrigation infrastructure	Poor irrigation infrastructure	Poor irrigation infrastructure
Agricultural productivity	Producer organizations, extension agents, radio, TV	Producer organizations, extension agents, radio, TV	Producer organizations, extension agents, radio, TV
Market links	Manual, animal-aided, mechanized	Manual, animal-aided, mechanized	Manual, animal-aided, mechanized

Sudan's current utilization of its 70 million hectares of arable land amounts to approximately no more than 30 percent due to poor infrastructure, limited access to technology, weaknesses of NARS, low rate of fertilizer use, and unavailability of adequate finance.

The advances in technology will play a pivotal role in revolutionizing agricultural production in Sudan. However, the introduction and adoption process is often challenging and has a long learning curve, especially since Sudan had been prohibited from technology import due to US sanctions. Therefore, we recommend a phased approach taking into consideration the current socio-economic state. It is critical to carefully identify the stakeholders in this journey (i.e., the innovators, early adopters, majority, laggers, support groups…etc.).

1. The role of technology in agriculture

Based on the weaknesses identified in the previous sections of the main three sectors, the table below highlights the technology interventions measures to strengthen the agricultural sector in Sudan:

Sector	Weaknesses	Technology Intervention
Rainfed	• Weak research, financial, and extension services and weak linkages among stakeholders: extension, farmers, research, private sector, and financial institutions…etc. • Dominance of traditional production practices resulting in low yields and low labor and capital productivity. In addition, some of the farmers are still operating little above subsistence level. • Limited use of improved technologies and external inputs, such as improved seeds and agrochemicals. • Poor key physical infrastructure affected access to services and inputs /outputs markets. • Full dependence on fluctuating rain in terms of quantity, distribution, and timing. • Shortage of labor and the high cost of labor because of migration and the emergence of gold mining. • Limited knowledge about climate change and climate-smart agricultural practices. • Low processing activities, cleaning, packaging, storage…etc. (Poor value chain development).	• Building a national agriculture digital framework and applications to facilitate communication and access to information. • Introduction of spraying, planting, and monitoring by tractors and drones. • Importing of seed coating machines and use of organic materials and nutrients to improve seed germination. • Increased mobile network coverage will facilitate communication and access to market information. • Adoption of smart agriculture technology for planting and harvesting will minimize labor-intensive activities. • Broadcast of customized meteorological forecast enhanced by AI algorisms through SMS to farmers. • Process reengineering and automation of the supply chain cycle.
Gum arabic	• Decline in gum productivity in terms of • quantity and quality and the deterioration of the natural resource base. • Unstable policy innervations ranging from monopoly to liberalization have disrupted the commodity market at the local, regional, and international levels. • Production sites distributed across wide geographical remote areas with poor infrastructure and services (drinking water, storage facilities, means of transportation, extension, official finance, education, and health units). • Lack and poor management of village nurseries' traditional way of gum production and improper post-harvest techniques (drying, use of plastic sacks and bags). • Low prices gained by direct producers. • Lack of VA activities and export, mostly crude gum, while processing, manufacturing and value addition take place outside of the country. • Limited research and poor technology transfer services. • Lack of effective producer partnerships with traders, exporters, and manufacturing companies.	• Use of hyper spectacle imaging analysis for planting new trees and performing soil analysis to improve productivity. • Plant new trees by regular planes using GPS coordinates. • Connect production sites by wireless network and establish a Monitoring Center. • Leverage mobile application technology to disseminate knowledge and training for best practices for tapping and harvesting. • Import seed coating machines and use coated seats to enhance germination rate.
Irrigated	• Deterioration of irrigation infrastructure. • Differences in irrigation network management between agriculture and irrigation authorities. • Weak supportive agricultural services (funding, marketing, training, and access to inputs and modern technologies). • Low productivity and poor value chain development. • Difficulties in applying modern agricultural technologies.	• Upgrade of irrigation infrastructure to use technologies such as drip irrigation triggered by IoT sensors THAT detect moisture levels. • Introduce solar and wind (or Hybrid) pumps to decrease dependence on diesel-powered pumps. • Import seed coating machines and use coated seats to enhance germination rate. • Perform soil analysis using hyperspectral imaging to apply the precise type and quantity of fertilizers and pesticides. • Experiment with drone technology for monitoring health and spraying. • Initiate pilot projects for planting with drones.

2. Sudan mobile and Internet: Technology framework and roadmap

Most African countries have intermediate-level mobile and Internet penetration. However, digital accessibility is much lower in rural areas and varies greatly according to age, gender, and income. Therefore, reaching all African farmers with DATs will require a range of tools that can operate in different connectivity scenarios, even within a country. for instance, low-connectivity scenarios require nascent technologies, intermediate-connectivity scenarios require transitional technologies, and high-connectivity scenarios require advanced technologies. Technologies for low-connectivity environments include offline digital solutions such as portable soil testers, SMSs, and interactive voice recordings, along with platforms that work offline and can upload or receive data when a connection becomes available. Transitional technologies, which can operate in intermediate-connectivity environments, include e-platforms, supply chain tools, and basic precision-agriculture tools. in high-connectivity scenarios (high Internet and mobile penetration), real-time monitoring and feedback are possible for advanced technologies such as controlled environment agriculture and farm robotics. Figure 25 shows the digital agriculture continuum and accompanying agricultural technologies that can operate in different connectivity scenarios.

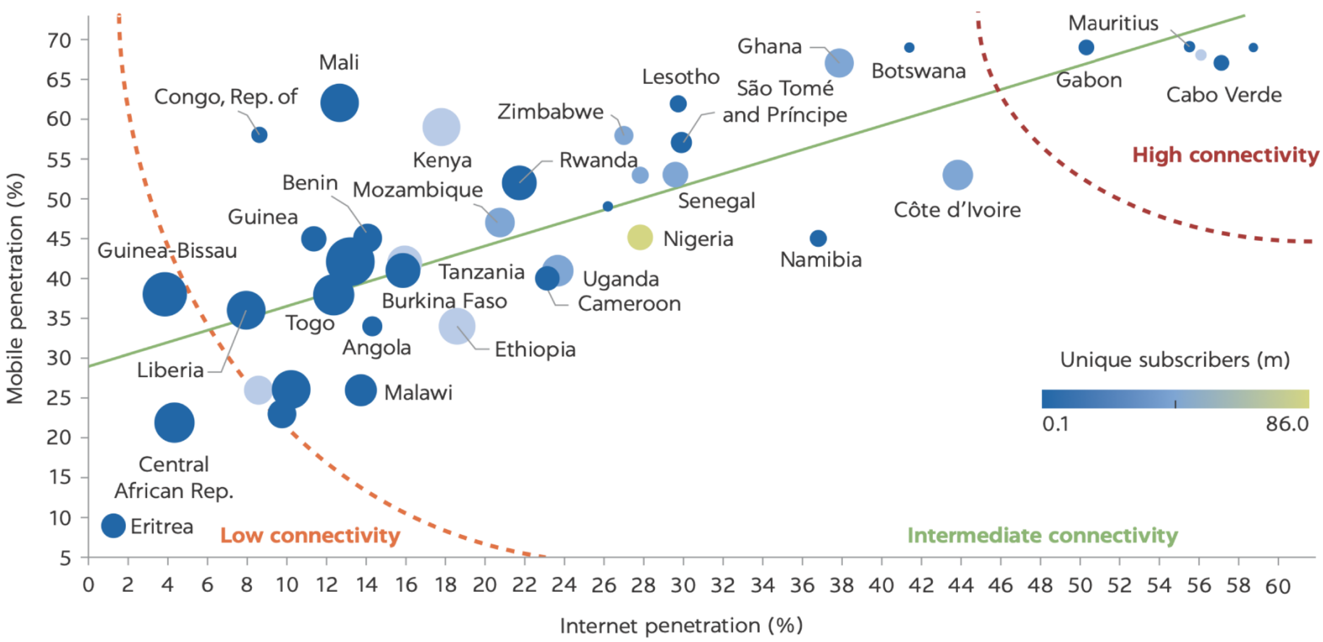
The following is a conceptual framework for the introduction and evolution of the technology roadmap in the agricultural sector, which must be integrated into a national digital and infrastructure development strategy. The proposed transformation approach is considering the maturity of various technologies and the time for acquisition and rollout.

The goal is to introduce technology as delivery systems and make it accessible for farmers, which will contribute to increased and sustained production, productivity, and farmers' profitability of cash crops relative to smallholder constraints and market requirements. Encourage the private sector and young innovators to produce solutions for agriculture and improve farmer access to technical and market information.

Phase zero

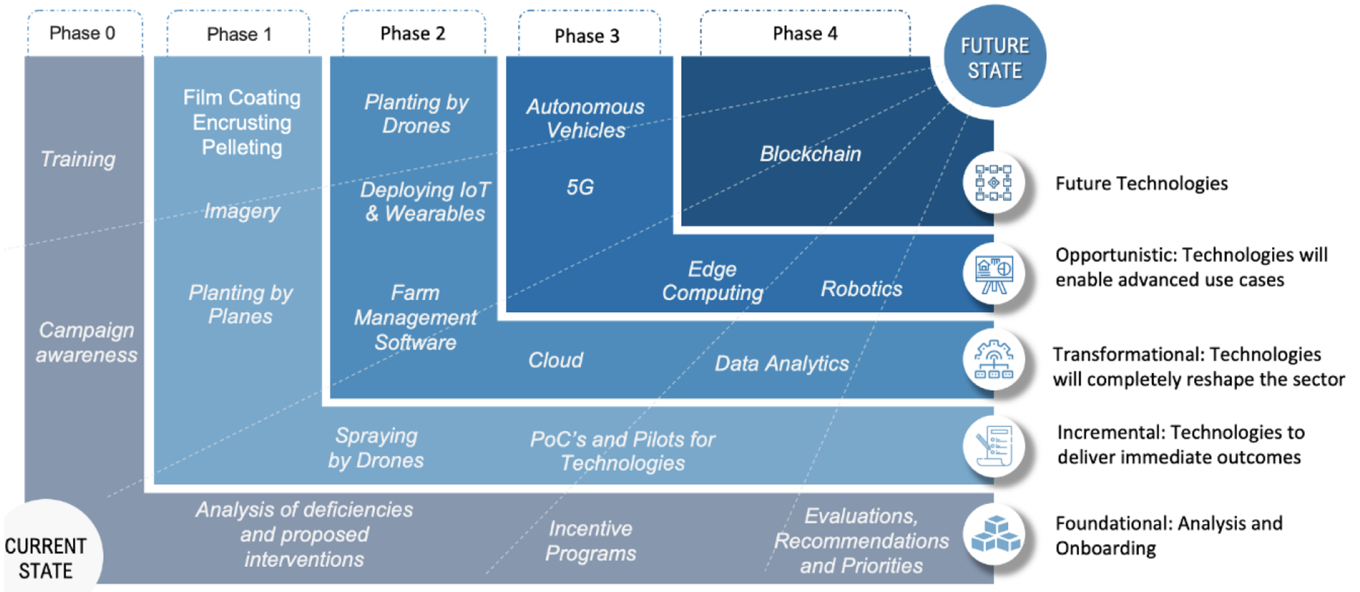
This will be the foundational phase divided into policy formulation and onboarding. On the policy side, public agricultural research has historically played a pivotal role in raising agricultural productivity and must be established in coordination with relevant departments in universities and as detailed in this paper. The research will identify the issues facing farmers in the current agricultural schemes and the impediments to expansion into the unutilized arable land. On the onboarding side, both the private and public sectors are required to launch awareness campaigns and training programs on the benefits and basic usage of prospective technologies.

Figure 24. Mobile penetration, Internet penetration, and agricultural GDP in Africa



Source: World Bank, based on internal data and data from Global System for Mobile Communications Association (GSMA) and the Internet Telecommunication Union.
Note: The size of the country markers (bubbles) corresponds to the magnitude of agricultural GDP and the color of the bubble corresponds to the number of unique subscribers in millions. Most African countries have intermediate-level mobile and Internet penetration. However, digital accessibility is much lower in rural areas and varies greatly according to age, gender, and income.

Figure 25. Technology roadmap



Phase one

This incremental phase will focus on the introduction of non-complex technologies that can be adopted without the requirements for the vast underlay layer of infrastructure and can produce significant results. Seed coating machines can be imported and distributed to various locations and organic local material can be used as ingredients. Imagery is used in a limited scope currently by few innovators in Sudan, but usage can be expanded either through UAVs or satellites. The Airbus OneAtlas platform provides imagery and analyses of agricultural lands worldwide and has a partnership with a local company in Sudan. As part of the Middle East Green Initiative, Sudan will be planting one billion trees, which presents an opportunity to experiment with planting by regular planes and the use of remote sensing techniques, especially in the gum arabic belt. Proof of Concept (POC) projects can be initiated to validate future technologies.

Phase two

This phase will be transformational as it will completely redefine agricultural sector practices and productivity. This phase will require the coordinated efforts of the government, the private sector, technology providers, research institutions, international sponsors, and, of course, users. The combination of advanced analytics powered by cloud capabilities and planting by drones will usher in the PA era in Sudan and will facilitate the expansion into the unused arable land. This must take place in tandem with advances in alternative energy sources to power the irrigation methods, such as solar, wind, hybrid, and supplemental irrigation.

Phase three

The underpinning of this opportunistic phase is the development of the telecom infrastructure and modernization of their network to the cloud ecosystem that can deliver intelligent and intent-based service orchestration rapidly using AI and predictive analytics. At this stage, the deployment of edge computing will be critical as 50 percent of the data are expected to be generated and processed by smart devices outside the data center and the cloud. Specific advanced use cases can be implemented, such as robotics for harvesting, autonomous tractors for planting, and other farming activities.

Phase four

In this future stage, we expect advanced technologies, such as blockchain, to roll out in various sectors, which will serve as a repository of data generated by all actors in the production and sale lifecycle and ensures the transparency and integrity of data, which fosters trust among the different stakeholders. Implementing an appropriate model for Sudan and identifying transacting users with reliable and precise input will require further research, but a simplified model can be implemented.

3. Proposed technologies

The following is a description of technologies that have low adoption overhead and can be implemented in the early phases of transformation.

3.1 Seed coating

Seed coating is the application of materials onto the surface of seeds for the purpose of making seeds' shape, size, weight, and seed surface more uniform to make them easier to plant and/or to apply active compounds that improve seed quality and protect the seed from biotic and abiotic stress. A seed coating machine is used to mix a liquid adhesive compound (Binder), a powder bulking agent (Filler), and active ingredients (protectants, nutrients, symbionts, soil adjuvant, phyto active promoters, colors, and tracers). There are three types of seed coating:

Film coating consists of producing a continuous thin layer over the seed surface. The rotary coater is the primary seed coating equipment used for film coating. Film coating polymers (liquid components) are formulated to dissolve/dispense active ingredients such as fungicides, insecticides, or bio-stimulants prior to application on seeds. The weight increases for film-coated seeds range from two to 10 percent of seed weight. Film coating reduces harmful dust from treated seeds and produces a smooth surface so that seeds flow easily through processing equipment. Adding a color helps in differentiating the seeds. Film coating does not change the shape of the seed.

Encrusting is a seed coating method with the addition of liquids and solid particulates that results in a coated seed that is completely covered, but the original seed shape is retained. The primary coating methods to produce encrusted seeds are the rotary coater or coating pan. The addition of large amounts of water during encrusting requires that the freshly coated seed be dried back to its original seed moisture content prior to packaging and storing. The weight increase after encrusting can range from eight to 500 percent. The seed coating thickness or percent build-up may impact germination rate, and encrusted seeds require more time to germinate compared to film coated seeds. The amount of binder used in producing encrusted coatings changes mechanical properties, including integrity, compressive strength, and time to disintegrate after soaking.

Pelleting is a continuation of the encrusting coating process that results in greater build-up so that the original size or shape of the coated crop seed is not visible. The binders may be liquid or formulated as dry powders. Dry powder binders are mixed with filler materials to produce a coating blend only requiring water applied during the coating process. The percent weight increases after pelleting and drying ranges from 500 to >5000 percent. Weight increase is expressed as a ratio of seed weight to dried pellet weight, so a 500 percent weight increase is a 1:5 build-up of seed to coating. Pelleting requires the most time and expertise compared to other coating technologies due to the extensive application of active components, liquids, and solid particulates. The pellet should not cause any restriction to germination when sown in the field. pellet integrity is dependent on the selection of material (fillers and binders) and appropriate technology.

3.2 Hyperspectral imaging

Identifying soil type is crucial for determining the type of crop to be cultivated. Each soil type, such as clay, soft, silt, or sandy, has its own distinct properties (e.g., moisture content, pH, organic matter, color, density, texture, and pore space), which impact crop health in terms of available nutrients and water absorption by the crops from the soil. There are several types of remote sensing imagery sensors, but our focus will be on hyperspectral imaging.

Hyperspectral imaging (HIS) produces 3-D maps with high efficiency to determine soil type and its physical properties in addition to monitoring changes in natural soil states. Hyperspectral images measure spectral reflectance of the soil that will vary according to texture, moisture, salinity…etc. Hyperspectral sensors can be mounted on different platforms, such as satellites, airplanes, UAVs, and close-range platforms. The workflow starts with image acquisition through HIS sensors in a raw format that requires enhancement or calibration by correcting radiometric or geometric errors as a pre-processing phase. Image analysis is performed by software packages that utilize machine learning that encompasses algorithms including deep learning (DL), artificial neural network (ANN) and support vector machine regression (SVM) that possess the ability to learn from data without relying on explicit programming and can process many variables (e.g., spectral reflectance and vegetation indices) efficiently.

3.3 Mobile applications

The mobile application contains a simplified frontend for the farmer that is easy to use and hides the complexity of the backend. It enables the user to take images of the plant (live mode) or choose existing images from the gallery (offline mode) and upload them to the cloud for analysis. It allows them to get the disease type of the uploaded images with a score reflecting the probability or accuracy of classification. It also enables the user to view a disease density map of the local area (if location service is enabled on the phone). The Disease Classifier is a standalone application running in the cloud platform that receives the images uploaded via the mobile application and uses a trained deep convolutional neural network (CNN) model to classify the disease type. The Deep CNN Trainer is a cloud application responsible for the more intensive work of training the neural network and builds the deep CNN model that is used by the Disease Classifier to classify images into the correct disease types. The Training Database is a cloud-based database that stores all images used to train the deep CNN model. In addition to the images, it stores the metadata, such as disease type, location of the images, and time stamps.

3.4 The Internet of Things (IoT)

IoT sensors are another way to collect soil variables and then transmit data to a data hub for analysis and predictions. The sensors can be classified into (i) temperature sensors that measure soil, plant, and air temperature; (ii) humidity sensors that measure soil moisture and soil pH; and (iii) nano biosensors that measure wind speed and raindrops. Due to the massive amount of data transmitted from IoT sensors, cloud computing is used to provide high processing power and storage space. IoT has a four-layer architecture; base layer (sensors), gateway or aggregation layer, processing layer, and application layer. The transmission can take place over the telecom network (3G, 4G, or LTE) using lightweight protocols, e.g., CoAP, AMQP, MQTT and HTTP.

Table 10. Agriculture sensors and their usage

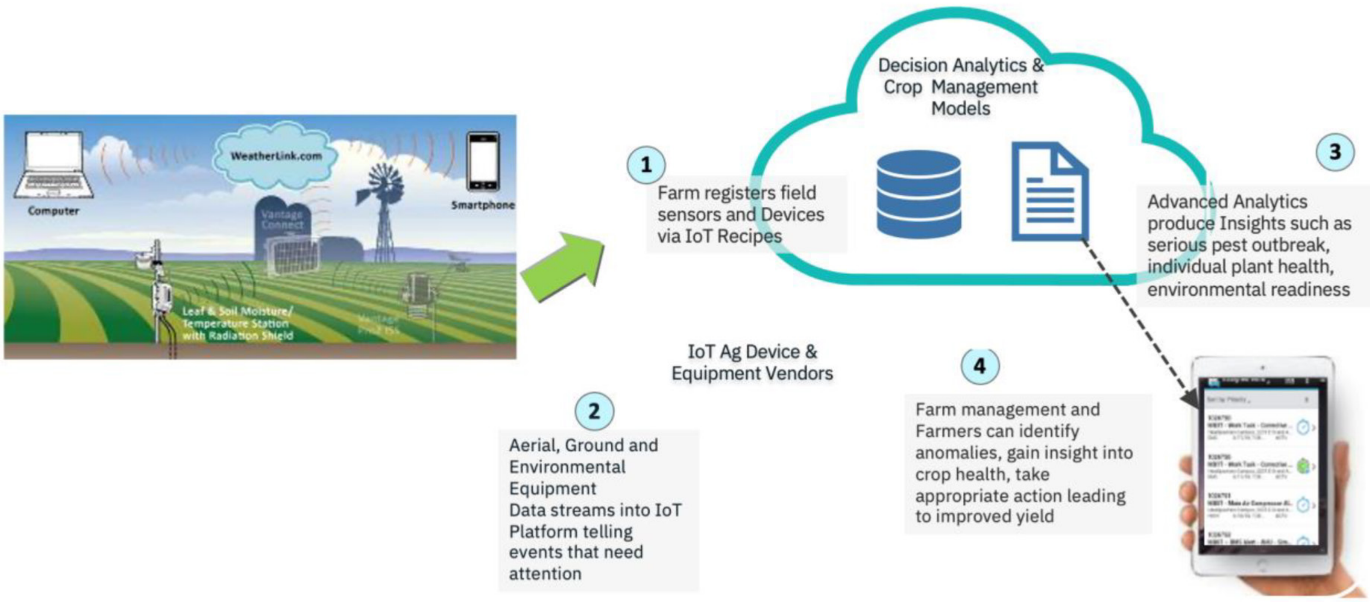
Agriculture sensors	Functional description
Location sensors	These sensors determine the latitude, longitude, and altitude of any position within the required area. They utilize GPS satellites for this purpose.
Optical sensors	These sensors use light in order to measure the properties of the soil. They are installed on satellites, drones, or robots to determine the clay, organic matter, and moisture contents of the soil.
Electrochemical sensors	These sensors help gather the chemical data of the soils by detecting specific ions in the soil. They provide information in the form of pH and soil nutrient levels.
Mechanical sensors	These sensors are used to measure soil compaction or mechanical resistance.
Dielectric soil moisture sensors	These sensors measure moisture levels by measuring the dielectric constant of the soil
Air flow sensors	These sensors are used to measure air permeability. They are used in a fixed position or in mobile mode.

IoT sensors generate massive amounts of data that require storage and processing. The complexity of the data can range from structured to non-structured data, which can be in the form of text, images, audio, and video. The data can range from historical data to sensor data or live streamed data. The use of cloud IoT platforms allows for big data collected from sensors to be stored in the cloud. This includes hosting applications that are critical in providing services and managing end-to-end IoT architecture. Recently, edge computing has advocated, where IoT devices and gateways carry out computation and analysis to reduce latency for critical applications, reduce cost and promote quality of service.

Wearables are another form of IoT that primarily targets livestock rather than humans. These devices can provide important real-time information about livestock and plants. They provide real-time tracking of livestock conditions (key use cases include ear tags, collar tags, and other wearable sensors that monitor livestock's location, surroundings, and physical conditions) and increased automation while reducing human involvement (key use cases include virtual fencing).

Variable rate technology (VRT) enables the application of fertilizers, pesticides, chemicals, and seeds at a customized rate from geospatial data preprogrammed from maps generated from various field and crop data sources. It contrasts with uniform application, which applies inputs at the same rate across the field. VRT can be directed using map-based data, which is provided by a digital map or sensor-based data, which is conducted with real-time data collected from the sensors attached to the applicator. The adoption of VRT can greatly reduce input costs and the environmental impacts resulting from over application of chemicals and water usage.

Figure 26. IoT for precision agriculture



3.5 Drones

Drones or UAVs are revolutionizing agriculture because of their precision and speed. Drones are widely used to survey and monitor soil and crops. Recently, drones have been introduced in deforestation to plant trees and most recently in the planting of rice. Drones are classified into Fixed Wing (where lift is generated by a forward thrust), Rotary drones (which have vertical take-off and landing (VTOL)), and hybrid Power-Lift drones (that use rotors or VTOL then transition to forward, fixed-wing-style propulsion). Most rotary drones are powered by rechargeable lithium-ion polymer (LiPo) batteries. Solar power could be an inflight battery recharge option. Gas-powered drones have significantly longer flight time because of their energy advantage. Hybrid-powered drones use a combination of batteries and gas power sources.

The application of drones in agriculture can be classified into monitoring and executing. The monitoring scope will be performed by taking digital images for different analyses whereas the execution scope will involve performing agricultural tasks in lieu of manpower. Identifying soil health condition, infections and pests, crop surveillance, and monitoring of livestock are key monitoring activities. Drones are also capable of carrying smart farming operations such as tree planting, crop seeding, and fertilizer and pesticide spraying using mounted vessels.

3.6 Solar Photovoltaic (PV) and wind pumps for irrigation

Leveraging renewable energy for the agricultural sector helps countries move toward the seventh SDG. The implementation of water pumps powered by diesel or electricity is placing heavy pressure on the economics of the agricultural sector as well as on the environment. Renewable energy sources, like solar, wind, and biomass, provide clean and sustainable energy in agriculture by installing solar PV and wind turbines.

The main components of the solar power pump are the solar panels which convert sun energy (photons) into DC power by using the photovoltaic effect. The inverter is responsible for the conversion of generated solar DC power to AC power for operating the pump, which runs on AC power. The water pump is used to draw water from the source for irrigation.

Wind power is simple and efficient. The blades of the windmill wheel catch the wind, which turns the rotor. The wheel assembly is attached to a hub assembly, which drives a geared mechanism that converts the rotary motion to an up-and-down motion. This motion drives a pump rod up and down inside of a pipe in the well. A cylinder with a sealed plunger going up and down inside forces the water up the pipe. Each upstroke pulls water into the cylinder, while on the downstroke, a check valve in the bottom keeps the water from being pushed out, so the water is forced up the pipe with the next upstroke.

4. Recommendations

- Develop an e-agriculture strategy to be integrated into the overall agricultural sector development strategy.
- Develop data policies that clarify data privacy, ownership, and sharing rules, as well as those mandating data collection and protection.
- Enable telecom infrastructure and payment systems in rural and remote areas to ensure good quality and predictable rural connectivity.

Institutional reforms

- Adopt pluralistic extension and service-delivery approaches to enable digital innovations and solutions to be tested and tried for smallholders. Digital innovators can link input suppliers and service providers on a digital platform.
- Develop incubators in higher-education institutions and develop good-quality curricula for digital skills, innovation, and applications.
- Link innovators with local and international investors and farmers through periodic forums, conferences, and industry network groups.

Public infrastructure investments

Public infrastructure investments can be made in the areas of collecting foundational data and developing platforms, such as the following:

- Digital farmer registrations.
- National soil maps.
- Real-time agricultural weather observatory and early warning systems (satellite, geospatial).
- E-government systems for all public services and resources administered through the ministries of agriculture.
- Digital surveillance technologies for pests and diseases.
- Support rural broadband access and last-mile Internet delivery programs.
- Invest in agricultural research, including partnerships between academic programs and industries tailored for digital agriculture technologies and innovations.
- Develop rural road networks, power, and irrigation infrastructure.

Private sector initiatives

- Establish associations as a platform for dialogue with governments.
- Establish incubator hubs to nurture agri-technology start-ups and use these to identify investment opportunities.
- Host events for disruptive agricultural technology innovators to discuss past failures and successes.
- A profusion of small companies are starting to bundle their services together to achieve deeper, stronger, and wider-scale financial viability.

- Emerging DATs can operate successfully offline at the farm level, updating only when connected in urban areas.
- Farmer databases support DAT development and uptake; these databases are a major investment cost for start-ups.
- Well-developed mobile payment systems are an essential ingredient for most DAT enterprises to function effectively.
- Financial technology solutions are bridging liquidity gaps for farmers for the benefit of the entire supply chain, from input suppliers to off-takers. Examples include installment payment systems, very short-term loans, and insurance products.
- Invest in a policy for pluralistic extension and service delivery approaches to enable digital innovations and solutions to be tested and tried for smallholders. Most of these solutions require partnerships between input suppliers, service providers, and digital innovators. Many existing agricultural policies have a scope for trying alternative and pluralistic approaches. it is difficult to develop these solutions in the absence of an enabling policy environment.
- Invest in policy and platforms for data collection and access from public and private sources to enable the development of appropriate products and services for smallholders. Data policy and platforms will also lead to the development of a foundation for data- and evidence-based policymaking. Digitizing farmer data would enable the development of data-based and digitally enabled products and services. Access to good-quality data will aid in the development of innovative service delivery and products.
- Invest in e-governance systems for all public services and resources being administered through ministries of agriculture. Channeling input subsidies and other incentives through digital services is also critical for the development of products and services.
- Invest in enabling policies for telecom infrastructure and payment systems in rural and remote areas to enable good-quality and predictable rural connectivity. Connectivity for smallholder farmers and service providers would enable better access to services and digital solutions.
- Invest in an agricultural technology start-up policy to enable innovators in the digital space to operate and grow. Also, invest in the enabling ecosystem for agricultural technology innovations to facilitate investment by local, regional, and international innovators.

Part 5:
Transforming Sudanese Agriculture Toward a New Business Model

XV. Agricultural and Agro-Industrial Growth Corridors

1. Introduction

The agro-industrial sector in Sudan shares more than two-thirds of the overall industrial output. Principal crops considered as promising products for agro-industry development include cotton, groundnuts, sesame, gum arabic, sorghum, and sugarcane, as well as some horticultural crops such as banana, mango, okra, and grapefruit. The sugar industry is next to the oil seed industry in terms of production capacity. The meat industry is still in the growing stage. Agro-industrial projects (transforming agricultural products to intermediary or final goods by using modern equipment) represent a key pillar of the economic renaissance and are the best strategy to transform the economy from agrarian to industrial. Agro-industrialization constitutes an added value for agricultural products, maximizes the return from agriculture, provides employment opportunities, utilizes technology, and strengthens the links between industry and agriculture. Few parts of Sudan offer the infrastructure necessary to support large-scale manufacturing. Small firms can be found everywhere, but larger firms are located primarily in Khartoum. The main agro-industries include the food, oil, sugar, and textile industries.

2. Growth corridors

Growth corridors promote the efficient use of resources by concentrating capital on the area of the greatest agricultural potential, eliciting a quick supply response that can generate central loops (Diwan, et al.). This large-scale approach has many advantages, such as:

- Attracting the participation of many investors because the risks are pooled.
- Concentration of agri-business allows economies of scale and lowers cost per unit of production.
- Diffusion of technology takes place more easily.
- Various supportive markets form to serve the area.

3. Proposed agro-industrial corridors

The following 12 corridors are proposed on the basis of the strengths of each, bearing in mind the necessity of stimulating growth, poverty reduction, and food security in the different regions of the country.

Corridors	Strengths	Prospective Industries
Merawi, Dongla, Halfa Corridor	• Cool weather suitable for the production of wheat, pulses, fruits, and alfalfa. • Proximity to the Egyptian market with a population of 100 million and expected to reach 180 million by 2050 • Established research and educational institutions. • Established banking services. • Two main airports.	• Wheat mills. • Slaughterhouses. • Fruit processing. • Animal feeds industry. • Fishery industry development (Lake Nuba).
Khartoub, Shendi, ElDammer Corridor	• Large market. • Established federal and state institutions. • Established research and education institutions. • Established public and private banking system. • Relatively adequate basic infrastructure in terms of electricity and communications. • Potential for expanding the irrigated agricultural area (e.g., Hawad Project with a size of four million feddans). • The existence of a large number of projects in food and related industries. • Khartoum International Airport.	• Milling of wheat, millet, and sorghum. • Meat (beef, sheep, poultry, fish). • Milk. • Vegetable oils. • Agricultural input procuring and/or manufacturing. • Processing of fruits and vegetables. • Leather industries.
Gezira, Managil Corridor	• More than two million feddan of irrigated land. • Ginning and textile factories. • Established agricultural research system. • Available finance from the Agricultural Bank and private banks. • Vegetable oil mills. • Established farmer organizations and contract farming models. • Proximity to Khartoum market.	• Textile industries. • Wheat and sorghum mills. • Vegetable oil mills. • Fruit and vegetable factories. • Feed factories. • Feedlots for livestock fattening. • Manufacturing of agricultural inputs. • Dairy Industry. • Aquaculture.
Sennar, Elsuki, Eldinder, Eldamazin corridor	• Large areas of fertile, under-utilized irrigated and semi-mechanized schemes. • New irrigation scheme to be implemented in Rosaries. • New irrigation scheme to be implemented in Eldinder. • Dinder wildlife reserve. • Large livestock population.	• Sorghum mills. • Ginning and textile factories. • Vegetable oil mills. • Animal feed industries. • Feedlots for animal fattening. • Sugar factories. • Development and promotion of tourism in Dinder Reserve.
Gedarif, Rahad Corridor	• Around four million feddans of semi-mechanized farming. • 330,000 feddans under irrigation. • Largest grain silo in the country. • Vegetable oil mills. • Ginning factory. • Connected with Port Sudan by paved road. • Access to banking system. • Research institutions. • Large livestock population.	• Sorghum milling. • Vegetable oil (sesame) industry. • Animal feeds. • Ginning and textile factories. • Feedlots for livestock fattening
New Half, Kassala Corridor	• 330,000 feddans under irrigation. • New Half Sugar Scheme. • Fruit production in Kassala. • Contract farming experience with cotton growers. • Gash irrigation project. • Proximity to Port Sudan. • New Upper Atbara Irrigation Project is in the pipeline. • Availability of finance. • Research stations.	• Sugar industry. • Wheat milling. • Vegetable oil processing. • Animal feed factories. • Textile industry. • Fruit processing. • Feedlots for livestock fattening.
Kosti, Eduiem Corridor	• Sugar factories, including the Kenana and Asalya factories. • 400,000 feddans of under-utilized irrigated lands. • Ginning factories. • Connected to Khartoum by a 30,000 km all-weather road. • Large livestock population.	• Textile. • Sugar. • Feed factories. • Meat and milk factories.
Enahud, Gobiesh Corridor	• Main sheep producing area for the domestic and export markets. • Main producing area for gum arabic. • Main producer of groundnuts.	• Slaughterhouses for export of sheep meat. • Groundnut oil production. • Animal feeds. • Leather industry. • Gum arabic processing.

Corridors	Strengths	Prospective Industries
Elobeid, Umrawaba, Bara, Sodari Corridor	• Central location. • Important as a producer of sesame, groundnut, and hibiscus. • Important gum arabic markets. • Main producer of the famous Kabashi sheep. • Production of fruits and vegetables, mainly at Bara and Khor Abu Habil. • Bara basin could be utilized to increase the production of high-value crops for the domestic market as well as for export. • The Elobeid-Bara-Omdurman Road reduced the time and cost of transportation. • Well-established agricultural research station at Elobeid. • Financial and banking institutions.	• Production of vegetable oils. • Processing of gum arabic. • Slaughterhouses for livestock. • Processing of fruits and vegetables. • Processing of hibiscus. • Leather industry.
Dilling, Kadugli, El Abassya Corridor	• Important area for the production of rainfed cotton. • Eight ginning factories. • Important area for fruit production, especially Abassya and Abugebeha. • Large animal population.	• Labor-intensive textile industry could contribute to poverty reduction. • Potential for using contract farming models. • Vegetable oil processing. • Fruit processing.
Nyala, Edien, Zalingi Corridor	• Large livestock population. • Major source of beef for the domestic and export markets. • Major producing area for groundnut and millet. • Important source of high-quality oranges. • Large tracts of semi-mechanized under-utilized lands. • Potential markets in neighboring countries. • Potential for wheat and sugar production irrigated by groundwater. • Colleges of agriculture, veterinary and animal production, and agricultural research stations constitute a good research system. • Airports at the main cities.	• Meat industry. • Leather industry. • Vegetable oil industry. • Fruit processing industry. • Production of honey. • Cereal milling. • Sugar industry. • Milling of cereals.

4. Financing of agro-industrial corridors

Growth corridors can be financed by the public sector and donors. Building partnerships with patient capital can be a more useful method of finance, since it is a long-term investment willing to suffer short-term losses for the sake of long-term development.

In addition to financing the corridors, the government is responsible for investment in infrastructure, especially roads connecting the corridors with the local and international markets, airports, electricity, and water, and improving the investment environment through appropriate investment policies to encourage large investors as well as farmers.

5. Problems associated with growth corridors

The main constraints facing growth corridors and the industrial sector development are:

- High dependency on agricultural inputs and lack of coordination between the industrial and agricultural sectors at all stages of production.
- Seasonality of the supply of agricultural raw materials.
- Coordination problems between the various public and private actors in the corridor.
- Low levels of technological improvements, obsolete machinery, shortages of skilled labor force, raw materials, investments, foreign currency, and spare parts availability.
- High production cost due to power and energy prices.
- Lack of approved technical specifications and quality standards and poor user confidence in the local product.
- Poor training programs targeting producers in the manufacturing field.
- Poor infrastructure and absence of proper economic policies (technology, storage, electricity, financing, duties, taxes, and VAT).
- Activities of the sector are concentrated in limited big towns and certain states.

Box 2. Value chain development/value addition of selected priority export commodities

A World Bank (2021) study indicated that agricultural value chains in Sudan remain underdeveloped, fragment-ed, and inefficient, with complex supply chains involving multiple actors from the formal and informal sectors, fluctuating product volumes, lack of standards, wide variations in product quality, poor infrastructure, and lim-ited access to market information. In addition, value chains suffer from low productivity, underdeveloped input and output markets, substandard processing, lack of modern technology, substandard inland logistics, poor quality and safety standards, lack of traceability and certification, inflation, and exchange rate fluctuations.

The study prioritized and selected five high-potential agricultural value chains with a strong impact on the livelihoods of the producers. These are gum arabic, sesame seeds, livestock (meat), horticulture, and dairy. Groundnut and cotton were added by the authors due to their high importance and potential.

Gum arabic: Sudanese gum arabic sets quality standards for global markets, and the crop is an important source of foreign exchange earnings. There is substantial poten-tial to enhance productivity and exports and create job opportunities for the rural youth. There is also potential to add value by expanding domestic pro-cessing. This value chain offers considerable opportunities for the livelihoods to poor farmers as well as job opportunities for the youth.

Sesame: Sudan produces high-quality sesame seeds and has a relative advantage in global markets because of its access to large and fast-growing import markets like China and Japan. Many smallholder farmers grow sesa-me seeds as a cash crop and could benefit from interventions that bolster demand and prompt productivity gains. Additionally, it also offers job creation opportunities. With a wide footprint of smallholder farmers and high potential for raising yields in addition to job creation from processing, targeting this value chain for the development of VA exports can deliver significant benefits.

Livestock (meat): The livestock value chain is a key contributor to foreign exchange earnings of the country. The value chain provides opportunities for the development of the value of production through value addition. This sector is also the source of livelihood for more than 50 percent of the Sudanese population, many of whom are part of pastoralist communities that could benefit by addressing the challenges in this sector.

Horticulture: Sudan has a relative advantage in the horticulture value chain because the geographical diversity in Sudan facilitates the cultivation of a wide variety of fruits and vegetables. Selected fruits like mangoes and bananas represent good potential for exports due to the substantial volume of production. The competitiveness of this value chain, however, is severely compromised because of poor cold chain logistics and fragmented supply chains. A large number of producers are involved. Geographical and climatic diversity offer significant potential to increase horticulture production and productivity. Horticulture offers potential opportunities for jobs along the entire value chain.

Dairy: Dairy production amounts to 4.5 million metric tons of milk, of which 98 percent remains unprocessed and is sold loose, although imports of processed dairy products are high and rising. The value chain presents high potential to boost smallholder livelihoods through milk processing due to a vast number of smallholders and pastoralists being involved in the dairy value chain activities. It also presents high job creation potential.

Sorghum: The second highest absolute value of production (after dairy) provides a large base on which even incremental improvements will create impact. As the single largest contributor to the nutritional requirements of an average Sudanese, sorghum's importance as a food security crop is undisputed. With a vast majority of farmers, especially smallholders, involved in the cultivation of sorghum, the development impact of interven-tions in this value chain is also high. However, compared to other value chains, the potential for value addition and job creation in processing and trade is relatively limited.

Groundnut: Groundnut is the most important legume crop grown by several of small-scale farmers in Sudan. Around 75 percent of the national groundnut production comes from smallholders' traditional rainfed sector. It is a primary source of edible oil and has a high oil and protein content. Moreover, groundnut cakes, formed after the oil is extracted, are a high-protein animal feed. Groundnuts are nature's "zero waste" plant, meaning from the roots to the hulls, no part of the plant goes to waste. There is a major potential for improving the groundnut value chain by increasing productivity and strict regulations for quality standards. The potential for value addition and job creation in processing and trade is high.

Sugarcane: Having turned from a net exporter of sugar into a net importer of sugar, this value chain is of high importance for the country. However, in the government's strategic investment plan, this value chain does not find a mention in the list of priorities. In the interest of ensuring strong alignment with the government's strate-gic agenda, this value chain is not selected for deeper study.

Cotton: Traditionally cotton has been a strong cash crop in Sudan. However, in the last three decades, farmers have shifted from cotton to other crops. This resulted in a significant decrease in area under cotton cultivation and production. Very recently, in 2021/22, around 500 ha of cotton was grown under both rainfed and irriga-tion conditions. The cotton supply chain can be broken down into raw cotton production, processing, ginning (seeds extraction), bolls cleaning, spinning, weaving, and garment manufacturing. The processing is undertaken for value addition to its products. Most of the cotton produced in the last years is exported out of the country in raw form. A major reason behind this is the absence of sufficient modern manufacturing capacities to consume cotton. The value addition oppor-tunity is lost by exports of raw cotton, and it also loses out on creation of extra jobs across the value chain. The reason behind the lack of upgrades of machines is the lack of major new investments in the sector. Value addi-tion in the sector should be promoted by providing fiscal incentives on value addition. Cotton growing and the textile sector provided direct employment to hundreds of thousands of people in Sudan. In addition to employing seasonal labor during harvest time.

Organic Hibiscus (Roselle): Sudan is renowned for producing high-quality hibiscus, reckoned by some as per-haps the best in the world. Hibiscus is widely used as a major ingredient in fruit teas and cold drinks. Primary producers within the hibiscus value chain are mainly poor rural women. The value chain of the crop can be promoted through the capacity building of producers in harvesting, cleaning, sorting, and packing. Primary pro-cessing (grinding) is an additional value addition for export. The total volume of export is usually about half of the production, and the rest is consumed in-country. The crop is predominantly produced by small-scale farm-ers in the traditional rainfed sector. Value addition can be achieved through cleaning and primary processing.

Adopted from World Bank (2021) and revised by the authors

XVI. Private Sector and Contractual Agriculture

1. Building on the experience of the private sector

udan's historic, state-dominated, and export-oriented agricultural venture is supported by a vibrant private sector operating in animal husbandry-cum-shifting cultivation. It also operates in irrigated cotton pump schemes in the White Nile, including cottage industries, manufacturing, and especially agro-manufacturing. However, the rise of oil production since 2000 is associated with a significant contraction in the contributions of agriculture to real VA and its growth, which dropped by one-third and one-half, respectively, compared to performance before oil. After the collapse of the oil boom, resources seemed to have moved out of manufacturing and services into low-productivity agriculture in contrast to the classic path of catching up through manufacturing-led industrialization. This is reflected in the continued unfavorable impact of Dutch disease that weighed on small-scale private producers in cottage industries and agro-manufacturing including the diverse unorganized farming communities (Konandreas, 2009).

Land input remains key in Sudanese agriculture. However, around 95 percent of the land is government owned. Private (individual) land ownership is limited to the Nile banks and some of its tributaries in the north. Land issues in the country are complex, highly politicized, fuel the fundamental tensions between formal and informal (customary) land rights, and are drivers of conflicts. Access to land and contested land rights are constraints on private investment, and agriculture is no exception. Moreover, lack of access to land heavily restraints access to credit, particularly for small-scale operators who generally lack the type of collateral (land or heavy machinery) preferred by the banks (Mansfield and Markhof, 2016). Hence, clear land usufruct rights and the demarcation of communal lands loom high in the national development strategy.

Indeed, incomplete land markets – including agricultural finance, capital markets, and inaccessibility to higher value markets – impact different farming communities differently. For example, policy interventions geared toward reforming land rights are less important in the irrigated and semi-mechanized subsector but are crucial in the animal husbandry-cum-shifting cultivation subsector. Farming communities operating in the irrigated subsector are well organized; for example, the Al Gezira Farmers Union was founded even before independence in 1953 to leverage farmers' compensation and benefits vis-a-vis the government. Also, wheat growers' unions and associations press for benefits by ensuring that the government's price offer is higher than the wheat price in the international market.

The irrigated Sudanese agricultural sector, the largest in Africa, featured centuries-old contractual agriculture based on partnership. Early examples include Alsagya,[16] [1]which is a farmers-based partnership system invented to enhance farms' land productivity. The Al Gezira scheme, which was the backbone of the economy in 1930-1987, highlights a case of a formal agricultural contract between the government and the private tenants' holders. The contractual model of the scheme became an ancestor of the big agricultural investments in sugar, wheat, and semi-mechanized rainfed agriculture.

Tenneco, a multinational company in the US, provides an example of early experiences with contract farming. In the early 1980s, the company undertook a venture with hundreds of local farmers who had organized their own cooperatives in northern states. The main objective of the project was to develop saline land in the desert and ultimately use it to export fruits and vegetables to Saudi Arabia. Despite a conscious effort to preserve farmer incentives, the experiment failed completely. The incentives provided under the contracts were singularly effective in motivating the farmers, yet the results were disastrous – not just for the company, but for the cooperatives and the farmers themselves. Lack of finance at the farmer level is among the causes that contributed to the project's failure. Also, while the project goal is long-run-oriented, that is to develop the marginal land in the desert, farmers focus more on the short-run calculations; meaning, reinvesting part of the profit through the cooperatives is not ranked high in their priorities, (Kontos, 1990).

Notwithstanding, the amendment of the Al Gezira Act in 2005 has given the owners great flexibility in the choices of the crop mix and provides an opportunity for undertaking contractual arrangements with private companies to increase crop production and yield. A new form of contractual agriculture emerged as a pragmatic solution to farmers' problems in accessing inputs, including improved seeds, fertilizers, crop protection, machinery, irrigation, agro-knowledge, and access to higher value markets, by linking up to companies' agri-business thanks to the

[16] Alsagya is a traditional system of irrigation.

rollback of the direct governmental involvement into the micro-management of the economy.

Typically, the contract is an agreement between a private company and a group of farmers whereby the former provides capital inputs, including tractors, planting materials, improved seed varieties, and finance in a timely manner as scheduled by the crop production cycle. In return, farmers carry out the agricultural operations and pay the company the total cost of production in-kind at an agreed upon price at the time of the signing of the contract. Private companies operating in this venture are usually insured, which significantly reduces the risks linked to farmers' failure to commit to the terms of the contracts. Also, these private companies negotiate with a representative of farmers, usually a local farmer-based union, which reduces their transaction costs.

Major manufacturing players are attracted to the venture. For example, in 2008, the Muawa Elbirar Agricultural Group launched the contract farming in cotton project for the first time after the rollback of the government interest in the crop. The project initially covered about 60 thousand feddans in Al Gezira. The company introduced the Indian cotton variety along with the required farming inputs and marketing facility. After the project's success, the company contracted farmers in the New Halfa and Al Suki agricultural schemes.

Dal Group also provides contracting services as a solution to soil problems that reduce yield or raise costs. Moreover, the company contributes to land leveling, canal clearing, and diching, as well as harvesting services by using the best available machinery and equipment. In addition, the company operates its own farms covering over one million feddans. Similarly, Mahgoub Sons provides contact farming to facilitate farmers' access to fertilizers and finance. The company's contractual relations also include link-ups to the high VA markets.

In 2019, the African Development Bank approved a USD 60 million loan to Elnefeidi Groups with the aim to directly boost the development of Sudan's livestock value chain, including poultry and beef, by increasing the export capacity for value-added products.

Also, Africorp International, a leading Sudanese exporter of cash crops established in 2002, contributes to farmers' access to higher value markets, including the provision of agricultural finance and access to agro-knowledge, tools, and technology. In 2020, more than 4,000 farmers benefitted from the company's services.

Besides domestic companies, a private Chinese-based company (China's New Epoch Agricultural Development Company Ltd) launched contract farming in Qadarif in 2012. The company provides cotton seeds, fertilizer, machinery, and other resources, in addition to marketing services. Furthermore, the company operates its own cotton ginning factory with an annual production capacity of 15,000 metric tons of lint cotton. The project covers 10,000 ha of cotton and is planned to grow an additional 60,000 ha of cotton in the medium term.

Irrigation and its related infrastructure as well as the presence of farmers-based organizations have significantly encouraged private companies-farmers contractual agriculture. Currently, these companies focus on cotton production, which is abandoned by the government. However, the promotion of private contract farming in dry agriculture requires government support. Indeed, the success of the venture in the irrigated subsector is brought on the back of substantial government investments in infrastructure. There are diverse communities operating in dry agriculture with different interests, but the land issue (as resources and collateral in the financial markets) continues to present grave challenges. The experience of the Dar system[27] indicates that government regulation of land usage would better serve the interests of these communities. Since the government is the main owner of land resources, the regulation of land usage could be indirectly influenced in dry agriculture through the provision of public services focusing on watering points, irrigation, health, veterinary services, and education. The establishment of the National Land Commission and State Land Commissions, which stalled for years, is expected to encourage large-scale investment in farming land while minimizing the associated risks in terms of livelihoods, inequality, land grabbing, and environmental degradation. Land reform under this institution is expected to integrate customary laws, practices, local heritage, and international practices. It is also expected to provide a mechanism for land dispute resolutions and strengthen farmer-based organizations in the subsector.

The private smallholders are not directly connected to the government and exist in spite of the government and not because of it (Mansfield and Markhof 2016). As suggested by the SNAIP 2016-2020 experience, which was a top-down, bottom-up strategy based on local partnership and dialogue, should help align public-private priorities. Legal and regulatory framework is needed to promote sound private sector-led agri-business aiming to provide a solution to missing agricultural markets and infrastructure in the context of achieving SDGs, especially the goal of eradicating hunger by 2030. Above all, a market-driven solution would require the government's commitment to

[17] The Dar system is largely informal and operated by the native administration system on behalf of the government.

sound macroeconomic stability in order to reduce the general price volatility and increase farmers' income. The proposed legal and regulatory framework should focus on leveling the playing field for contract farming between big agri-businesses and farmers. The government could encourage private sector companies to deliver integrated packages to facilitate farmers' access to finance, markets, seeds and fertilizers, machinery, information, and extension services, and training in exchange for ensuring reliable energy supply to the private agri-food sector, including the facilitation of importing food processing technologies.

Part 6:
Toward a Strategy for Transforming Sudanese Agriculture

XVII. Agricultural Transformation

The African Center for Economic Transformation (ACET) defines agricultural transformation as a process that leads to higher productivity in farms, commercially orients farming, and strengthens the link between farming and other sectors of the economy. Timmer (1988) defined agricultural transformation as the process by which an agri-food system transforms over time from being subsistence-oriented and farm-centered into one that is more commercialized, productive, and off-farm centered. AGRA (2016) simplified agricultural transformation as the process through which farms gradually move from highly diversified, subsistence-oriented production systems toward more specialized and business-oriented production processes. In Sudan, Bakheit (2021) indicated that the main objective of agricultural transformation is to transform agriculture from a mere means of subsistence and livelihood for rural communities into an economic activity characterized by its ability to improve productive capabilities, increase farmers' incomes, remove them from the line of poverty, achieve food security, improve the standard of living, provide employment opportunities for the population at the country level, and achieve sustainable development and the steady growth of the national economy.

Across the previous chapters of this study, a set of interventions were proposed to catalyze the transformation of Sudan's agricultural sector from a subsistence-oriented, low-output sector to a high-performing sector well integrated into the national economy through:

- Ending the legacy of excessive direct and indirect taxation of agriculture and adopting policies that address all the agricultural transformation interventions and government commitment to annually allocate sizeable resources of the national budget to agriculture.
- Strengthening the role of the private sector in agricultural transformation. The government should focus on the policies and plans that will create a conducive environment through the provision of incentives for investment in the agricultural sector and the removal of obstacles limiting effective participation.
- Improving agricultural support services, including the development of agricultural research, technology transfer, and extension services; the expansion of agricultural credit and insurance services, weather forecasts and climate information, animal vaccination and market information services; and the enhancement of agricultural education.
- Enhancing the accessibility of agricultural inputs to enhance crops and livestock productivity. The inputs that are most needed include improved seeds, agro-chemicals (pesticides, fungicides, fertilizers, and herbicides), animal feeds, and tools and implements (drugs and vaccines).
- The establishment and upgrading of markets by strengthening ICT.
- Strengthening farmers' cooperatives and producers' organizations, promoting the formation of strong farmer CBOs, building the capacities of producers and their institutions, and increasing their productive and managerial capacities
- Improving gum arabic infrastructure and services (storage facilities, transportation, water points, and feeder roads).
- Rehabilitating and modernizing the irrigation water infrastructure and achieving the full mechanization of agricultural operations, from planting-harvesting and post-harvest operations.
- Value chain development: Promoting industrial crops that can be used in agro-industries such as cotton, peanuts, sesame, fruits, vegetables, sugarcane, livestock, and others, to enable the processing and manufacturing of produce in order to maximize VA to exports.
- Establishing agricultural commodity development councils: establishing a development council for each commodity or group of related commodities, implementing a package of incentives for the producers, and promoting applied research and transfer of technology and improvement of marketing. The participation of all the stakeholders, including the producers, is necessary.
- Building on the capacities of the industrial sector to manufacture agricultural inputs, satisfy
- agro-industries with their requirements of raw materials, link the production-processing marketing chain, and utilize the ideal capacities in the agro-industries.

- Agro-industrial growth corridors: Growth corridors promote the efficient use of resources by concentrating capital on the area of greatest agricultural potential and eliciting a quick supply response that can generate central loops.
- A strong early warning mechanism and forecast-based farming.
- Resolving conflicts on land tenure systems and resource users between different stakeholders through the support and capacity building of local governance (local administration and conflict resolution mechanisms).
- Contract farming should be promoted by involving the private sector to accelerate technology transfer, capital influx, and assured produce marketing through necessary legislation and arrangements.
- Grants to research institutions are intended to replace the fragmented research organizations in the state with a multidisciplinary approach. Teaching functions are combined with all activities to train university graduates. Research institution resources are combined with federal and state support.
- Promoting fertilizer use to increase productivity by establishing a competitive fertilizer industry in Sudan.
- Renewable energy has multiple uses in agriculture and could be an important vehicle for developing the agricultural sector (irrigation systems).
- Introduction of disruptive technology in agriculture: digital and technical innovations that enable farmers and agri-business entrepreneurs to leapfrog current methods to increase their productivity, efficiency, and competitiveness.

In line with these interventions, Nyoni (2021) indicated that agricultural transformation requires distinct agricultural policies and strategies focusing on food security, maximizing farmers' incomes, promoting sustainable agriculture, and enhancing private sector roles in input and output markets, public support, and investment in agriculture. This is in addition to creating an enabling environment to attract private sector and smallholder interest in farm production, processing, and trade. Furthermore, it is concluded that agricultural transformation must be anchored on eight main pillars:

1. Agriculture mechanization.
2. Climate change adaptive agricultural practices.
3. Higher public investment in agriculture.
4. Extensive extension services.
5. Competitive agriculture pricing models.
6. Substantive titles to agricultural land for the majority.
7. Diversification in agriculture.
8. Adoption of agricultural technologies.

XVIII. Summary and Key Messages

The initial conditions of the Sudanese agricultural sector are quite dire. Despite more than half a century of several economic development plans and public policy initiatives all centered on transforming the sector, the country's vast agricultural potential is far from realized. Notwithstanding sad past experiences, modernizing agriculture remains critical for promoting win-win solutions, and it must be the focal point of any serious transformational project for the Sudanese economy.

The modern growth literature focusing on the process of catch-up growth contrasts between the growth processes of industry and agriculture. The overall evidence shows that poor countries with initially low productivity could grow faster and catch up with richer countries if they adopt growth-promoting policies and build the right institutions to allow them to absorb knowledge and learn from the technological frontier. Therefore, poorer economies can only grow faster than richer economies, conditional on their endowments, policies, and institutions (Rodrik, 2011). However, more recent evidence suggests that productivity in manufacturing tends to converge unconditionally regardless of the prevailing institutions or policy environment (Rodrik 2013). In the light of this evidence, it is natural to question whether the unconditional convergence property also extends to the agricultural sector (Ishac et al., 2013).

Against this backdrop, the paper first asked a fundamental question as to what went wrong with the Sudanese agricultural development model. Second, it probed into the issue of how agriculture could be developed as an industry within a national development plan.

In order to address these two questions, the paper first conducts a preliminary descriptive analysis of the aggregate and sectoral value-addition in the Sudanese economy. Second, it assesses the determinants of the conditional convergence of agricultural VA by estimating an empirical agricultural growth model using global data covering more than 120 countries. Here, the paper compares the agricultural VA in Sudan to other comparators and analyzes the factors associated with the key three pillars of productivity: (i) policies and institutions (macroeconomic, environment, and pricing policies); (ii) inputs and capital base of agricultural supply (fertilizers, road infrastructure, and finance); and (iii) human capital and empowerment. Third, the paper provides a detailed SWOT (strengths, weakness, opportunities, and threats) analysis of developing agricultural and agro-industrial growth corridors in the main agricultural sub-sectors: traditional rainfed non-gum arabic field crops and gum arabic; semi-mechanized; and irrigated. Fourth, building upon the results of the descriptive regression and the SWOT analyses, the paper addresses the challenging question of how to achieve the overarching objective of “transforming Sudanese agriculture.” Here, the paper reviews the role of institutions and the empowerment of rural communities through establishing a robust agricultural commodities development council, an agricultural research system, a seed industry, and farmers’ cooperatives. Then, it evaluates the critical need to invest in agricultural supply for affecting the much-needed transformation, including by mainstreaming fertilizer use; expanding irrigation systems and renewable energy; and, considering the impending digital revolution, incrementally embracing the adoption of technology and precision agriculture. Finally, the paper proposes a new business model for transforming agriculture by making the sector look more like an industry. The proposed business model is built around agro-industrial growth corridors and private sector-led contractual agriculture. The rest of Part 6 presents the key messages of the report.

Key findings

First, over the last six decades, Sudanese agriculture ranked second to services in terms of contribution to total value addition, and it grew by 2.8 percent, which is half the average growth of services. However, it remains the home for more than 60 percent of the population. As the source of almost all non-oil and mineral exports, it contributes more than half of paid and unpaid family work and more than two-thirds of own-account businesses work in the sector. The sector is also beset with low productivity and weak linkages to the modern agro-industry.

Second, the Sudanese agricultural development model has been lopsided, with virtually all capital stock, agricultural technology, and extension concentrated in the irrigated sub-sector, leaving the vast rainfed agriculture at near subsistence level of productivity.

Thirdly, agriculture has been subjected to heavy taxation, both at the sectoral and macroeconomic policy levels. The sector became the tax base of choice for the predatory practices of the cash-poor states created under the new federal system since the early 1990s. Perhaps even more damaging to the sector were the macroeconomic policies that produced long episodes of hyperinflation during the early 1990s and, more recently, since the last two years of the former regime. Accordingly, the competitiveness of the highly tradable agricultural sector has been severely damaged by the RER appreciation associated with the oil decade (2000-2011) and the subsequent gold boom.

Fourth, agriculture suffered from the combined impacts of exchange rate overvaluation due to Dutch Disease, which is associated with the oil boom and the lack of commitment of the political elite to develop the sector, especially the rainfed subsector, which is dominated by diverse and politically unorganized rural communities. However, the response of the irrigated and rainfed subsectors to these developments has been different. While the irrigated sector remained resilient in terms of crop productivity, harvested areas, and access to high-value markets, the rainfed subsector continued to face significant challenges relating to the decline of crop productivity despite the huge growth of harvested areas and the missing of key inputs and outputs markets. This evidence clearly indicates that the prevailing patterns of land use, particularly in the rainfed subsector, are inconsistent with the long-run goal of sustainable growth in the country’s food production, thereby calling for deep-seated land reforms.

Fifth, the total factor productivity growth recently turned negative, and the contribution of structural change to the path of catching up through manufacturing has been limited. Moreover, the bulk of employment growth occurred in low-productivity sectors, mainly agricultural and informal services.

Six, evidence confirmed that the agricultural growth process is actually divergent, but, like countries, it tends to converge conditionally on the key three stalwarts of productivity: (i) policy variables (measured by REER under/overvaluation); (ii) infrastructure and input variables (measured by the overall infrastructure index, ICT, transport, and finance); and (iii) human capital variables (measured by the Human Development Index and educational attainment). Moreover, the evidence suggests that agriculture could be developed as an industry along a variety of emerging business models for commercializing agriculture and strengthening forward linkages to agro-industries, such as building growth corridors centered around productive cities; contractual agriculture in the form of partnerships between farmers’ associations and modern private sector entities; and marketing boards.

Seventh, the key messages and recommendations of the SWOT analyses are summarized in Box 4.

Box 4. Key messages and recommendations of the SWOT analyses

Domain	Recommendations
Gum arabic	• Improving inputs and service delivery through a services and inputs delivery-centered model and strengthening the capabilities of technology transfer centers. • Improving infrastructure and services (storage facilities, transportation, drinking water, and feeder roads) at the gum arabic production areas. • Encouraging the development of intermediate technologies to design suitable tools for gum arabic tapping, collection, and primary processing. • Providing suitable extension services: improved technology transfer and reforestation as well as training on seedling nursery establishment. • Promoting gum arabic research and supporting relevant research institutions. • Supporting climate change adaptation and resilience through the development and dissemination of climate adaptation and resilience practices. • Resolving conflicts on land tenure systems and resource users between different stakeholders through the support and capacity-building of local governance (local administration and conflict resolution mechanisms). • Enabling and encouraging the local processing and manufacturing of gum to maximize VA to exports. • Building the capacity of gum producers on gum drying cleaning, sorting, and packing. • Setting and executing a prompt marketing strategy to develop the gum arabic sector, including the participation of local communities and stakeholders in preparing policies and strategies for crop production and marketing. • Building/developing value chains by mobilizing all value chain partners and enhancing the interrelationship and interaction among the components of the chain. • Developing market and information systems and improving access to information via media, mobile, SMS…etc.

Rainfed and irrigated sectors	• Transitional Facilitation Commission for Rainfed Farming Reform (SMRF), reestablishing the Mechanized Agriculture Corporation to enable rapid and effective sectoral reform and infrastructure rehabilitation.
	• The National Land Commission should be made fully operational to establish the current status of land tenure and use.
	• Establishing a standardized system of leaseholds for rainfed farming for investment security.
	• Modernizing the irrigated sector through the GIS data to be developed, irrigation scheme hydraulic simulation, land tenure, institutional and management structure, technical aspects for canal modeling, cropping pattern, and the future production model.
	• Establishing agricultural commodity development councils.
	• Increasing financial resources and sources of funds for agricultural research to carry out its research activities.
	• Strengthening linkages between research institutions and national, regional, and international organizations.
	• Backing the farming system research/extension approach in the traditional rainfed sector to ensure community involvement and participation in technology development and evaluation through on-farm research/demonstration.
	• Supporting the Grant Institution System to improve NARS effectiveness to promote the three functional pillars of the grant institutions: teaching function, research, and extension.
	• Supporting sustainable seed enterprises through:
	    • Educational awareness campaigns and increased promotional activities (variety demonstrations and farmer field days) by community seed producers to stimulate the demand for improved varieties.
	    • Developing partnerships and linkages with other service providers (research, formal seed sector, financial services, extension, federal seed administration, private seed companies…etc.).
	    • Developing and promoting a seed production market for smallholders.
	    • ARC should be supported to establish seed multiplication and processing units and sites to increase its capacity to produce a sufficient quantity of foundation seed.
	    • Creating an enabling environment for the private sector, including CBOs, to ensure the sustainability of the production of improved seeds.
	    • Improving the regulatory framework through the enforcement of the Seed Act and capacitating and empowering the National Seed Administration to carry out its seed quality regulatory functions effectively.
	    • Developing seed regulations, laws, guidelines, and protocols for quality seed production.

Fertilizers	• Improving the agricultural resource base so that the use of fertilizers can be more profitable (for example, by investing in soil and water conservation measures and irrigation infrastructure).
	• Interventions that can be used to strengthen the supply of fertilizers include:
	    • Reducing fertilizer sourcing costs and distribution costs, procuring fertilizer in bulk, and entering the market at the time when prices are lowest.
	    • Strengthening business finance and risk management instruments (for example, by implementing credit guarantee schemes and innovative types of insurance).
	    • Improving supply chain coordination mechanisms (for example, by enacting and enforcing regulations relating to product grades and standards and by introducing market information systems that can help reduce information costs).
	• The establishment of a competitive fertilizer industry in the country can be achieved through:
	    • A large enough local market.
	    • Abundance of natural gas with very low opportunity cost (since natural gas has alternative uses, such as the generation of electricity, which is a national priority).

Renewable energy	• Introducing and expanding the use of renewable energies, especially solar energy. at a vast scale for modernizing irrigation systems.

Domain	Recommendations
Technology	• Technology interventions to strengthen the agricultural sector in Sudan include: • Building a national agriculture digital framework and applications to facilitate communication and access to information. • Introducing spraying, planting, and monitoring by tractors and drones. • Importing seed coating machines and using organic materials and nutrients to improve seed germination. • Increasing the coverage of mobile networks to facilitate communication and access to market information. • Adopting smart agriculture technology for planting and harvesting to minimize labor-intensive activities. • Broadcasting customized meteorological forecasts enhanced by AI algorithms through SMS to farmers. • Processing the reengineering and automation of the supply chain cycle. • Using hyper spectacle imaging analysis for planting new trees and performing soil analysis to improve productivity. • Planting new trees by regular planes using GPS coordinates. • Connecting production sites by wireless network and establishing a monitoring center. • Leveraging mobile application technology to disseminate knowledge and training for best practices for tapping and harvesting • Importing seed coating machines and using coated seeds to enhance the germination rate. • Upgrading irrigation infrastructure to use modern irrigation technologies, such as drip irrigation triggered by IoT sensors that detect moisture levels. • Introducing solar and wind (or hybrid) pumps to decrease dependence on diesel-powered pumps. • Performing a soil analysis using hyperspectral imaging to apply the precise type and quantity of fertilizers and pesticides
Growth corridors	• Developing agricultural and agro-industrial growth corridors to promote the efficient use of resources by concentrating capital on the area of greatest agricultural potential, thereby eliciting a quick supply response that can generate central loops.
Laws and infrastructure	• Creating the appropriate environment (laws, infrastructure): • Encouraging investment in the agricultural industries. • Developing policies to develop the agricultural value chain with a focus on encouraging small industries.
Private sector	• Building on the positive private sector experience in improving productivity and promoting the use of fertilizers and contract farming.

XIX. Policy Recommendations

An agricultural strategy aiming to transition Sudan from poor agriculture to agro-industrial growth and sustainable development would require tapping the diversities of the agro-climatic and production systems of the county, empowering the farming communities and their access to inputs and basic services, enhancing productivity, and strengthening linkages with industry, especially manufacturing. In the proposed strategy (henceforth referred to as 'the strategy') poverty combating is strongly linked to the process of growth and structural transformation.

Sudan PRSP (2021) has already suggested building a solid foundation for a diversified economy, and sustained growth remains crucial for inclusive, poverty-reducing growth. The strategy in this paper recommends building a foundation for a diversified economy, which is conditional upon building robust growth fundamentals (that is, the long-term component), while pursuing a short-term objective based on engineering growth-enhancing structural transformation through a targeted industrial policy that allows for the transfer of labor and other factors of productions from low to higher productivity sectors. In addition, the strategy proposes the following recommendations:

First, unlike the previous experience with top-down and government-driven plans, the strategy recommends bottom-up and evidence-based policy interventions. The complete rollback of the micromanagement of the economy by the government is an important steppingstone for the formal engagement of the private sector in realizing both the long- and short-term objectives of the strategy. The last SNAIP 2016-2020 envisages to commit 10 percent of the budget to finance agriculture, and the private sector is envisioned to contribute 60 percent of planned investments. However, the realized performance is disappointing on both counts. The largely uncoordinated regulations, taxation laws at different levels of government, as well as the unpredictability of changes loom high in the incentive structure and the promotion of market roles. Based on this experience, the strategy recommends focusing the government's role on coordinating policies, laws, and regulations, including contract enforcement.

Second, the strategy recommends the expedition of the implementation of the long-awaited land reform. The contested land rights between the federal government and state governments, including the fundamental tensions between formal and informal (customary) land rights, continue to present grave challenges. Land resources remain critical for farming and animal raising systems and as collateral for accessing finance. Also, clear land demarcation is essential for empowering small-scale farming and herding communities. It should be noted that the key exports in which Sudan has global market power and significant regional markets (gum arabic, sesame, and livestock) are produced in dry agriculture, which is the most negatively affected by lack of land access and land contestations. Based on this, the envisaged strategy recommends expediting the establishment of the National Land Commission and State Land Commissions, which are expected to encourage large-scale investments in farming land while minimizing the associated risks in terms of livelihoods, inequality, land grabbing, and environmental degradation. Land reform under this institution is expected to integrate customary laws, practices, local heritage, and international practices. It is also expected to provide a mechanism for land dispute resolutions and strengthen farmers' organizations in the subsector.

Third, the strategy recommends adherence to the key pillars of productivity-growth that are at the heart of any plan aiming to advocate a renaissance of Sudanese agriculture:

1. Policies and institutions: the commitment to sound macroeconomic stability based on transparent pricing policies and institutions ranks high in augmenting the growth of agricultural productivity.
2. Infrastructure and input variables: promoting the capital base of agricultural supply, mainly fertilizers, road infrastructure, transport, finance, and ICT, remains critical for the successful implementation of any strategy advocation structural transformation through agro-industrialization.
3. Human capital base: enhancing health and educational attainment are at the heart of the SDGs and remain crucial for productivity-intensive growth. Successful industrial policy targeting the development of agro-industrial growth corridors requires the improvement of growth corridor productivity growth from within, which enhances factor movement from the low-productivity agricultural systems to high-productivity sectors.

Fourth, the strategy's business model recommends the adoption of industrial poles building on the proposed agro-industrial growth corridors to be developed by lead private companies cum farmers contacting to leverage durable integrated market-based support for the pillars of productivity-growth. In particular, the strategy recommends the institutionalization of the legal protection of the contracts between the lead private companies and SMEs that are capable of forging vertical and horizontal linkages in infrastructure, agricultural inputs, and human capital sectors. It should be noted that promoting the modalities of vertical and horizontal linkages and networking between large companies and SMEs is of strategic importance for these enterprises to survive the ruthless competition driven by the rising tide of globalization.

The simultaneous implementation of the strategy's recommendations should trigger effects-loops that work in circular and cumulative causation. The successful implementation of land reform and the government's commitment to implementing the key pillars of productivity-growth are core components of the strategy's business model, which entails fostering the development of agro-industrial growth corridors and private sector-led contractual agriculture. In addition, establishing a reasonable land tenure arrangement is crucial for the aggregation of farm enterprises for contract farming as well as for securing bank credit. Furthermore, the success of a private sector-led integrated-markets solution to the major challenges in agriculture requires the government to commit credibly to macroeconomic stability. Ensuring a stable price system is of critical importance in the contract farming model. Accordingly, contract prices should be inflation-adjusted and the government should pay the difference. Moreover, direct cash transfers, especially through mobile money, should be strengthened to protect the poor and promote local development and financial inclusion. These downstream issues of the strategy's business model relate to the engagement and incentivization of the diverse small-scale and family businesses at the grassroots of the model. At the top of the model, the government should play a key role in rectifying the legal and regulatory framework for leveling the playing field for contract farming between big agri-businesses, middle enterprises, and farmers. The government should also encourage the lead-private sector companies to deliver integrated packages to facilitate farmers' access to finance, markets, seeds and fertilizers, machinery, information and extension services, and training, in exchange for ensuring reliable energy supply to the private agri-food sector, including the facilitation of importing food-processing technologies. In addition, targeted subsidies should be used by the government to leverage its growth corridor priorities.

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Annexes

Appendix Table 1. List of Countries

This table presents the list of countries used in the analysis according to their income groups.

Low Income	Low-Middle Income		Upper-Middle Income		High Income		
Afghanistan	Angola	Nicaragua	Albania	Kazakhstan	Argentina	Italy	Switzerland
Benin	Bangladesh	Nigeria	Algeria	Lebanon	Australia	Japan	Trinidad and Tobago
Burkina Faso	Bolivia	Pakistan	Azerbaijan	Malaysia	Austria	Korea, Rep	United Arab Emirates
Burundi	Cambodia	Papua New Guinea	Belarus	Mauritius	Belgium	Latvia	United Kingdom
Ethiopia	Cameroon	Philippines	Bosnia-Herzegovina	Mexico	Canada	Lithuania	United States
Guinea	Congo	Sri Lanka	Botswana	Namibia	Chile	Netherlands	Uruguay
Madagascar	Egypt	Sudan	Brazil	Macedonia	Croatia	New Zealand	
Malawi	El Salvador	Tunisia	Bulgaria	Paraguay	Czech Republic	Norway	
Mali	Georgia	Ukraine	China	Peru	Denmark	Oman	
Mozambique	Ghana	Uzbekistan	Colombia	Romania	Estonia	Panama	
Nepal	Honduras	Vietnam	Costa Rica	Russia	Finland	Poland	
Niger	India	Zambia	Dominican Republic	Serbia	France	Portugal	
Rwanda	Indonesia		Ecuador	South Africa	Germany	Saudi Arabia	
Senegal	Kenya		Guatemala	Thailand	Greece	Singapore	
Tajikistan	Kyrgyz Republic		Iran	Turkey	Hungary	Slovak Republic	
Tanzania	Moldova		Iraq		Ireland	Slovenia	
Uganda	Mongolia		Jamaica		Israel	Spain	
Yemen	Morocco		Jordan		Sweden		

Source: F. Ramli (2007).

Appendix Table 2. Data Sources

This table presents the definitions and data sources of all the variables used in the analysis.

Variable	Definition	Source
Agricultural Value Added	Agricultural value added in constant 2010 US dollars. Value added is the net output of the agricultural sector, adding up all outputs and subtracting intermediate inputs. The agricultural sector includes the cultivation of crops, livestock production, forestry, hunting, and fishing.	• World Bank's World Development Indicators (WDI).
Total and Agricultural Employment	Agricultural employment refers to the total number of persons employed in the agricultural sector. Total employment is the total number of persons employed in all economic sectors. The series represent modelled estimates. The employed comprise all persons of working age who, during a specified brief period, were in paid employment or self-employment.	• International Labor Organization (ILO), modelled estimates and projections, employment by sex and economic activity.
Agricultural Productivity	Computed as total agricultural value added (in constant 2010 US dollars) per agricultural worker.	• World Bank's WDI and ILO modelled estimates.
Real Effective Exchange Rate	Annual real effective exchange rate index, based on the consumer price index and 66 trading partners.	• Darvas (2012), Bruegel.
Inflation Rate	Annual consumer price index inflation rate, taken as the average of period.	• International Monetary Fund's World Economic Outlook (WEO).
Energy Infrastructure Index	An index on the quantity and quality of energy infrastructure, scaled between one and 10, with higher values indicating better infrastructure. Construction includes using data on a country's yearly per capita electric power consumption and production, as well as the percentage of electric power transmission and distribution losses to output.	• Donaubauer et al. (2016).
ICT Infrastructure Index	An index on the quantity and quality of information and communications technology infrastructure, scaled between one and 10, with higher values indicating better infrastructure. Construction includes using data on a country's yearly number of fixed telephone lines, mobile cellular telephone subscriptions, the number of integrated services digital network (ISDN) subscriptions, and the number of faults per 100 fixed telephone lines.	• Donaubauer et al. (2016).
Finance Infrastructure Index	An index on the quantity and quality of finance infrastructure, scaled between one and 10, with higher values indicating better infrastructure. The index encompasses measures of financial system stability, efficiency, access, and depth. Construction uses data on the banks' Z-score, stock price volatility, stock market turnover ratio, the number of per capita bank accounts, the value of all traded shares outside the largest 10 traded companies as a share of the total value of all traded shares, and the number of publicly listed companies per capita, private credit to GDP, the total value traded stocks to GDP, in addition to money and quasi money (M2) to GDP.	• Donaubauer et al. (2016).
Transport Infrastructure Index	An index on the quality of energy infrastructure, scaled between one and 10, with higher values indicating better infrastructure. Construction includes measures of land transport, sea transport, and air transport. Land transport includes the total length of the road network, the percentage of paved roads, the percentage of motorways, the number of registered passenger cars and commercial vehicles, the total length of the railway route, goods transported by rail, and total railway passengers. Sea transport includes the ratios of total ships' carrying capacity to a country's geographic area and to the world's total carrying capacity. Air transport includes the number of registered carrier departures to population and the volume of air freight.	• Donaubauer et al. (2016).
Overall Infrastructure Index	An index on the quality of overall infrastructure, scaled between one and 10, with higher values indicating better infrastructure. This is a composite infrastructure index of energy, ICT, finance, and transport, constructed using an unobserved components model.	• Donaubauer et al. (2016).
Arable Land Area	Arable land is the total area (in hectares) under temporary crops, temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow. This does not include land that is not cultivated for shifting crops.	• Food and Agriculture Organization (FAO).
Total and Rural Population	Total population represents midyear estimates of the total number of residents in a country, regardless of their legal status or citizenship. Rural population represents the total number of residents who are living in rural areas, as defined by national statistical offices.	• World Bank's WDI.
Yearly precipitation	Total yearly precipitation in a country is the total water released from clouds in the form of rain, freezing rain, sleet, snow, or hail.	• World Bank's Climate Change Knowledge Portal.
Landlocked	A country is defined as landlocked if it is completely surrounded by other countries and without any direct coastline.	• Geography Realm, Landlocked Countries. https://www.geographyrealm.com/landlocked-countries/

Appendix Table 3. Summary Statistics

This table reports summary statistics of the variables used in the analysis for 121 countries over the period 1991-2010, in five-year intervals. The dependent variable used in the analysis is the five-year average of the annual growth rate in agricultural VA per agriculture labor (in constant 2010 USD). Initial agricultural VA is the first-year value of each five-year interval. Control variables are divided into policy, infrastructure, and input, in addition to human capital variables, which are all computed as five-year averages. Real exchange rate (REER) undervaluation is the log of the ratio of the five-year moving average to the contemporaneous value of REER, whereas REER variability is its coefficient of variation. Infrastructure is proxied by the indices developed by Donaubauer et al. (2016), which capture infrastructure for energy, finance, information and communications technology (ICT), and transport. Human capital is proxied by the human development index, the mean years of schooling, and the mean years of primary schooling. All the control variables are computed as the five-year averages, except for the mean years of secondary and primary schooling, which are only available from Barro and Lee (2013) in five-year intervals starting 1990 and hence are taken as the value in the year just before the five-year period.

	Units	Mean	Std. Dev.	Median	Minimum	Maximum
Growth in Agricultural VA per Worker	Percentage	2.28	4.58	2.47	-16.08	20.61
Initial Agricultural VA per Worker	Thousands, Constant 2010 USD	11.66	21.64	3.81	0.22	208.90
Policy Variables						
REER-Undervalue	Index	0.01	0.08	0.00	-0.21	1.11
REER-Variability	Index	0.09	0.14	0.06	0.00	1.21
Inflation Rate	Percentage	29.85	155.65	6.07	-0.71	2000.94
Infrastructure and Input Variables						
Overall Index	Index, 1-10	4.50	1.71	3.90	1.70	9.58
Energy Index	Index, 1-10	4.55	1.09	4.29	1.23	9.71
ICT Index	Index, 1-10	4.65	1.43	4.05	2.51	9.47
Finance Index	Index, 1-10	4.57	1.48	4.24	1.66	9.16
Transport Index	Index, 1-10	3.69	1.60	3.13	1.39	8.71
Fertilizer Consumption	Thousand metric tons	1,227.50	4,441.47	181.51	0.23	46,961.16
Human Capital Variables						
Human Development Index	Index	0.66	0.16	0.68	0.24	0.94
Mean Years of Schooling	Years	7.50	3.13	7.73	0.52	13.66
Mean Years of Primary Schooling	Years	4.30	1.68	4.33	0.22	8.99
Mean Years of Secondary Schooling	Years	2.46	1.49	2.19	0.06	6.89

1) Sudan regions:
The general features, indicators, and potentials of regions and states
The country is administratively divided into 18 states, which are grouped into six regions:

1. *Eastern, Kordofan, Northern, Gezira and Khartoum Regions*

Characteristics /Indicator	Region/state								
	1. Eastern			2. Kordofan			3. Northern		4. Khartoum
	Gedarif	Kassala	R Sea	North	West	South	Nile	Northern	Khartoum
Area (km2)	75,263	36,710	218,887	185,302	111,373	79,470	122,123	348,765	22,142
Total Population	2,208,400	2,519,100	1,482,100	2,216,200	1,764,800	1,300,700	1,511,400	936,300	7,993,900
Proportion of rural population (%)	71.5	73.7	60.5	80.1	76.5	76.5	70.4	83.1	9.0
Poverty rate (%)	57.6	58.7	72	66.1	71.8	85.5	48.4	44.8	46.2
Predominant farming system	Mechanized	Traditional & Mechanized	Traditional	Traditional	Traditional	Traditional & Mechanized	Irrigated	Irrigated	Irrigated
Agro-ecological zone	Semi-arid	Arid to semi-arid	Arid	Arid	Semi-arid to sub humid	Semi-arid to sub humid	Semi-desert	Desert	Semi-desert to arid
Predominant soil types	Heavy cracking clays and alluvial soils	Cracking clays and alluvial Silty clays in deltas	Steep and stony shallow sandy soils, and Silty clays in deltas	Stabilized sand dunes (goz)	Stabilized sand dunes (goz) and cracking clays	Cracking clays and sand dunes	Sandy plain/ mixture of sand silt and gravel, alluvium silty along the Nile	Sand sheet, dunes, and gravelly plains and alluvium along the Nile	Loamy sandy and a mixture of sand and gravel plains and alluvium along the Nile
Climate change indicators: Rain-mm - variability (CV%) or yearly drop in mm per year	429(35%) +0.5	230(38)	110	347(30) -5.0	356(60)	685(20) 3.99	51(99) -0.56	-0.48	160 -4.9
Frequent extreme climatic events	Drought	Drought Dust Storms	Drought Dust Storms	Drought Dust Storms	Drought	Drought	Floods Dust Storms	Floods Dust Storms	Floods Dust Storms
Vulnerability to environmental hazards (risk level)	Very high risk	Very high risk	Very high risk	Very high risk	Low	Moderate	High	Low	Very high risk
Average annual total cultivated area (000ha)	2691	1042	23	1152	1808	2146	118	56	20
Irrigated (000ha)	64	125	13	10	0	0	36	56	2
Rainfed (000ha)	2627	917	10	1142	1808	2146	82	0	18
(%) Share in national area	12.8	4.95	0.11	5.47	8.59	10.2	0.56	0.27	0.10
Main cereal crop	Sorghum	Sorghum	Sorghum	Millet	Millet	Sorghum	Sorghum and Wheat	Wheat	Sorghum
Main cash crop	Sesame	Sesame	-	Sesame	Groundnut	Sesame	Lucerne	Faba bean	Sorghum and fodder crops
Main cereal crop productivity (Kg/ha)	0.57	0.53	0.51	0.34	0.20	0.64	2.28	2.79	1.19
Main cash crop productivity (Kg/ha)	0.21	0.23	-	0.22	0.83	0.24	-	-	-
Livestock population (million heads)	4.692	5.356	1.594	8.479	10.688	8.987	2.512	2.489	1.370
Access to safe drinking water (% of population)	28	56	34	67	59	84	86	93	86
Forest cover (% of total state area)	10.0	8.2	2.1	3.4	27.8	50.9	0.2	0.1	2.1
Households using firewood (%)	59.1	66.4	51.1	79.7	82.7	82.7	37.4	50.2	6.0

Characteristics /Indicator	Region/state								
	1. Eastern			2. Kordofan			3. Northern		4. Khartoum
	Gedarif	Kassala	R Sea	North	West	South	Nile	Northern	Khartoum
Agroindustry and processing potential	Oil, sweets, and flour	Vegetables and fruits	Fishing	Oil, gum arabic, sweets, and hibiscus	Oil, gum arabic, groundnut, hibiscus, and forestry products	Meat, fruits and sesame, and forestry products	Fishing, vegetables, and fruits	Fishing, vegetables, and fruits	Oil, flour, and animal feed
(Electricity access deficit) Grids cover geographical distribution	About 60% deficit	About 60% deficit	About 60% deficit	About 60% deficit	About 60% deficit	About 60% deficit	About 40% deficit	About 40% deficit	About 40% deficit
Knowledge Systems (NARs): Number of agricultural research stations & colleges of agriculture	2 research stations and 2 colleges	2 research stations and 1 college	1 research station and 1 college	1 research station and 1 college	1 research station and 1 college	1 research station and 1 college	2 research stations and 1 college	3 research stations and 1 college	3 research stations and 3 colleges

2. *Darfur and Central Regions*

Characteristics /Indicator	Region/state								
	5. Darfur					6. Central			
	North	South	Central	West	East	Senar	Gezira	W-Nile	B-Nile
Total population	2,305,000	3,765,800	751,400	1,024,500	1,587,200	1,918,700	5,096,900	2,493,900	1,108,400
Proportion of rural population (%)	82.7	78.4	82.7	82.7	78.4	78.3	80.9	66.4	75.7
Poverty rate (%)	71.5	72.7	86	81	71.5	56.4	47.7	64.7	68.9
Predominant farming systems	Traditional	Traditional	Traditional	Traditional	Traditional	Traditional and mechanized	Irrigated	Traditional and mechanized	Traditional and mechanized
Agro-ecological zone	Arid	Semi-arid to sub humid	Semi-arid to sub humid	Semi-arid	Semi-arid to sub humid	Semi-arid	Semi-arid	Semi-arid	Semi-arid to sub humid
Predominant soil type	Stabilized sand dunes (goz), alluvium along streams	Stabilized sand dunes (goz), alluvium along streams	Loamy clay, stabilized sand dunes (goz), alluvium along streams	Stabilized sand dunes (goz) Loamy, alluvium along streams	Stabilized sand dunes (goz), alluvium along streams	Cracking clays, alluvium along streams	Deep cracking clays	Clays, sand dunes (goz), alluvium along the Nile	Cracking clays, alluvium along streams
Climate change indicators: Rain-mm & variability (CV%) or yearly drop in mm per year	198(35)	384(26) -5.12	600	428	580	414(30) -3.9	323(44) -4.7	336(34) -3.03	629(19) -5.4
Frequent extreme climatic events	Drought Dust Storms	Drought	Drought	Drought	Drought	Floods	Floods	Floods	Floods
Vulnerability to environmental hazards (risk)	High	Very low	Moderate	Moderate	Very low	Low	High	High	High
Average annual total cultivated area (000ha)	769	1844	712	1142	1540	2532	856	1308	1284
Irrigated (000ha)	0	0	0	0	0	69	390	145	0
Rainfed (000ha)	769	1844	712	1142	1540	2463	466	1163	1284
(%) Share in national area	3.65	8.76	3.38	5.43	7.32	12.03	4.07	6.22	6.10
Main cereal crop	Millet	Millet	Millet	Millet	Millet	Sorghum	Wheat	Sorghum	Sorghum
Main cash crop	Groundnut	Groundnut	Groundnut	Groundnut	Groundnut	Sesame	Cotton Groundnut	Sesame	Sesame
Main cereal crop productivity (Kg/ha)	0.91	0.49	1.02	0.53	0.34	0.67	2.32	0.39	0.63
Main cash crop productivity (Kg/ha)	0.45	0.80	0.67	1.00	1.07	0.40	3.33	0.21	0.32
Livestock population (million heads)	8..132	6.340	5.906	7.215	5.184	4.834	7.412	8.871	6.563
Access to safe drinking water (%)*	48	46	50	68	44	87	87	33	72
Forest cover (% of total state area)	1.5	22.3	20.5	20.5	22.3	12.2	2.5	7.1	41.5

Characteristics /Indicator	Region/state								
	5. Darfur					6. Central			
	North	South	Central	West	East	Senar	Gezira	W-Nile	B-Nile
Households using firewood (%)	92.1	89.6	94.8	94.8	89.6	49.2	27.3	35.3	80.1
Agroindustry and processing potential	Hibiscus and forestry products	Oil, meat, and groundnut processing	forestry products processing	forestry products processing	Oil, meat, and groundnut processing	Textile and oil	Oil, flour, and textile	Sugar	Sesame processing and forestry products
(Electricity access deficit) Grids cover geographical distribution	More than 65% deficit	More than 65% deficit	More than 65% deficit	More than 65% deficit	More than 65% deficit	About 40% deficit	About 40% deficit	About 40% s deficit	About 40% deficit
Knowledge Systems (NARs): Number of agricultural research stations & colleges of agriculture	1 research station and 1 college	1 research station and 1 college	1 research station and 1 college	1 research station and 1 college	1 research station and 1 college	3 research stations and 1 college	2 research stations and 1 college	1 Research station and 1 college	1 research station and 1 college

**Around 526,000 ha area of fruits and vegetables across the country.*

2) Regions SWOT

1. Kordofan Region

Strengths	Weaknesses
• Main livelihood and income source for most of the households. • Diverse agro-climatic conditions and different crop and livestock production systems. • Comparative advantage in the production of livestock oil crops and horticultural crops. • Largest market for gum arabic, and other gums (covers the largest part of the gum arabic belt). • Integration between crop and livestock production systems. • Women participate in the production process, which mitigates the effect of males' migration. • Presence of some infrastructure such as roads, communication, markets, and government research and financial institutions.	• Desert expansion in the northern part accelerated land degradation and the natural resource base. • Narrowing in the traditional livestock routes, which increases the potential of sporadic conflicts. • Dominance of traditional production practices resulting in low yields compared to potential yields. • Limited use of improved technologies and external inputs. • Low processing activities/cleaning, packaging, and storage (poor value chain development). • Weak linkages among stakeholders: extension, farmers, research, private sector, financial institutions…etc.
Opportunities	**Threats**
• Financial institutions are established across the three states. • High potential for oil crops, livestock, and the horticulture crops industry (raw material). • Presence of several agricultural research stations and agricultural colleges distributed across the region.	• Risky environmental conditions (climate change). • Insecurity and social conflicts. • Declining interest among youth in agriculture and the tendency of labor force migration after the emergence of local gold mining.

2. Eastern Region

Strengths	Weaknesses
• Agriculture is the main livelihood and income source for most of the households. • Vast agricultural lands and diverse production systems (mechanized traditional rainfed, irrigated, horticulture, and fishing). • Largest market for sorghum and sesame crops. • Vast areas of the region area are located in the rich savanna belt, with annual rainfall of 700-900 mm and fertile clay cracked soil, gum arabic, and other gums (Fashga) (part of the gum arabic belt). • Wealth of animal resources and movement and the presence of rangelands (Butana) and agricultural residues in the summer for grazing (New Upper Atbara Project). • Presence of Halfa, Rahad, Gash and Tokar schemes, irrigated from permanent rivers or seasonal streams (spate). New Upper Atbara Project planned. • Industry is represented in the oils, soap, and sweets industries in the city of Gedaref. • Presence of infrastructure, such as road communication, storage facilities, input services, markets, and government, research, and financial institutions. • Presence of workshops for the installation and rehabilitation of agricultural machinery and spare parts.	• Poor accessibility in the far east to some production areas, especially near the borders. • Expansion of rainfed agriculture at the expense of livestock routes, range land, and forest, which resulted in increased deforestation and accelerated land degradation that reduced the area of the natural pastures (Butana). • Poor pasture conditions and no reliable stock routes reserved, and sites demarcated for grazing. • Large numbers of animals and various herd groups compete for the (Butana) grazing areas. • Low processing activities/cleaning, packaging, and storage (poor value chain development). • Weak integration and linkages among the segments of the agricultural systems i.e., cropping, livestock, and forestry.
Opportunities	**Threats**
• Close proximity to the port and neighboring several countries (market). • High potential for the oil crops, livestock, and horticulture crops industries (raw material). • Presence of several agricultural research stations and agricultural colleges distributed across the Darfur sector area. • Increased awareness of the fact that agriculture is the main source of rapid and balanced economic growth. • Field for investment in horticulture. • Presence of grain storage facilities (silos and other stores). • Well-established specialized financial institutions.	• Risky environmental conditions (climate change). • Conflicts in some areas and cross-border insecurity. • Declining interest in agriculture and the tendency of the labor force to move to gold mining. • Government's ignorance of some parts of the region's development. • Security instability by Ethiopian militias for the purpose of agriculture and settlement and delay in the border demarcation.

3. *Central Region (Senar, White Nile, Gezira, and Blue Nile)*

Strengths	Weaknesses
• Agriculture is the main livelihood and income source for most of the households. • Vast agricultural lands and diverse production systems (mechanized and traditional rainfed and irrigated, horticulture, and fishing) and production of food and cash crops in vast areas and relative stability in production. • Well-established large irrigation production schemes, including the Gezira, Suki, and sugar schemes. • Available different water sources and water infrastructure (dams) and a hierarchical controlled irrigation system of canalization that governs water distribution from the water source to farms. • High livestock population. • Presence of historical good processing activities (sugar, oil, food, textile, and milling). • Tangible resource base: soils, water, forest and rangeland and gum arabic, and other gums (part of the gum arabic belt). • Presence of infrastructure, such as road communication, input services, markets, and government, research, and financial institutions.	• Deterioration of the infrastructure of irrigated schemes and rigid irrigation system. • Breakdown of the established crop rotation based on the efficient use of available resources and standards (after 2005 law). • Lack of full mechanization and dependency on manual labor in some operations and crops • Poor accessibility to some production areas, especially neighboring borders. • Rapid expansion of cropping at the expense of livestock routes and forest. • Low productivity. • Low processing activities/cleaning, packaging, storage (poor value chain development) and backward processing technologies. • Weak integration and linkages among the segments of the agricultural systems i.e., cropping, livestock, and forestry.
Opportunities	**Threats**
• High production diversity in crop, fishing, horticulture, and livestock production • Established financial institutions. • High government and international community attention to rehabilitate the irrigated schemes. • Strategic location, rich resources, and access to all states. • Closeness to the capital and port through railway lines and roads. • Presence of the agricultural research headquarters, several research stations, and agricultural colleges distributed across the region. • Increased awareness of the fact that irrigated agriculture is the main source of rapid and balanced economic growth.	• Conflicts in some areas and cross-border insecurity. • At-risk water flow after renaissance dam filling. • Continuing deterioration of the scheme's basic infrastructure. • Declining interest in agriculture and the tendency of the labor force to move after the emergence of local gold mining.

4. *Northern Region*

Strengths	Weaknesses
• Presence of several tangible surface and groundwater resources. • Highly controlled modern irrigation systems, from rivers or groundwater. • Vast land areas for agricultural investment. • High contribution to wheat winter legumes and horticulture production. • Two agricultural seasons (summer and winter). • Presence of some infrastructure, such as communication technology, roads, markets, and government institutions. • Registered land tenure system along the Nile and lack of (or very limited) conflicts.	• Expansion of the desert resulted in accelerated land degradation. • Narrow land fragmented along the Nile threatened by sand dune movement. • Bureaucracy and unclear investment policies and conditions. • Low population density, especially far from the Nile. • Low processing activities/cleaning, packaging, and storage (poor value chain development).
Opportunities	**Threats**
• Financial institutions are established across the region. • Increased awareness about agriculture investment and presence of large foreign investment. • Presence of several agricultural research stations and agricultural colleges distributed across Darfur sector area. • Increased awareness of the fact that agriculture is the main source of rapid and balanced economic growth.	• Risky environmental conditions (climate change, desertification, floods). • Obstructed regular normal Nile flow. • Declining interest in agriculture and the tendency of the labor force to move to gold mining.

5. *Khartoum*

Strengths	Weaknesses
• Mostly irrigated agriculture with modern irrigation systems controlled by rivers or groundwater. • Production of forage crops to meet the expanded dairy industry. • Potential to produce different crops in two seasons (summer and winter). • Presence of historical processing facilities (food, textile, and edible oil and dairy and poultry industry). • Presence of infrastructure, such as road communication, input services, markets, and government, research, and financial institutions.	• Deterioration of the infrastructure. • Low-efficiency processing technologies. • Limited areas and expansion of urbanization.
Opportunities	**Threats**
• Government headquarters and Investment Administration. • Closeness to the services and government authorities. • Large consuming market for vegetables, fruits, dairy, and poultry. • Available wage labor. • Increased awareness of the fact that agriculture is the main source of rapid and balanced economic growth.	• Climate change. • Labor migration after the emergence of local gold mining. • Land right and tenure system. • Expansion of residential areas at the expense of agricultural land.

6. *Darfur Region (North, South, East, West, and Central)*

Strengths	Weaknesses
• Agriculture is the main source of income and livelihood for most of the households. • Comparative advantage in the production of livestock and oil crops and gum arabic. • Integration between crop and livestock production systems. • Part of gum arabic belt. • Presence of some infrastructure in some areas. • Women participate in the production process, which mitigates the effect of males' migration.	• Desert expansion in the northern part accelerated land degradation and the natural resource base. • Loss of the traditional livestock routes increased and expanded the conflicts. • Dominance of traditional production practices results in low yields. • Poor key physical infrastructure affected access to services and inputs- outputs markets. • Absence of effective CBOs. • Low processing activities/cleaning, packaging, and storage (poor value chain development). • Weak linkages among stakeholders: extension, farmers, research, private sector, financial institutions…etc. • The northern parts of both states are highly vulnerable to food insecurity.
Opportunities	**Threats**
• Resources allocated and recent government attention to rehabilitate the area. • Presence of several NGOs working in livelihood issues and rural development. • Presence of five ARC stations working across the region. • Huge potential for the development of mechanized rainfed farming. • Potential for producing wheat and sugar in Jebel Mara. • Developing Nyala as a meat and leather industry corridor	• Risky environmental conditions (climate change). • Widespread insecurity, conflict, instability, and displacements. • Declining interest in agriculture and the tendency of the labor force to move to gold mining.

Source: Authors' analyses

Table 11: Sensors, actuators, and platforms used in agricultural applications based on IoT

Sensors/Actuators	IoT End Device Wireless Protocol	IoT Platform/Device	IoT Application Layer
Soil temperature, soil moisture, air temperature, air humidity and light intensity/alert messages	LoRa	Lora WAN	User interface, remote monitoring, and email
Soil moisture, temperature, pressure, and water electrical conductivity and temperature	ZigBee	GSM/GPRS	Web application (HTML5, PHP, and JavaScript)
Air temperature, soil moisture, air humidity, and light intensity camera to monitor the rice leaf disease	WiFi (ESP8266) Sensor networks	WiFi	Web services Web application and user-defined
Temperature, humidity, soil moisture, and wind direction and speed Temperature and soil moisture/electrovalve	nRF wireless protocol	Wisekar and cloud computing	User interface and custom server web applications
Temperature and soil moisture/ irrigation system	eZ430-RF2500 (IEEE802.15.4/ ZigBee-based CC2500)	Intel Edison and cloud computing	Server application, user interface, and do-it-yourself visualization
Temperature, humidity, light, pressure, camera, CO2, and wind direction and speed/air flow, sprinkler, and sunlight screen	Libelium WaspMotes, Remote, Netatmo, etc.	WiFi 802.11 or GPRS through http and cloud computing	User applications and server applications
Ambient temperature, soil moisture, pH value, and humidity/valves and pumps	ZigBee	SmartFarmNet and cloud computing	User applications
Air temperature, wind speed/direction, air humidity, air pressure, net radiation, sunshine duration, and precipitation/ irrigation system	ZigBee (XBee)	Ethernet shield and GPRS	User applications (desktop client, web client, and mobile client) and web processing service
Pesticide concentration sensor	IEEE 802.11 or Bluetooth	Ethernet/WiFi/GSM	HTML files, Webpage, and Smartphone
Air temperature, relative humidity, solar radiation, precipitation, water, and nutrients/irrigation system	Hypogynous computer	GPRS	Web services, data analysis, and database
Temperature, luminosity, PH, moisture, EC/lamps, electro-valves, and pumps	IEEE 802.15.4/ZigBee	Epigynous computer	Web services, data analysis, database, and HMI interfaces
Temperature, light intensity CO2 concentration, and humidity	IEEE 802.15.4/ZigBee	FIWARE platform and cloud computing	User application Graphical user interface
Soil moisture/water pumps, fan, and mist	ZigBee (CC2530) ZigBee (XBee)	Cloud computing	Data visualization, data storage, data analysis, and application program interface
Air temperature, wind speed and direction, leaf wetness, soil moisture, air humidity, rain volume/fertilizers or spraying chemicals and watering system	nRF24L01		User interface, remote monitoring, and email

Table 12: Drone type pros, cons, and uses

Type	Pros	Cons	Typical Uses
Multi-Rotor	• Accessibility • Ease of use • VTOL and hover flight • Good camera control • Can operate in a confined area	• Short flight times • Small payload capacity	Aerial photography and video aerial inspection
Fixed-Wing	• Long endurance • Large area coverage • Fast flight speed	• Launch and recovery needs a lot of space • No VTOL/hover • Harder to fly, more training needed • Expensive	Aerial mapping, pipeline and power line inspection
Single-Rotor	• VTOL and hover flight • Long endurance (with gas power) • Heavier payload capability	• More dangerous • Harder to fly, more training needed • Expensive	Aerial LIDAR laser scanning
Fixed-Wing Hybrid	• VTOL and long-endurance flight	• Not perfect at either hovering or forward flight • Still in development	Drone delivery

Table 13: Comparison of hyperspectral imaging platforms

	Satellites	Airplanes	Helicopters	Fixed- wing UAVs	Multi- rotor UAVs	Close-range platforms
Operational Altitudes	400–700 km	1–20 km	100 m – 2 km	< 150 m	< 150 m	< 10 m
Spatial Coverage	400–700 km - Very large- e.g., one Hyperion scene covers 42km×7.7k m	1–20 km- Medium - large - ~100 km2	100 m – 2 km – Medium - A 10-min flight/operation covers ~10 km2	< 150 m - Small - medium - A 10-min flight/operation covers ~5 km2	< 150 m – Small - A 10-min flight/ operation covers ~0.5 km2	< 10 m - Very small - A 10-min flight/ operation covers ~0.005 km2
Spatial Resolution	20-60 m	1-20 m	0.1-1 m	0.01-0.05 m	0.01-0.05 m	0.0001-0.01 m
Temporal Resolution	Days to weeks	Depends on flight operations (hours to days)	Depends on flight operations (hours to days)	Depends on flight operations (hours to days)	Depends on flight operations (hours to days)	Depends on flight operations (hours to days)
Flexibility	Low (e.g., fixed repeating cycles)	Medium (e.g., limited by the availability of aviation company)	Medium (e.g., limited by the availability of aviation company)	High	High	High
Operational Complexity	Low (final data provided to users)	Medium (depends on who operates the sensor: users or data vendors)	Medium (depends on who operates the sensor: users or data vendors)	High (users typically operate sensors and need to set up hardware and software properly)	High (users typically operate sensors and need to set up hardware and software properly)	High (users typically operate sensors and need to set up hardware and software properly)
Applicable Scales	Regional - global	Landscape - regional	Landscape - regional	Canopy - landscape	Canopy - landscape	Leaf - canopy
Major Limiting Factors	Weather (e.g., rain and clouds)	Launch and recovery needs a lot of space No VTOL/hover Harder to fly, more training needed Expensive				Aerial mapping, pipeline and power line inspection
	Unfavorable flight height/speed, unstable illumination conditions	Unfavorable flight height/speed, unstable illumination conditions	Short battery endurance (e.g., 10-30 mins), flight regulations	Short battery endurance (e.g., 10-30 mins), flight regulations	Platform design and operation	Aerial LIDAR laser scanning
Image Acquisition Cost	Low to medium	High (typically requires hiring an aviation company to fly)	High (typically requires hiring an aviation company to fly)	High (if it needs to cover a large area)	High (if it needs to cover a large area)	High (if it needs to cover a large area)
Number of publications	59	133	3	4	38	79

Table 14: Examples of 5G potential applications in industry verticals

Industry	Potential 5G Applications
Manufacturing	Smart factories, AR and remote expert, precision monitoring and control, collaborative robotics, and advanced predictive maintenance.
Automotive/transportation	Autonomous driving, car infotainment, airborne taxis, and fleet management and tracking.
Entertainment	Collaborative gaming, consumer AR/VR, 3D calls/holograms, and smart wearables.
Healthcare	Remote patient monitoring, virtual consultations, remote diagnosis, robotic nursing, robotic surgery, and fall detection.
Energy and utilities	Smart metering, smart grid automation, off-shore drilling operations, and drone surveillance.
Retail	AR/VR shopping, in-store experience, store operations, and warehouse automation.
Public sector	Smart streetlights, sensor networks, drones for public safety, and smart parking management.
Smart home industry	Access control, video surveillance, intrusion detection, appliance control, and assistive robots.
Agriculture	Smart farming equipment, AI-enabled farming drones, crop yield monitoring, and soil/nutrient monitoring.

ERF at a Glance: *The Economic Research Forum (ERF) is a regional network dedicated to promoting high-quality economic research for sustainable development in the Arab countries, Iran and Turkey. Established in 1993, ERF's core objectives are to build a strong research capacity in the region; to encourage the production of independent, high-quality research; and to disseminate research output to a wide and diverse audience. To achieve these objectives, ERF's portfolio of activities includes managing carefully selected regional research initiatives; providing training and mentoring to junior researchers; and disseminating the research findings through seminars, conferences and a variety of publications. The network is headquartered in Egypt but its affiliates come primarily from different countries in the region.*

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