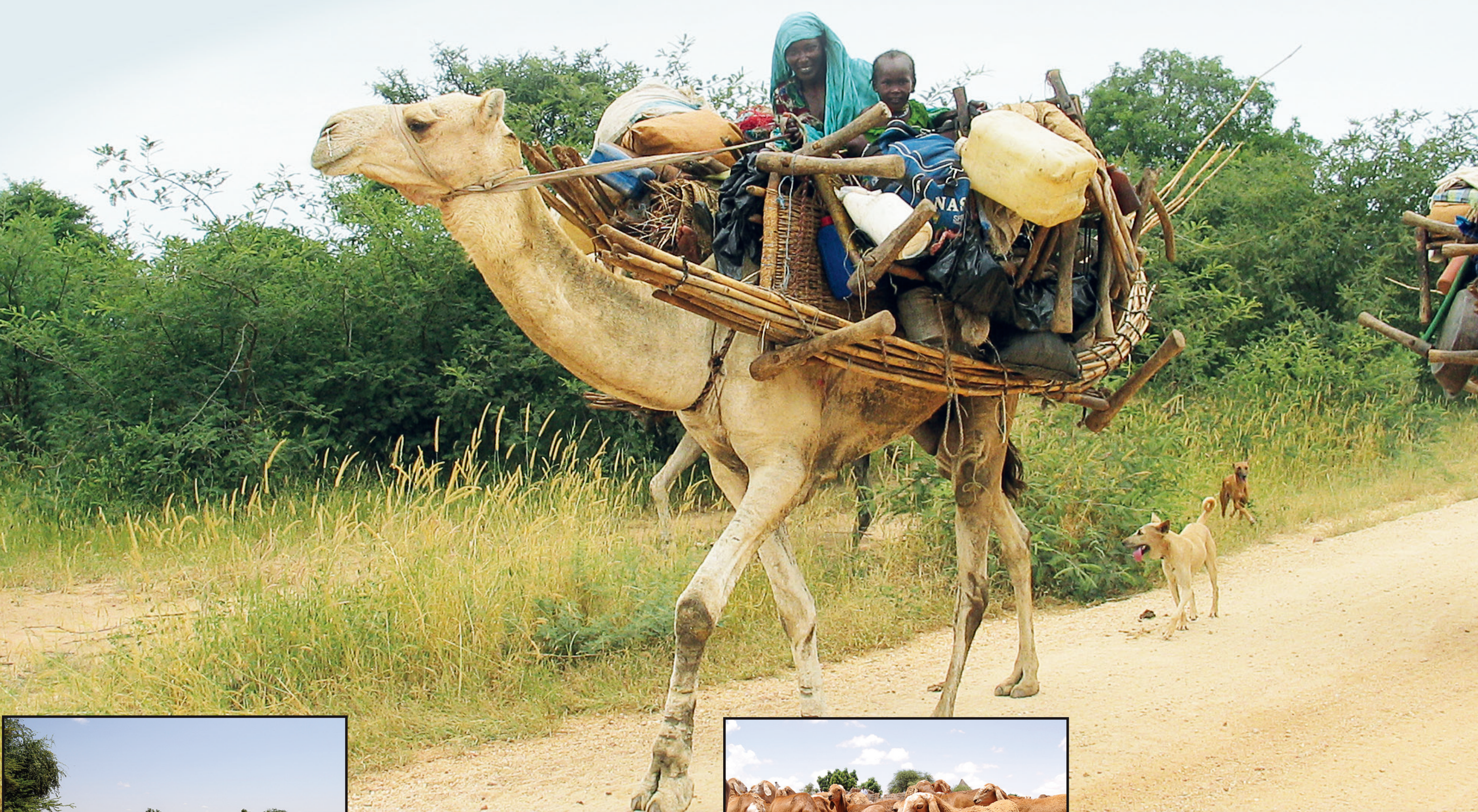
REPUBLIC OF THE SUDAN
Ministry of Environment, Forestry & Physical Development
Higher Council for Environment and Natural Resources

Sudan's Second National Communication under the United Nations Framework Convention on Climate Change



Khartoum - January 2013

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Foreword

Responding to the challenge of climate change is national priority for Sudan. While our contribution to global emissions of greenhouse gases is virtually zero, less than 0.04% of global emissions, our rural communities, natural resources, agricultural productivity and coastal infrastructure are particularly vulnerable to climate change. The increasing frequency of severe droughts and declining rainfall are already a present reality for us, one that requires urgent action in cooperation with the international community.

Sudan will continue to take aggressive steps to adapt to climate change. This is essential so that our children and their children can also enjoy Sudan's unique natural heritage and precious ecosystems. Our Second National Communication outlines concrete steps to build resiliency into our development plans for water resources and coastal zones. We believe that adaptation to climate change must be both the motivation for such climate resilient plans as well as the output of future development strategies, policies, and initiatives.

We understand that financial support and technology cooperation with Annex I countries are essential to support our actions to adapt to climate change, as well as to update the national inventory of greenhouse gases, and to ensure that future growth in greenhouse gas emissions remains as low as possible. Increased access to international support will help to strengthen our technical capacity to identify and implement needed policy reforms.

Hassan Abdel Gadir Hilal
Minister of Environment and Physical Development
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Preface

It is my great pleasure to present Sudan's Second National Communication under the United Nation Framework Convention on Climate Change.

As signatory to the UNFCCC and its Kyoto Protocol, Sudan has implemented various policies and measures to fulfill Sudan's commitments as a non-Annex I Party to the convention. Sudan also actively participates in international cooperation and regional climate change initiatives.

The First National Communication, the National Adaptation Programme and now this Second National Communication have not only fulfilled our country's obligation but have helped to raise public awareness, establish climate change institutions and build capacity. This enables us to work in close coordination and cooperation with the international community to tackle climate change issues and challenges.

The Second National Communication presents background information about the country, its ecology, natural systems, economy, resources and the performance of various sectors. Emissions of greenhouse gases are presented for each sector for the year 2000. This document also describes vulnerability of two major sectors, water resources and costal zones. It identifies specific adaptation measures to build future resilience against looming impacts. The Second National Communication also demonstrate potential mitigation options in both energy and non-energy sectors. Matters related to article 6 of the Convention such as education training, awareness raising, as well as research, systematic observations and gap are discussed in the final chapter.

On behalf of the government of Sudan I would like to express my sincere appreciation and gratitude to the Global Environment Facility, the United Nations Development Program in Sudan, and the Secretariat of the United Nation Framework Convention on Climate Change for the financial and technical support as well as to the Stockholm Environment Institute – US Center, the Climate Change Research Group, and specialized institutes, national expertise and civil society organizations for their contribution to the prepare of this report.

Prof. Saadeldin Ibrahim Mohamed

Secretary General,

Higher Council for Environment and Natural Resources

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Acknowledgments

A large number of individuals and institutions, both official and private, have assisted in producing the Second National Communication in many ways. They are too numerous to mention all of them by name. We gratefully acknowledge this invaluable help and extend our sincere thanks to all of them. Nevertheless there are many individuals who deserve particular recognition due to their valuable contribution to this report.

His Excellency Hassan Abdel Gadir Hilal, Minister of Environment and Physical Development has been very supportive and provided valuable leadership.

Special thanks go to the Steering Committee of the project, which has provided continuous support and guidance to our work.

Deserving special recognition and gratitude are the members of the project technical task forces for their outstanding and exemplary work. Without their untiring commitment during the entire length of the project and their willingness to make every effort required, it would not have been possible for us to work so intensively and to present this report.

Deserving special thanks are our stakeholders of the project. In particular, these include the Ministries of Petroleum, Agriculture, Health, Finance, Foreign Affairs, and Technical Cooperation. Thanks are also extended to the Forest National Cooperation, the Meteorological Authority, the University of Khartoum (the Institute of Environment studies, Faculty of Engineering and faculty of Forestry), the University of el-Neilain, the Sudanese Environment Conservation Society, and the Industrial Chamber.

We are also indebted to all the national experts and resource persons who gave high quality technical assistance throughout the course of the project.

Generous and professional support by the MFNE, GEF, UNDP and UNFCCC is gratefully acknowledged. We are especially grateful to Omer Haggam from MFNE and Ms. Hanan Mutwakil, Shama Mekki and Gaafer Elsheik from UNDP Khartoum office for their continuous support.

Deserving special thanks our technical support partners in SEI-US and the Climate Change Research Group; in particular we would like to express our personal and very special gratitude to Dr. Bill Dougherty and Dr. David Yates. Without their continuous technical support the project would not have been possible.

Last but not least, we extend our special gratitude to Professor Saadeldin Ibrahim Mohamed, Secretary General of the HCENR and our colleagues and the staff of HCENR and sister projects for their follow up and support to our work.

Deserving special recognition are Nagm Eldin Goutbi ELhassan Deputy Project Manager and Ms. Rehab Ahmed Hassan Assistant Project Manager who shouldered with me all the project activities and provided valuable research assistance and contributed greatly to the outcome of this project. Finally deserving special thanks are Mr. El Ghali Atwa accountant, and Ms. Manal Ahmed executive secretary.

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°C	Degrees Celsius
ACMA	African Center for Meteorological Application
AIACC	Assessments of Impacts and Adaptations to Climate Change
AOAD	Arab Organization for Agriculture Development
AWRM	Adaptive Water Resources Management
BCAS	Bangladesh Centre for Advanced Studies
bcm	Billion Cubic Meters
CAN	Climate Action Network
CBAA	Community Based Adaptation in Africa
CBS	Central Bureau of Statistics of Sudan
CH_4	Methane
CLACC	Capacity strengthening for Least developed countries for Adaptation to Climate Change
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COP	Conference of the Parties
CPA	Comprehensive Peace Agreement
EIA	Energy Information Administration (USA)
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agricultural Organization Statistical database
FNC	Forest National Corporation
FOB	Fixed at border
GCM	Global circulation model
GDES	General Directorate of Environment and Safety
GDP	Gross Domestic Product
GDPAE	General Directorate for Planning and Agricultural Economics
GEF	Global Environment Facility
Gg	Giga gram (billion grams)
GHG	Greenhouse gas
GIS	Geographic Information Systems
GWP	Global warming potentials
HCENR	Higher Council for Environment and Natural Resources
HFC	Hydro fluorocarbons
IAEA	International Atomic Energy Agency
ICPAC	International Climate Prediction and Application Center
ICZM	Integrated Coastal Zone Management
IDRC	International Development Research Centre
IGAD	Intergovernmental Authority on Development
IIED	International Institute on Environment and Development
IMF	International Monetary Fund

I &M	Inventory and Mitigation
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for the Conservation of Nature
IWRM	Integrated Water Resources Management
JJAS	June, July August, and September
km	Kilometers
kWh	Kilowatt-hour (thousand watt-hours)
LDC	Least Developed Countries
LDCF	Least Developing Countries Fund
LOCATE	Local Options for Communities to Adapt and Technologies to Enhance Capacity
LPG	Liquefied petroleum gas
LUCF	Land use change and forestry
MAMJ	March, April, May, and June
mcm	Million cubic meters
MD	Millennium Development Goals
MEA	Multilateral environmental agreement
MEM	Ministry of Energy and Mining of Sudan
MFNE	Ministry of Finance and National Economy
MHESR	Ministry of Higher Education and Scientific Research
MIWR	Ministry of Irrigation and Water Resources
mm	Millimeters
MSW	Municipal solidwaste
MTN	Bashayer Company for Mobile-phone Services
MW	Megawatts (million watts)
N_2O	Nitrous Oxide
NAPA	National Adaptation Plan of Action
NCSA	National Capacity Self-Assessment
NEAD	National Energy Affairs Directorate
NEC	National Electricity Corporation of Sudan
NGO	Non-Governmental Organization
NMVOC	Non-Methane Volatile Organic Compounds
NOU	National Ozone Unit
NOx	Nitrogen Oxides
PA	Practical Action
PERSGA	Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden
PFC	Perfluorocarbons
PM	Project Manager
PSMSL	Permanent Service for Mean Sea Level
SCCN	Sudanese Climate Change Network
SECS	Sudanese Environment Conservation Society

SEI	Stockholm Environment Institute
SF_6	Dulfurhexafluoride
SLR	Sea Level Rise
SMC	Sudan Meteorological Corporation
SO_2	Sulfur Dioxide
SST	Sea-surface Temperatures
START	Global Systems for Analysis, Research, and Training
Sudatel	Sudan Company for Telecommunications
SUST	Sudan University of Science and Technology
SWDS	Solid Waste Disposal Sites
TOE	Tonnes of Oil Equivalent
TWAS	The Academy of Sciences for the Developing Worlds
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
UNFF	United Nations Forestry Forum
UoK	University of Khartoum
V & A	Vulnerability and Adaptation
WEAP	Water Evaluation And Planning Model
WMO	World Meteorological Organization
ZAIN	Sudanese Company for Mobile-phone Services

1 National Circumstances

Sudan's ability to adapt to climate change as well as its greenhouse gas (GHG) emissions are influenced by a number of national circumstances. These include its geography, climate, people, and economy, among others. By far, the greatest development on its national circumstances with implications on its strategic response to the challenge of climate change is 9 July 2011, the date on which South Sudan was declared a sovereign state.

Nevertheless, as this historic event occurred near the completion of this Second National Communication, a mostly pre-separation review of national circumstances is offered in the sections below. When the term "Sudan" is used throughout this and other chapters, it refers to the territory not including the Southern Sudan. This Sudan continues to be governed within a federal system that, according to the 1998 constitution, is responsible for issues of national interest including planning, defense and foreign policy. The state carries out functions and provides services at a regionalized level. States, in turn, are divided into provinces, and each province, according to its size, is divided into local councils. The councils are represented by people's committees, in a structure that tries to link grassroots governance to the federal level. Overall, the system divides most responsibilities between the federal government and the states, though some joint responsibilities exist.

1.1 Geography

Figure 1-1 provides a map of Sudan and South Sudan. The overall territory of the two states encompasses an area of about 2.5 million km^2 and stretches over land between latitudes 3°N and 23° N and longitudes 21°45 E and 38°30 E. The territory borders nine African nations and the Red Sea. Sudan is divided administratively into 17 states, while South Sudan is comprised of 10 states. The River Nile cuts through roughly half of the states as either the White or Blue Nile.

Figure 1-1: Map of Sudan and South Sudan

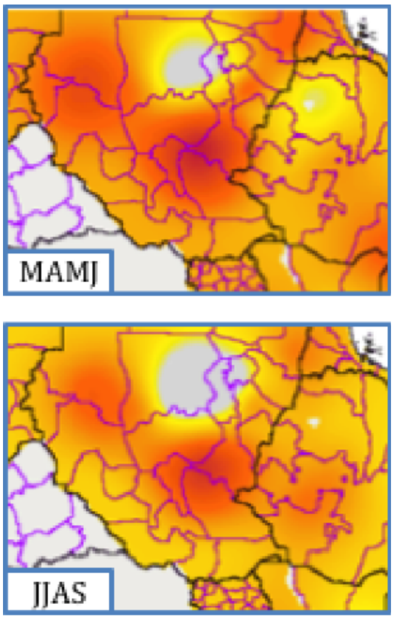
Arid and semi-arid ecosystems constitute most of Sudan. Desert and semi-desert areas dominate the northern part of the country above El Obeid. In the east and west and along the border with South Sudan low rainfall savannah and Montana vegetation is prevalent. High rainfall savannah woodlands dominate the geography of South Sudan. Much of this area was once considered rainforest.

1.2 Climate

The climate of the overall territory is characterized by its diversity. In the north near the Egyptian border, desert conditions prevail and rain is rare. Throughout South Sudan, annual rainfall averages around 700 mm, with most of it coming over a four-month period. In central areas between El Obeid and Atbara, there are four seasons, each defined relative to rainfall. The rainy season extends from June through September (denoted as JJAS); the retreating rainy season from October through November; the dry season from December through February; and an advancing rainy season from March through June (denoted as MAMJ).

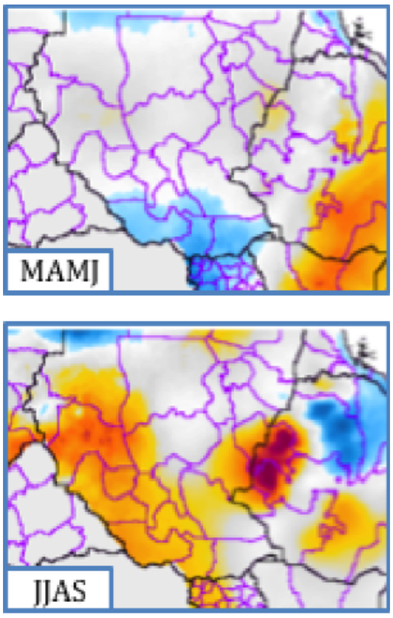
Air temperatures have been steadily increasing in Sudan over the period 1960-2009. This unmistakable pattern is illustrated in Figure 1-2, which shows a map of the semi-arid areas of Sudan (i.e., below the Northern, River Nile, and Red Sea state) and all of South Sudan superimposed with the change in average monthly temperature per decade. During both the MAMJ and JJAS periods, temperatures have been increasing between 0.2°C and 0.4°C per decade, depending on the locations within the countries. The figure also shows that decadal trend of increasing temperature is more intense during the MAMJ period. When averaged across all seasons, temperatures in the 2000-2009 periods are roughly between 0.8°C and 1.6°C warmer than they were in the 1960-1969 period.

Figure 1-2: Temperature trends for Sudan and South Sudan, 1960-2009 (source: Funk, et al., 2011)



Rainfall patterns are less clear. Figure 1-3 shows the decadal change in average annual rainfall patterns. During the MAMJ period (i.e., the advancing rainy season), rainfall has been increasing between 20 mm and 30 mm per decade in the northernmost and southernmost areas of the territory, with no change in rainfall patterns evident in other areas. However, during the JJAS period (i.e., the rainy season), annual rainfall levels have been decreasing between 10 mm and 30 mm per decade. This is evident primarily in the western part of the territory, stretching from the lower portion of North Darfur state in Sudan to Central Equatorial state in South Sudan.

Figure 1-3: Rainfall trends for Sudan and South Sudan, 1960-2009 (source: Funk, et al., 2011)



The frequency of extreme climatic shocks is also increasing, particularly drought. Once a feared event that occurred rarely (i.e., historically severe droughts occurred in the 1910s, 1940s, and 1970s, and 1980s), drought is now one of the most important and frequently recurring challenges that Sudan faces. Since the end of the last drought in 1984, droughts have recurred in 1987, 1989, 1990, 1991, 1993, and 1996, mainly in western Sudan in Kordofan and Darfur states, as well as in areas in central Sudan. Future drought threatens about 19 million hectares of rain-fed mechanized and traditional farms, as well as the livelihoods of many pastoral and nomadic groups.

Extreme flooding events also exact a heavy toll in Sudan. The most severe floods are associated with periods of exceptionally heavy rainfall that causes the overflow of the River Nile and its tributaries. While highly unpredictable, the frequency of floods has been noticeably increasing. In the 100-year period 1878-1977, there have been two severe floods in the 25-year period since there have been three severe floods. This corresponds to a 6-fold increase in flooding frequency. The most vulnerable groups are the thousands of communities who live in low lands and along the riverbanks of the River Nile and its tributaries.

1.3 Population

Figure 1-4 highlights major population trends over the past decades. A diverse population of many tribal subdivisions and language groups, Sudan's population has been growing rapidly over the past few decades. Since 1956, the year of the first census, to the latest census in 2008, total population has increased fourfold to 39.2 million people, an average annual growth rate of about 2.6% per year. Between 1993 and 2008, the growth rate is even higher, 2.88%, and remains one of the highest in the world.

Figure 1-4 also highlights the strong urbanization trends evident since 1956, though the rate of urbanization has plateau somewhat over the past 15 years. Urban dwellers comprised 30% of the population in the latest census, which is similar to the level of 29% in the 1993 census, and over three times the 8% urbanization level of 1956.

Figure 1-5 shows that rural populations have also grown substantially over the period 1993-2008, from 18.1 to 27.6 million people. The average annual growth rate of 2.86% is only marginally less than the overall population growth rate during this period. In rural areas, famers, pastoralists, fishing, cottage industries, and other sedentary dwellers comprise the overwhelming share of the non-urban population. The nomad population, while only a tenth of total rural population, nevertheless continues to show significant growth of about 2.5% per year.

The age distribution in the population has remained fairly stable over the 1993-2008 periods (see Figure 1-6). People younger than 15 years of age represented 45% of the population in 1993 and have increased slightly to 47% in 2008. The ratio of boys to girls is 1.05 in this age bracket (i.e., 9.4 million boys and 8.9 million girls). For ages 15 and older, the ratio of males to females is somewhat less, 1.03, likely due to out-migration to other countries in search of work opportunities and casualties of the civil war.

With about 16 persons per km^2 in 2008, Sudan exhibits a fairly low population density. However, most of the population is concentrated along the River Nile and its tributaries, as well as in the rich savannah lands from east to west, which makes the average value somewhat misleading. For example, central states such as Khartoum and Gezira States have much higher population densities (238 and 153 people per km^2, respectively) due to the availability of basic services (e.g., health facilities, schools, employment opportunities). The three northern states (i.e., Red Sea State, Nile River state, and Northern state), large in area and with much of their populations concentrated on the banks of River Nile, have much lower population densities than the national average, roughly 4.8 persons per km^2.

Figure 1-4: Population trends for Sudan and South Sudan, 1956-2008 (source: Central Bureau of Statistics CBS, 2010))

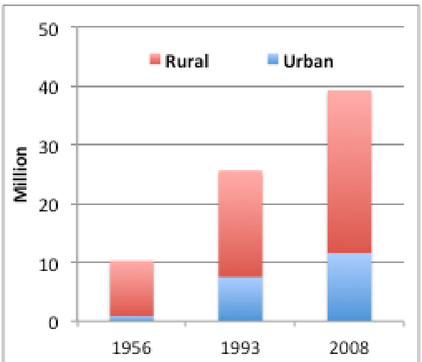


Figure 1-5: Rural population trends for Sudan and South Sudan, 1993-2008 (source: Central Bureau of Statistics,CBS,2010))

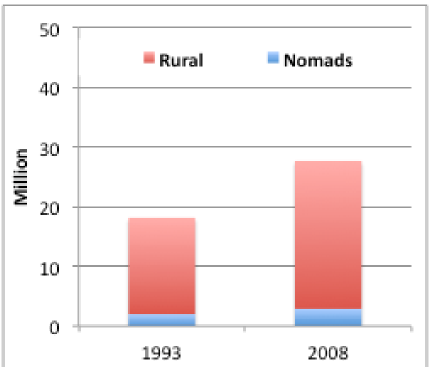
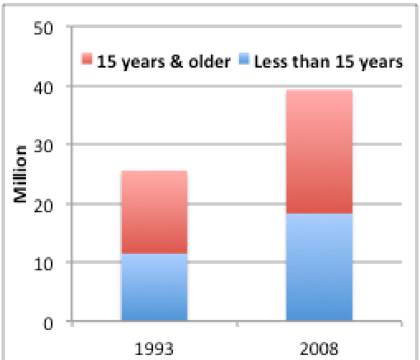


Figure 1-6: Population age trends for Sudan and South Sudan, 1993-2008 (source: Central Bureau of Statistics,CBS,2010)



Much of the population in Sudan lives in poverty. Overall, almost 51% live below the poverty line. In the northern part of the territory this is somewhat lower at 47%. Lack of adequate quantities of food was higher among female-headed households (37%) compared to households where two parents were present (31%).

The portion of the population involved in the labor force can only be roughly estimated. This is due to the fact that the most recent labor force survey took place in 1996. At that time, 7.4 million people comprised the labor force, with unemployment estimated at about 15%. About 70% of the population depends on agriculture for income earning activities. These shares are likely to be substantially different in the current day although survey data is lacking to better characterize the present labor force.

1.4 Water Resources

The River Nile is Sudan's most valuable water resource ands hared with ten riparian

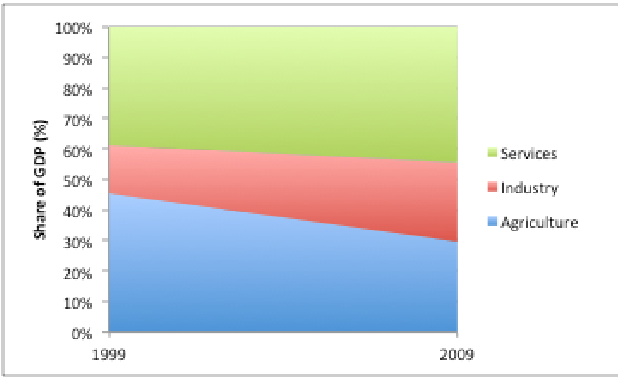
Figure 1-7: River Nile major characteristics (source: Prof. S. Hamad, Ministry of Irrigation and Water Resources, MIWR, 2010)

Tributary Name	Average Supply (bcm/year)	Average flow Characteristics
Blue Nile	50.7	Peak flow (mcm/day): 535 in August; 11 in April
Rahad	1.09	Flow from July to November
Dinder	3.0	Flow from June to November
White Nile	27.8 (at Malakal)	Peak flow (mcm/day): 114 in November; 54 in April
Bahr El Gazal	14	Only 0.5 bcm reaches Malakal (swamps)
Bahr El Jebel	26 at Mongalla	Only 14.0 bcm reaches Malakal (swamps)
Sobat	13.3 reaches Malakal	Losses in Baro and Machar reach 8 bcm. Flow (mcm/day): 8 in April; 66 in November
Atbara	12 (7 from Setit; 5 from Atbara)	Low regulated flows from February to June
Main Nile	84 (at Aswan)	Average daily peak flow of 690 mcm/day (August-Sept.) and a low flow of 74 mcm/day (April-May)

countries including Burundi, Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda. The River Nile is the main source of water supply for Sudan. About 63% of the Nile watershed falls within Sudan. Conversely, more than 67% of the area of Sudan lies within the Nile Basin. Major features of the Nile, including its geographic context, main gauging stations, and hydrological characteristics are summarized in Figure 1-7. Other water supply resources, including Wadis, groundwater, and unconventional sources are described in detail in Chapter 3, together with an overview of water consumption characteristics.

Water quality tends to deteriorate during the dry season when flow is low, and during the flood time when sediment concentration is high. Attenuation of water and growth of waterweeds in the swamps and lakes of the White Nile also affect the quality of water. Finally, agricultural chemicals, industrial wastes and urban effluents can cause water hazardous when discharged to a low flowing river or stream.

Figure 1-8: Structure of GDP, 1999-2009 (source: World Bank, 2011)



1.5 Economy

Figure 1-8 shows the change in the sectoral share of GDP over the period 1999-2009. Clearly, the importance of agriculture in the economy is undergoing a transformation. Once the dominant share of GDP, the overall contribution of agriculture to GDP has declined considerably over the period, from 45% to 30% of GDP, or roughly 4% per year. The industrial sector, comprising manufacturing, oil production, mining, construction, and power generation, has shown the greatest increase in GDP share, from 16% of GDP in 1999 to 26% in 2009. The service sector is the largest contributor to the economy, accounting for 44% in 2009.

Manufacturing and oil production are the most important industrial subsectors of Sudan's economy. In particular, the manufacturing subsector is critical for achieving several national objectives including technology transfer; diversification of income; and increased employment and exports. These priorities are reflected in the manufacturing share of GDP reaching nearly 11% in 2009, compared to oil production whose share of GDP in 2009 was only 7.2%.

Figure 1-9 shows the trends in real growth rate for GDP over the period 2004-2009. Since achieving close to 12% annual growth in 2006, GDP growth rates have been in decline in recent years with 2009 experiencing the lowest growth of the period, only 4.5%. This has been due primarily to the global recession and a drop in the price of oil. Preliminary forecasts for 2010 and beyond suggest annual GDP growth will rebound to levels ranging from 5% to 6%.

Figure 1-9: Growth in GDP, 2004-2009 (source: IMF Sudan, 2010)

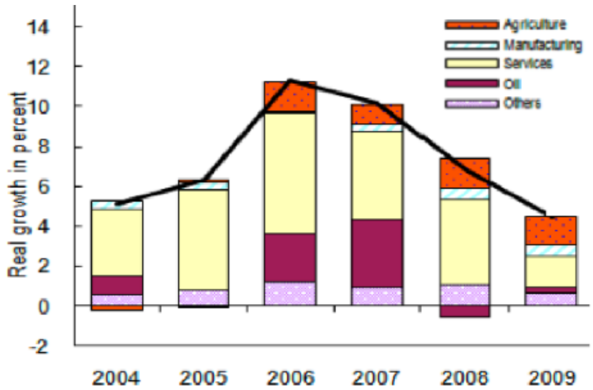


Table 1-1 provides a snapshot of Sudan's economic situation for the 2008-2009 periods. The overall position switched form a net surplus of US$ 21.1 million in 2008 to a deficit of US$ 502.0 million in 2009. This was primarily due to a change in the balance of payments, evidenced by a sharp decrease in exports (from receipts of US$ 11,760.5 to US$ 7,833.7, or a drop of 33%) combined with a modest increase in imports (from payments of US$ 8,229.4 to US$ 8,528.0 or an increase of 4%).

Prospects are considered promising within the country for steadily improving economic performance in coming years. However, any confidence in optimistic GDP forecasts is tempered by the challenge of Sudan's large debt service burden. By the end of 2009,the external debt was aboutUS$35.7 billion compared to US$33.7 at the end of the previous year. The bulk of these amounts represent the payment of interest. Sudan will likely remain under debt distress in the foreseeable future even under a benign global economic environment and the implementation of appropriate policies (IMF, 2010). Clearly, the debt burden represents serious constraints to meet the Millennium Development Goals (MDGs) and Comprehensive Peace Agreement (CPA) commitments.

Table 1-1: Balance of payments (million US$2009), 2008 and 2009 (source: Central Bank of Sudan)

	2008	2009
A. Current Account:	($1,575.70)	($3,908.10)
Exports (FOB):	$11,670.50	$7,833.70
Imports (FOB):	($8,229.40)	($8,528.00)
Balance of Trade	$3,441.10	($694.30)
Services, Income and Transfers Account:	($5,016.80)	($3,213.80)
B. Movements in Capital and Financial Account:	$1,218.40	$4,703.30
Deficit or Surplus in Current, Capital and Financial Accounts	($357.20)	$755.20
Errors and Omissions	$378.30	($1,257.20)
C. Official Reserve Assets of Convertible Currencies:	($21.10)	$502.00
D. Overall Position	**$21.10**	**($502.00)**

In the mid-term, Sudan's economy is expected to continue its transformation from agrarian-based to more industry- and service-oriented. Oil production is viewed as a critical resource for continuing Sudan's economic development and a key element in accelerating economic development. In the longer-term, as oil reserves become steadily depleted, Sudan will strive to secure a diversified economy, with agriculture and its value-added products once again assuming an important share of GDP.

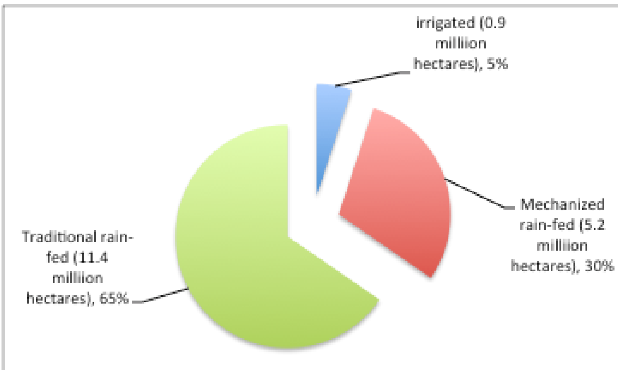
1.6 Agriculture

Sudan has historically benefited from favorable land, surface water, and soil conditions, which have allowed the country to grow a wide variety of perennial crops in different regions. Three major types of agricultural cultivation systems are practiced. Irrigated agriculture is practiced along the Nile and its tributaries, with several large schemes such as Gezira, New Halfa and Rahad and sugar factories. Mechanized rain-fed agriculture is practiced in central clay plain areas. Finally, traditional rain-fed agriculture is practiced in all other areas.

Total cultivated area has increased slightly from 2007 to 2009, from 17.4 million hectares to 17.5 million hectares. This expansion is due to an increase in land area cultivated under mechanized rain-fed systems and comes at the expense of irrigated and traditional rain-fed systems whose area under cultivation decreased by 13% and 1%, respectively between 2007 and 2009.

Figure 1-10 summarizes the total areas under cultivation for each agricultural system in 2009. Traditional rain-fed agriculture still accounts for the largest share of the land under cultivation, about 65%, followed by mechanized rain-fed systems comprising 30% and the share of irrigated systems at 5%. These shares have shifted considerably since the time of Sudan's Initial National Communication when irrigated systems accounted for 25% of total cultivated land, and traditional systems accounted for only 42%. Mechanized rain-fed systems have held

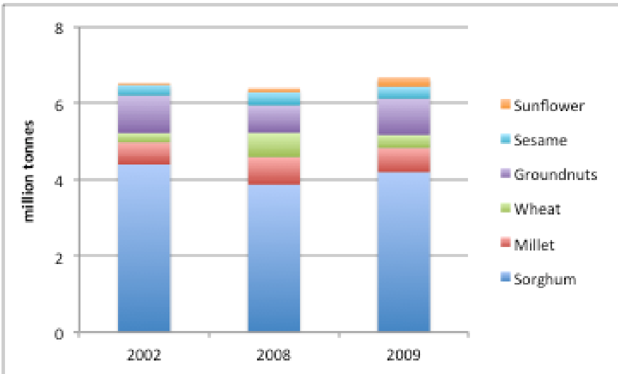
Figure 1-10: Types and shares of agricultural production systems in Sudan, 2009 (source: Ministry of Agriculture, 2010)



fairly steady from a previous share of 33%.

Figure 1-11 summarizes the annual production of some of the major crops in Sudan for the years 2002, 2008, and 2009. Total production of these crops has remained fairly stable over this period, increasing slightly from 6.5 million tonnes in 2002 to about 6.7 million tonnes in 2009. Sorghum dominates the total production of these crops, accounting for at least 60% of production. Groundnuts (with shell) are the next most productive crop, accounting between 11% and 15% over this period. Wheat production represents a small share of the total, accounting for only 5% in 2009.

Figure 1-11: Agricultural production, 2002, 2008, and 2009 (source: Ministry of Agriculture, 2010)



The average yields of major crops are summarized in Figure 1-12for the years 2002, 2008, and 2009. Wheat, mostly grown under irrigated conditions, shows the consistently highest yield, about 1.6 tonnes per hectare in 2009. There has been a decline in productivity between 2002 and 2009 for certain crops. Sorghum, wheat, and millet experienced declines in yields of 37%, 24% and 9%, respectively. On the other hand, yields for other crops increased substantially. Sunflowers, groundnuts, and sesame increased by 97%, 11% and 10%, respectively. Across all the crops shown in Figure 1-12, annual yields dropped on average by about 22% over the 2002-2009 period.

Figure 1-12: Yield estimates of major crops, 2002, 2008, and 2009 (source: Ministry of Agriculture, 2010)

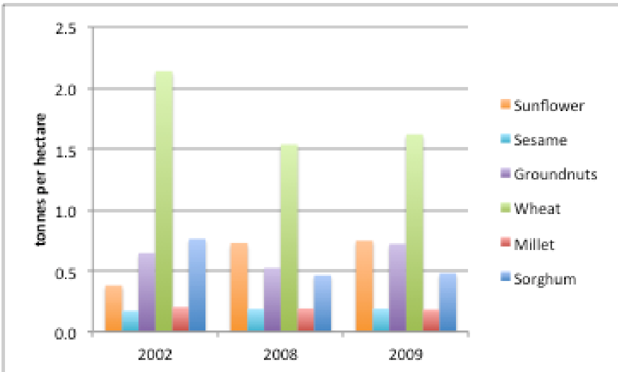
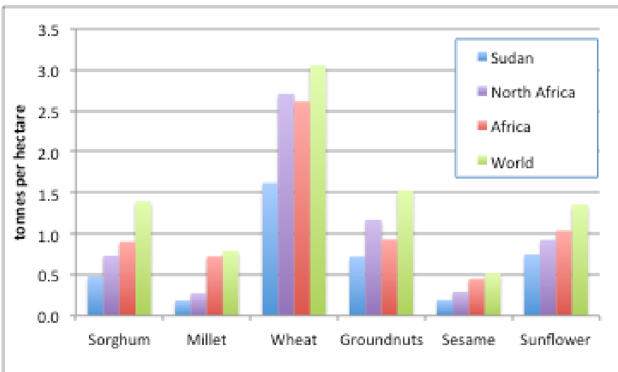


Figure 1-13shows a comparison of average annual yields of selected crops for Sudan, North Africa, Africa, and the world in 2009. As shown in the figure, crop yields in Sudan are consistently less than those achieved in each of these other regions. Compared to North Africa, yields in Sudan are between 24% and 67% less productive, depending on the crop. The greatest difference in yields is evident in comparison to world averages showing yields in Sudan between 81% and 331% lower. These differences can be explained by a combination of erratic rainfall, lower fertilizer availability, and more difficult soil conditions, particularly for traditional and mechanized rain-fed agricultural systems.

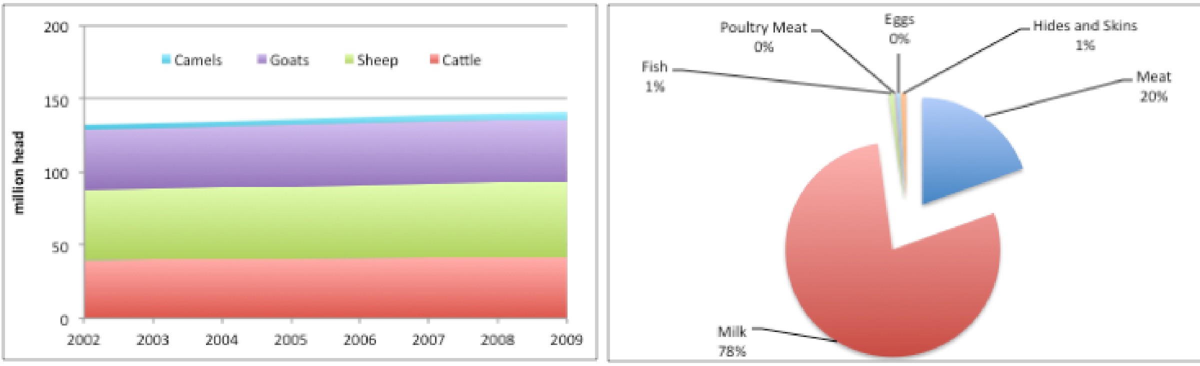
Figure 1-13: Comparison of selected crop yield estimates in 2009 for Sudan, North Africa, Africa, and the World (source: FAOSTAT database, 2011)



Other major crops in Sudan include cotton and gum Arabic, both of which are important export crops. Sudan is the world's largest producer of gum Arabic, a resin that is extracted from acacia trees and used as an emulsifier in sodas, a thickener in candies, a binder in some inks and drugs. Over the 2002-2009 period, gum Arabic production nearly doubled in Sudan, from 16.5 thousand tonnes to nearly 30 thousand tonnes, all of which was exported. On the other hand, cotton production over this same period showed a decline of about 60% due to a decline of the amount of irrigated land devoted to the crop. Given that roughly 80% of all cotton is exported, this has resulted in sharp reduction in agriculture export revenues.

In addition to agricultural practices, animal husbandry contributes significantly to achieving food security in Sudan. Animals and their by-products such as fertilizer, milk, meat, eggs, and wool are important for domestic consumption as well as regional exports. Figure 1-14(left) summarizes recent growth patterns for major animal herds, showing modest growth of about 0.9% per year on average. Figure 1-14(right) also provides a snapshot for 2009 regarding production levels of major animal by-products. Of the 9.5 million tonnes produced, most of this quantity is consumed as milk (78%) and meat (21%). Fish plays only a minor role in the food security framework in Sudan.

Figure 1-14: Animal herd sizes, 2002-2009, and animal by-products breakdown by quantity produced, 2009 (source: Ministry of Animal Resources and Fisheries, 2010)

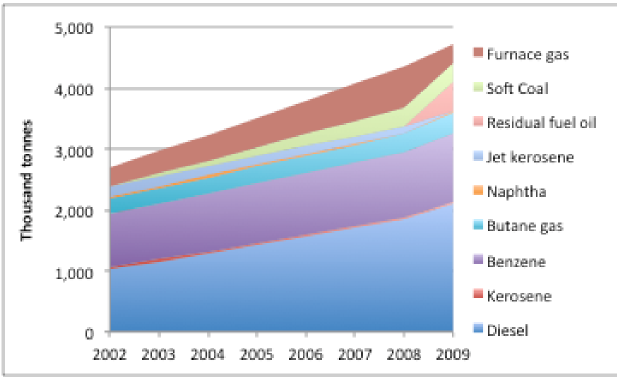


1.7 Forestry

Forest development in Sudan commenced at the beginning of the 20th century. Since then several important changes have occurred. These changes, legal and constitutional in nature, have introduced wide-ranging changes in forest management (FNC, 1989). Key statutory documents include the Wood and Forest Ordinance of 1901, The Forest Ordinance of 1908, Forest Conservation Rules of 1917, and the Forest Acts and Forest Policies of 1932. The statutes of 1932 have undergone continuous change by the development of the Forest Policy of 1986, Forest Legislation of 1989, and various ministerial decrees. The Forest legislation of 1989 is particularly notable in its call for the active participation of community and private sectors in forestry development and management. This legislation is widely perceived to have resulted in improved forest management practices, as well as increased levels of forest reserves and protected areas.

Forests are typically classified in Sudan as either natural or plantation forests. They are further distinguished by ownership, whether governmental, institutional, communal, or private sector. At the state and national levels, forest management is entrusted to various institutions, agencies and community sectors that support and/or benefit from forest products and services. Forests under the control of these institutions are able to reap some benefits in terms of sustainable production levels and environmental protection. However, the lack of integrated land use plans and coordination across institutions has resulted in the uncontrolled land use changes and conversion of vast forest tracts into agricultural areas over the past 40 years.

Figure 1-15: Production of refined oil products, 2002-2009 (source: Sudan Energy Hand Book, Ministry of Petroleum, 2010)



Note: 2003-2007 levels are interpolated.

Forest density and biomass availability show great diversity across the territory of Sudan and South Sudan. Woodland savanna forests are characterized by a wide range of crown cover, between 10% and 30%, as well as biomass quantity, between 10 and 60 m^3 of biomass per hectare (Ali, 2007). In the equatorial region of southern Sudan, there are dense forests with high cover, between 30%and 60%, with biomass quantities reaching up to 300 m^3 per hectare in certain areas. In semi-arid areas of Sudan, tree cover is sparse. What little tree cover there is exists in the form of short, xerophytes thorny trees and shrubs. Tree stock density is quite low with biomass quantities typically below 5 m^3 per hectare (Elsiddig 1980; FNC/FNI, 1998).

The Forests National Corporation has been the key national institution overseeing forest management. Under authority granted by the Forest legislation of 1989 Act, its principal function is to establish general policies and regulations to govern forest exploitation, development, and protection. It also undertakes forestry education and research activities. Other national institutions with a role in forest management include the Range and Pasture Administration whose mandate is to protect forests for livestock; the Wildlife Administration whose mandate is to manage Nature Reserves; and a number of other institutions such as the General Administration for National Energy Affairs, and Higher Council for Environment and Natural Resources.

Deforestation continues to be a major environmental challenge facing Sudan. Historically, land use has been characterized by traditional practices reflected by traditional small-scale agriculture, sedentary pastoralist, and nomadic pastoralist. Starting in the early 1970s, changes in national land use legislation led to a steady increase in areas devoted to rain-fed mechanized agricultural production as well as large-scale irrigated agricultural systems. These changes have come at the expense of large tracts of rangeland and forested land, leading to extensive deforestation particularly within the Savannas zone. Moreover, annual extraction of biomass for wood fuel typically exceeds annual forest increments by about 45% (NFI, 1996).

Combined, these factors help to explain high deforestation rates. The remaining forest cover in the territory of Sudan is roughly estimated at 12% of its land area (1.882 million square Km). This corresponds to average deforestation rates over the past 40 years between 0.4 – 0.7 million hectares per year (World Bank 1985, FRA 2005, Daak 2007, Elsiddig*et al*. 2007). This places Sudan’s deforestation rate among the ten highest in the world.

1.8 Energy

Since major oil production began in 1999, oil exports have been an increasing force in Sudan’s economy and energy system. Oil production has grown rapidly from about 24.6 million barrels in 1999 to about 183.5 million barrels in 2010, a growth rate of roughly 20% per year (EIA, 2011). The start of major oil production coincided with the operation of a 1,600 km pipeline, with a capacity of 400,000 barrel/day, from southwest Sudan, through Khartoum, to a new oil export terminal on the Red Sea. Most of the oil is produced in the South, but the pipeline, refining and export infrastructure is in the North of the country.

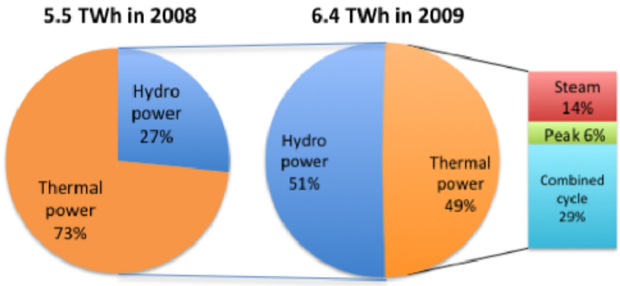
This trend coincides with steadily rising domestic production of refined oil products used for power generation, industrial operations, and transport activities, roughly 8% per year across all fuels. Figure 1-15summarizes major trends in the production of refined oil products for the period 2002-2009. Diesel and benzene consistently account for about 70% of total annual production. Diesel is primarily used in the transport sector, while benzene is used primarily in the industrial sector to make plastics, lubricants, rubbers, dyes, detergents, and pesticides.

Despite the recent increase in the production of refined oil products, biomass remains the dominant energy resource accessible to most of the Sudanese population, as it has been throughout Sudan's history. Even though the government has promoted fuel switching in recent years from wood/charcoal to LPG to reduce deforestation pressures, the Sudanese population continues to overwhelmingly rely on wood fuel such as charcoal and firewood for cooking. On an energy basis, wood fuel accounted for nearly 68% of final energy consumption in 2009. This share decreased slightly from the 1995 level of about 71% of final energy consumption.

Electric supply is provided by a mix of hydro and refined oil products; no natural gas or coal is used. The resource mix between hydro and oil can be volatile from year to year due to the vagaries of rainfall as well as the types of power stations that become operational. For example, hydropower accounted for only 27% of total power generation in 2008 but provided nearly double that share in 2009 (see Figure 1-16). This was primarily due to the start of operations at the Marawi Dam, 350 km north of Khartoum, and the launch of the first transformer stations for the high voltage transmission lines from Dongla and Al-Markhiat. High efficiency diesel-fired combined cycle unit provided nearly a third of electric supply in 2009 compared to about 14% by lower-efficiency steam units. Small peaked units using diesel or LPG provided the remaining 6% of power generation. T&D losses are quite high compared to international standards, currently averaging a little over 20%.

Electricity consumption has been growing rapidly (see Figure 1-17). Between 1998 and 2009, electricity consumption grew at about 12% per year, roughly 6 times the population growth rate. The residential sector is the largest consumer, consistently accounting for close to 50% of total electricity consumption. On the other hand, overall per capita electricity consumption is low, roughly 125 kWh/capita per year in 2009. This is one of the lowest electricity use levels in the world and reflects the continuing economic development challenge of meeting rural electrification targets.Capacity expansion planning within the National Electricity Corporation (NEC) are considering electric load forecasts that reflect high growth in all planning scenarios, from 8.2% per year in the low growth scenario to 11.4%/year in the high growth scenario.

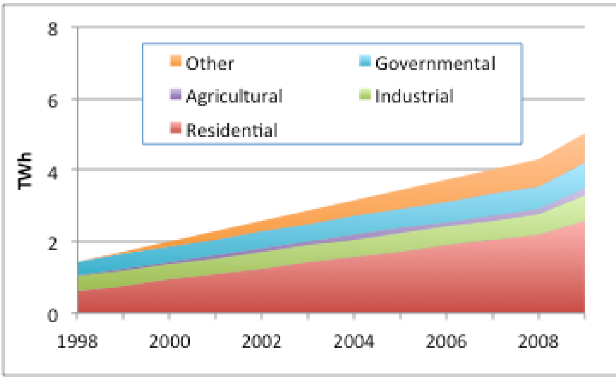
Figure 1-16: Electric power generation in Sudan, 2008-2009 (source: National Electricity Corporation NEC, 2010)



Sudan enjoys a diverse resource base for meeting future electric power requirements, as briefly summarized in the bullets below (NEAD, 1981, 2003).

- *Hydro:* Sudan has an estimated hydropower potential of 4,860 MW from the River Nile and its tributaries. At present, only about 20% has been harnessed for electric power generation. The Nile River Basin Initiative, active in seeking to diffuse potential tensions arising from competition for the use of Nile waters, is at the heart of a proposed hydro-based electric interconnection scheme between Ethiopia, Sudan, and Egypt that could promote efficient use of hydro resources through coordinated planning and development.

Figure 1-17: Electric power consumption in Sudan, 2008-2009 (source: National Electricity Corporation NEC, 2010)



Note: 1999-2007 levels are interpolated.

- *Solar:* Sudan has abundant solar resources, enjoying high annual solar radiation levels of around 6 kWh per square meter per day throughout the country. There have been recent plans by foreign investors in a 2,000 MW concentrating solar power (CSP) plant, with 250 MW planned by 2014.

- *Wind:* Several studies confirm that Sudan has considerable wind energy potential. Many inland areas north of 12°N along the Nile valley show annual average wind speeds that exceed 5meters per second. Currently there is an ongoing project for mapping wind energy potential along the Red Sea coastline carried out by Energy Affairs Agency and the Ministry of Petroleum. Other studies have indicated significant potential for wind-powered water pumping.

- *Nuclear:* Sudan is considering adding nuclear power to its energy resources mix. Plans have started in close coordination with the International Atomic Energy Agency (IAEA) for a medium-sized, four-unit nuclear station with a total capacity of up to 2,400 MW. The motivation for integrating such a high-cost power supply option is driven by current load forecasts, which show a nearly 8-fold increase in power requirements by 2030 for the low-growth scenario.

1.9 Infrastructure

Major infrastructure includes transport, communications, buildings, and medical facilities. Each is briefly discussed in the paragraphs below. Regarding transport, several main forms exist for the transport of people and goods, as briefly described in the bullets below.

- *Roads:* Sudan has between 20,000 km and 25,000 km of road, of which only 3,000 km to 3,500 km are paved outside of cities and towns. In 2009, another 330 km of paved roads were added by the National Corporation for Roads and Bridges. Roads account for almost three quarters of all commercial transport through heavy-duty trucks and light duty trucks. Annually, buses typically transport between 20 and 30 thousand people within and between cities.

- *Rail:* Sudan has about 6,000 kilometers of narrow-gauge, single-track railroads that serve the northern and central portions of the country. The Sudan Railway Network is one of the longest systems in Africa and accounts for about 10% of all commercial transport. Annually, between 80 and 90 thousand people use rail service inter-city transport.

- *River:* Sudan has about 5,000 kilometers of navigable inland waterways on the River Nile and its tributaries. The Nile River Transport Company, a private sector company launched in 2008, operates a system that connects the cities of Kosti, Malakal, and Juba on the White Nile in the south (1,436 km) and connects Karima to Donglain the North (287 km). The annual volume of goods transported is typically between 70 and 90 thousand tonnes. Transport of passengers has been largely replaced by land-based options, dropping from 44 thousand passengers in 2008 to only 4 thousand passengers in 2009.
- *Air:* There are 88 airports in Sudan, 15 of which have paved runways. There is also one heliport. Passenger traffic reached nearly half a million people in 2009, and has been growing rapidly in recent years. Cargo transport is typically between 10 and 15 thousand tonnes per year.
- *Marine:* There are four seaports in Sudan, Port Sudan, Bashair, Oseef and Osman Digna. These ports accommodate roughly 8 million tonnes of goods per year. Port Sudan is the main port for the country, where 80% of the country's ocean transports passes. The port is equipped with 15 docks, and is divided into two sections: the main port serves ships bringing general cargo, and the southern port serves tankers, containers and liquid materials. The volume of goods transported by the Sudan Shipping Line decreased from about 112 thousand tonnes in 2008 to only 33 thousand tonnes in 2009, primarily due to temporary maintenance.

Telecommunication services have experienced remarkable growth in recent years. The total number of mobile phone subscribers jumped from 11.8 million in 2008 to 15.5 million in 2009, an increase of 30% in just one year. This is primarily due to greater competition made possible by the entry of international companies such as the Sudanese Company for Mobile-phone Services (ZAIN) and Bashayer Company for Mobile-phone Services (MTN). These new entries are in addition to the incumbent Sudan Company for Telecommunications (Sudatel), which originally introduced mobile phone services. The evolving competitive landscape has benefited Sudanese consumers through better service and technology choices.

Buildings in Sudan can be classified into four groups: a) those made of clay and unbaked brick; b) those made of red brick, and c) buildings made of reinforced concrete cement and d) from forest materials. Structures made in the first manner (i.e., from clay or unbaked bricks - methods from the Turkish era) also include other construction materials such as bamboo. These comprise about 35% of buildings in Sudan. Buildings made of red brick - a stylistic influence of both the Egyptians and British - comprise most government buildings, and fully half of all construction. The remaining 15% of all building are modern structures made of reinforced concrete. During summer months, energy use in these buildings is quite high for cooling purposes (i.e., fans, evaporative air coolers, and air conditioners).

Medical facilities have been expanding rapidly in Sudan. The number of hospitals increased from 309 in 2000 to 395 in 2008, or 3.1% per year, which is slightly greater than the population growth rate during the same period. Also, there was an increase in the number of beds from 23,076 beds in 2000 to 28,389 beds in 2008. Primary health care units also increased from 3,719 units in 2000 to 6,220 units in 2008. With the exception of Khartoum which has higher coverage, there is, on average, one medical care facility per 6,143 people, which is about 20% less coverage than required.

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2 Greenhouse Gas Inventory

This chapter presents an inventory of greenhouse gases (GHG) for the year 2000. It has been prepared to comply with the obligation under Article 4, paragraph 1(a), and Article 12, paragraph 1(a) of the United Nations Framework Convention on Climate Change (UNFCCC) for all parties have to communicate to the Conference of the Parties (COP) a national inventory of anthropogenic emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol, to the extent its capacities permit, using comparable methodologies and following the provisions of Decision 17/CP.8.The inventory includes five categories: energy; industrial processes; agriculture; land use change and forestry (LUCF) and waste. It represents the first update to the initial national inventory submitted as part of Sudan's Initial National Communication in 2003.

2.1 Methodology

The methodology used in the development of the updated inventory is based on the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1996). In addition, the Good Practice Guidance 2000 (IPCC, 2000) and the Good Practice Guidance for Land Use, Land–Use Change and Forestry (IPCC, 2003) were consulted. Unless otherwise noted, default IPCC emission factors have been used. The calculation of carbon dioxide-equivalent values was based on Global Warming Potentials from the IPCC's Second Assessment Report. Version 1.3.2 of the non-Annex I GHG Software (UNFCCC, 2007) was used to derive the estimates and tabulate emissions from different sources and sinks.

The preparation of the updated GHG inventory was coordinated by the Climate Change Unit of the Higher Council for Environment and Natural Resources (HCENR). About 50 experts from relevant institutions including government, research, academia and civil society were trained in the methodologies and software. Over a dozen national institutions contributed to the preparation of the inventory, together with selected resource persons from universities and research institutions. The overall team was organized into expert-led sector-based groups, about half of them had participated in the initial national GHG inventory.

Data was collected for the 5-year period, 1998-2002. Activity data was collected from a variety of sources including official governmental reports, published research, statistical reports, and publication from international agencies such as the FAO, the Arab Organization for Agricultural Development, the International Energy Agency and other international groups. Activity data was available for all IPCC categories except fugitive emissions, carbon dioxide emissions from soils, and waste incineration emissions. The IPCC's default emissions factors were used except for a few cases where local values and/or expert judgment were used (i.e., land use change and forestry, waste management, and industrial sectors).

2.2 Total GHG emissions

Table 2-1 presents total GHG emissions and sinks for the year 2000. Total GHG emissions in 2000 were 77,650 GgCO_2-equivalent (CO_2e), which includes57,611Gg from agriculture, 9,392 Gg from LUCF, 8,539Gg from energy;2,015Gg from waste, and only 93Gg from industrial processes.

Agriculture-related activities accounted for the dominant portion of GHG emissions in 2000. Approximately 74% of all CO_2e emissions are associated with enteric fermentation and manure management. LUCF accounts for about 12% of all GHG emissions, mostly from forest and grassland conversion. The combustion of fossil fuels in the energy sector is small, accounting for only 11% of total emissions. The remaining 3% of total emissions are mostly

Table 2-1: Total GHG emissions in Sudan and South Sudan, 2000 (Gg)

GHG Sources & Sinks	CO_2e	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2	HFCs
Total National Emissions	**77,650**	**14,201**	**2,153**	**59**	**112**	**2,892**	**188**	**1**	**6**
1 Energy	8,539	6,090	95	1	80	2,020	176	0	0
2 Industrial Processes	93	93	0	0	0	0	12	1	6
3 Solvent & Other Product Use	0	0	0	0	0	0	0	0	0
4 Agriculture	57,611	0	1,923	56	17	353			
5 Land-Use Change & Forestry	9,392	8,018	59	0.4	15	520			
6 Waste	2,015	0	76	1					

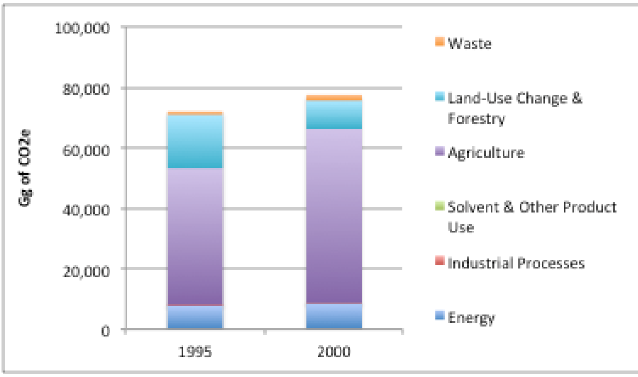
Notes:
Only emissions of CO_2, CH_4 and N_2O were included in the determination of total CO_2e levels.
Grey-shaded cell indicate not applicable.

associated with solid and wastewater management activities as industrial processes account for less than 0.5% of all emissions.

2.3 GHG emission trends

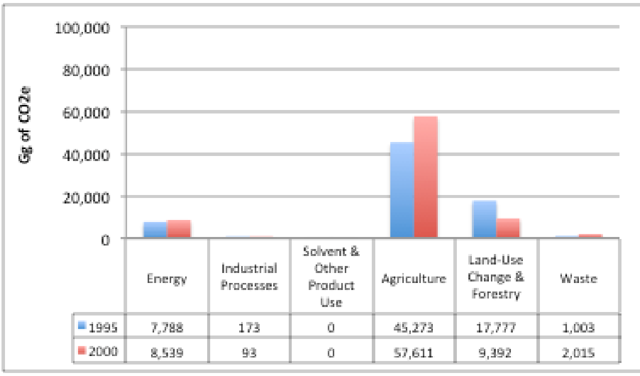
Figure 2-1 presents the trend in total GHG emissions for 1995, the year of the initial GHG inventory, and 2000. GHG emissions have increased by about 8%; from 72,014 Gg of carbon dioxide-equivalent (CO_2e) in 1995 to 77,650 Gg CO_2e in 2000. The major drivers for these changes in GHG emission levels are briefly described below and illustrated in Figure 2-2.

Figure 2-1: Total CO_2e emission trends, 1995& 2000



- *Energy:* Emissions from energy increased by roughly 10%. Increased fossil fuel consuming activities in electricity production, transport, and manufacturing are the primary reasons. This increase is partially offset by significant switching from biomass/charcoal use in the household sectors (with its corresponding high CH_4 emissions) to greater LPG use.
- *Industrial processes:* Industrial process emissions decreased by a substantial amount, 46%, although total levels are virtually negligible in both 1995 and 2000 relative to other sectors. The decrease is because one of the main cement factories was not operational during 2000, while another factory underwent renovations in that year.
- *Agriculture:* Emissions from agriculture increased by roughly 27%, primarily due to an increase in livestock populations.

Figure 2-2: CO_2e emission trends by sector, 1995, 2000



- *LUCF:* This sector is responsible for most of the decrease in GHG emissions since 1995. Emissions have reduced by almost 50% compared to 1995 levels, or almost 12% per year. This is a result of reductions in forest and grassland conversion, coupled with the expansion in afforested areas and managed forested land, in addition to improve application of the inventory methodology (forest characterization).
- *Waste:* Emissions from waste management more than doubled. The majority of this increase is due to greater amounts of municipal solid waste sent to landfill sites.

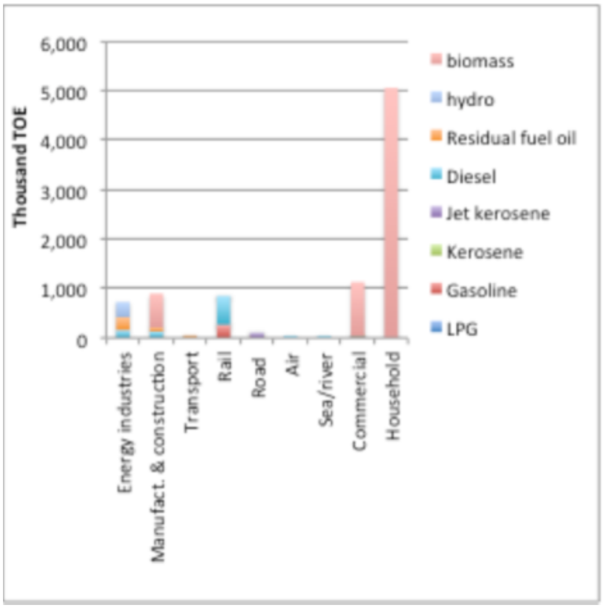
2.4 Energy Sector

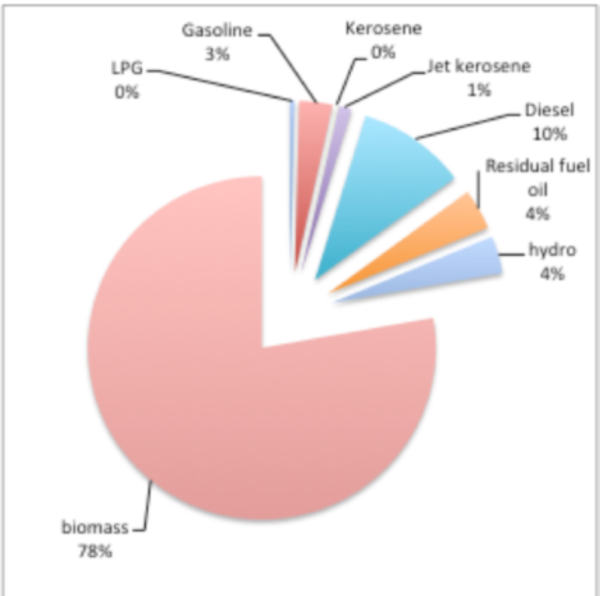
Significant developments in the energy sector have taken place in Sudan since 1995, the base year for the first inventory. This involves greater crude oil production and increased refinery capacity at the Abu-Jabra, El-Obied and Khartoum facilities. Economic reforms also took place during this period, which helped to stabilize the Sudanese currency and reduce inflation. These changes have led to greater availability and use of petroleum products for electric power production, as well as for commercial, industrial and agricultural activities.

2.4.1 Sectoral overview

Generally, there are only three types of energy that are combusted in Sudan, namely biomass, electricity (i.e., fossil fuels and hydropower), and refined petroleum products, as briefly summarized below and illustrated in Figure 2-3.

Figure 2-3: Total energy consumption, 2000





- *Biomass:* Combined, fuel wood, charcoal, agricultural residues, and animal dung accounts for about 78% of total energy consumption. Households consume more than 74% of total biomass (mostly in rural areas), followed by 16% in the service/commercial sector, and 10% in the industrial sector.
- *Electricity:* Power is produced by a combination of hydro stations and thermal stations that use diesel and residual fuel oil. Together, hydro and fossil fuels account for about 8% of total energy consumption. Since 1980, power generation has been growing at a rate 6% per year, with thermal power generation increasing at roughly six times the rate of hydropower generation.

- *Petroleum products:* Gasoline, diesel, residual fuel oil, kerosene, and jet kerosene account for about 14% of total energy consumption. The consumption of petroleum products has significantly increased since 2000 when the Khartoum Refinery began operations. The transport sector is the largest consuming sector of petroleum products, followed by agriculture, services, industry and households.

2.4.2 Data sources

The Sudanese Petroleum Corporation and General Directorate for National Energy Affairs within the Ministry of Energy and Mining (MEM) provided the fossil fuel data used to update the GHG inventory. Biomass data was obtained from the second national energy assessment report published in the year 2003. Hydro data was obtained from the National Electricity Corporation of Sudan (NEC). The reliability of these data is considered high.

2.4.3 Assumptions and key uncertainties

There are two key sources of uncertainty. First, petroleum product consumption data are based on official allocations by the MEM to consuming sectors rather than actual consumption levels. Actual sectoral consumption likely differs from allocated amounts due to fuel swapping between sectors. For example, diesel allocated to the transport sector is frequently consumed in the household and commercial sectors for on-site generation of electricity. LPG, typically allocated to the household sector in government records, is used in the transport sector (Amjad Taxi fleet) as well as some food industries.

Second, no records are available for bunker fuels in the transport sector by fuel type and/or mode of transport. Bunker aviation fuels have been estimated at 60% of the total amount of jet kerosene consumed by Sudan airways. Third, the second National Energy Assessment estimated that 90% of fuel allocated for river/sea transport is used by Sudan Shipping Lines as international bunker fuel. Finally, lubricants have been assumed to represent 3% of the total petroleum product consumption, or about 29 thousand TOE.

2.4.4 Results

Table 2-2 summarizes GHG emissions associated with energy sector in 2000. Relative to overall anthropogenic GHG emissions, the total 8,539Gg CO_2e represents about 11% of total CO_2e emissions.

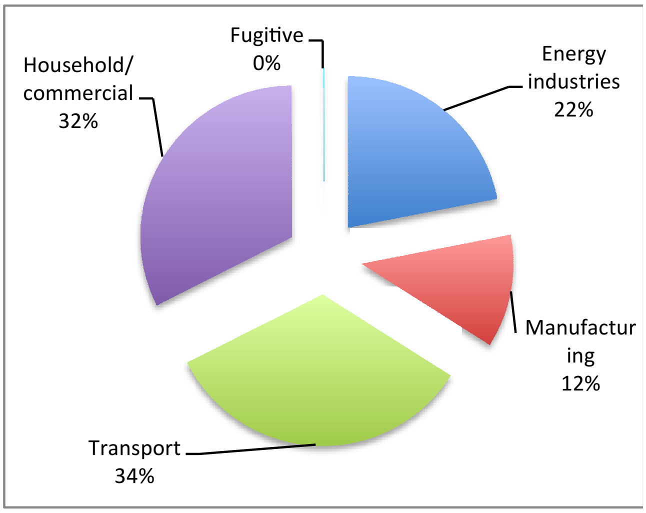
Table 2-2: GHG emissions from the energy sector, 2000 (Gg)

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO2e	CO2	CH4	N2O	NOx	CO	NMVOC	SO2
Total Emission from Energy	**8,539**	**6,090**	**95**	**1**	**80**	**2,019**	**175**	**0**
A Fuel Combustion (Sectoral Approach)	8,531	6,090	95	1	80	2,019	175	0
1 Energy Industries	1,873	1,873	0	0	5	0	0	0
2 Manufacturing Industries and Construction	1,029	912	2	0	8	189	3	0
3 Transport	2,867	2,851	0	0	29	123	0	0
4 Other Sectors	2,762	454	93	1	38	1,707	172	0
B Fugitive Emissions from Fuels	8	0	0	0	0	0	0	0
1 Solid Fuels	0		0					
2 Oil and Natural Gas	8		0.4					
Memo Items								
1. International Bunkers	200	198	0	0	1	0	407	0
Aviation	200	198	0	0	1	0	407	0
Marine	0	0	0	0	0	0	0	0
2. CO2 Emissions from Biomass	45,777	45,777						

Notes:
Only emissions of CO_2, CH_4 and N_2O were included in the determination of total CO_2e levels
Grey-shaded cell indicate not applicable.

Figure 2-4 illustrates the breakdown in energy-related GHG emissions in 2000 by consuming activity. Transport activities accounted for about 34% of all energy-related CO_2e emissions, followed by the household and commercial sectors, which accounted for 32% of energy-related CO_2e emissions.

Figure 2-4: Breakdown of CO_2e emissions associated with energy activities, 2000



Power production is based largely on the use of diesel and residual fuels and accounted for about 22% of total CO_2e emissions, plus a considerable amount of CO and NMVOC emissions. Manufacturing activities accounted for only 12% of emissions while fugitive emissions from oil production activities were negligible. The results of the 2000 inventory, does not include an emission estimate for SO2 due to data limitations.

2.4.5 *Recommendations*

The experience gained in updating the energy portion of the GHG inventory leads to the following recommendations for the next update.

- *Improve data availability:* A detailed study and survey of energy sector is needed in the future to collect the actual energy consumption data, and particularly for petroleum products to improve the estimation of the actual GHG emissions in energy sector.
- *Address bunker fuels:* Activity data relating to marine, aviation bunker fuels and lubricants need to be improved.
- *Characterize distributed generation*: A study is needed to develop data for small-scale electricity self-generation in the commercial and household sectors.
- *Develop emission factors:* Develop or find local/better emission and conversion factors that are appropriate to Sudan for both biomass and petroleum products.
- *Characterize biomass consumption* :A study is needed for biomass energy including biomass burnt for purposes other than energy.

2.5 Industrial processes

Industrial processes are focused primarily on agricultural activities, which accounted for a large share of GDP in 2000, with agro-based industrial processes having a prominent role. Major agro-based industries are focused on sugar, flour milling, confectionary biscuits, textiles, edible oils and ethanol from animal and leather products, diary products, animal fodder, and packing/canning activities. Future agro-industrial expansion is expected to focus on fertilizers, pesticides and agricultural appliances. Other major industries include cement, lime and gypsum production, decorative stone and metal smelting/shaping, Ferro-alloy production, and the manufacture of assorted items for local use.

2.5.1 *Sectoral overview*

In 2000, the gross product of the industrial sector in the Sudan amounted to about 3 billion USD. The profile of the sector is briefly described in the bullets below.

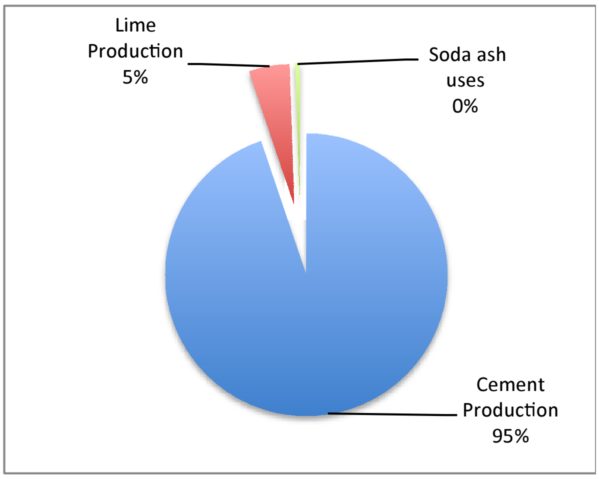
- *Large-scale industries:* These industries accounted for 82% of GDP. Most of the output is focused on food/beverages (48%), oil refining (21%), and tobacco (6%). The production of cement and other large-scale industries make up the remaining contribution to GDP.
- *Small-scale industries:* These industries accounted for 18% of GPD. Most of the output is focused on food/beverages (15%), and the remaining contribution is from wood fabrication, metals, textile sand other small-scale industries.

2.5.2 Data sources

There are several sources for the data used to estimate GHG emissions associated with industrial processes, as listed below. The reliability of these data is considered high.

- Ministry of industry (Comprehensive Industrial Survey 2000-2001)
- Annual reports of industrial facilities (e.g., Sudanese Sugar Company)
- Khartoum State Industrial Department
- Customs & Duties Authority
- Central Bureau of Statistics (CBS)
- Bank of Sudan
- Defense Authority

Figure 2-5: Breakdown of CO_2e emissions associated with mineral production in the industrial sector, 2000



2.5.3 Assumptions and key uncertainties

There are some industrial activities that took place in 2000 that were considered so minor that they were not included in the inventory. These include asphalt roofing production and fugitive emission of HFCs/PFCs. In addition, pulp/paper and glass production were not included in the inventory as each of the associated facilities was not operational in 2000. Default IPCC emission factors were used for all processes. Key uncertainties are associated with the lack of regularly updated and reliable industrial survey data. For some categories, production levels were assumed on the basis of secondary sources due to the absence of actual data.

2.5.4 Results

Table 2-3 summarizes GHG emissions associated with industrial processes in 2000. Relative to overall anthropogenic GHG emissions, the 93Gg CO_2e represents about 0.1% of total CO_2eemissions.

Figure 2-5 illustrates the breakdown in industrial process GHG emissions in 2000 within the mineral products category, which accounts for all industrial CO_2e emissions. Cement production activities account for the overwhelming majority of CO_2e emissions, about 95%. Lime production accounts for about 5% followed by soda ash uses, which account for less than 0.5% of industrial CO_2e emissions.

2.5.5 Recommendations

The experience gained in updating the industrial process portion of the GHG inventory leads to the following recommendations for the next update.

Table 2-3: GHG emissions from industrial processes, 2000 (Gg)

									HFCs		PFCs		SF_6	
GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**CO2e**	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2	P	A	P	A	P	A
Total Emissions from Industrial Processes	**93**	**93**	**0**	**0**	**0**	**0**	**12**	**1**	**6**	**19**	**6**	**6**	**6**	**6**
A Mineral Products	93	93				0	0	1						
B Chemical Industry	0	0	0	0	0	0	0	0						
C Metal Production	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D Other Production	0	0			0	0	12	0						
E Production of Halocarbons and Sulphur Hexafluorid	0								0	0	0	0	0	0
F Consumption of Halocarbons and Sulphur Hexafluo	0								6	19	6	6	6	6
G Other	0	0	0	0	0	0	0	0				0		0

Notes:
P = Potential emissions based on Tier 1 Approach; A = Actual emissions based on Tier 2 Approach.
Grey-shaded cell indicate not applicable.
Only emissions of CO_2, CH_4 and N_2O were included in the determination of total CO_2e levels

- *Develop systematic database system:* There is no regularly updated survey and hence reliable data, since the comprehensive industrial survey is carried out only once every 10 years, and the last one was in completed in 1986. It is recommended that an industrial database be developed and maintained based on a regular basis.
- *Enhance IPCC software:* A separate spreadsheet tabulation system should be developed to complement the IPCC inventory spreadsheet as the latter structure was considered unsuitable for data entry of multiple factories of the same type of production (e.g. cement factories) with different emission factors.
- *Strengthen local technical capacity:* There is an overall need for greater local capacity building in the industrial process area of GHG inventory development.

2.6 Agriculture

The agricultural sector accounted for about 46% of GDP in 2000. It was the main source of employment and household income in rural areas where agricultural activities accounted for about 80% of the labor force.

2.6.1 Sectoral overview

The features of the agricultural sector most relevant to the development of the agriculture GHG inventory are briefly described in the bullets below.

- *Livestock management:* About 90% of livestock are managed in traditional pastoral production systems. Pastoral herds are mainly semi-nomadic, especially in western Sudan and southern Blue Nile State where traditional movements occur between wet and dry-season grazing areas.
- *Rangelands:* These areas cover over 96 million hectares and comprise grasslands and shrub-lands. Nearly 80% of all rangelands are located in semi-desert and savanna ecological zones that are characterized by variable and unpredictable rainfall.
- *Other:* There are several other agricultural activities that are common practices in Sudan, particularly field burning of agricultural residues and prescribed savanna burning.

2.6.2 Data sources

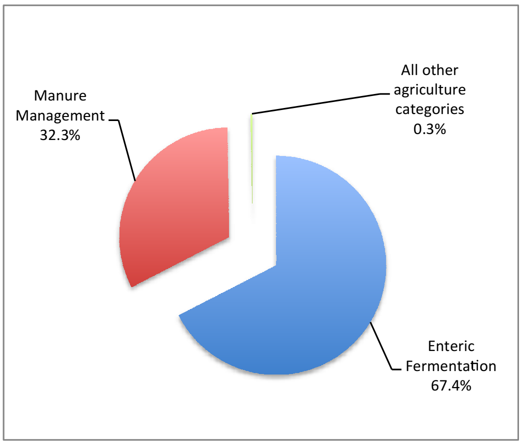
There are several sources for the data used to estimate GHG emissions associated with the agriculture sector, as listed below. The reliability of these data is considered high.

- Ministry of Animal Resources and Fisheries
- Range and Pasture Administration
- Arab Organization for Agricultural Statistics Yearbook
- Arab Organization for Agricultural Development Yearbook
- General Administration for Planning
- Food and Agriculture Organization of the United Nations (FAO)

2.6.3 Assumptions and key uncertainties

Default factors from the IPCC's 1996 Guidelines were assumed to be adequate for most categories. The sole exception concerned some livestock categories where local factors were developed and were used to develop emission estimates. Some of the key uncertainties of the agriculture portion of the GHG inventory are highlighted below.

Figure 2-6: Breakdown of CO_2e emissions associated with agricultural activities, 2000



- *Livestock number and type:* As the last livestock census was carried out during 1975-1976, animal herd populations in 2000 were estimated based on extrapolations and limited surveys. Also, the differentiation of cattle by type was not possible as there was no statistical information available by sex, breed or function.
- *Data temporal coverage:* Calculations of GHG emissions associated with enteric fermentation and manure production are based on the average of livestock numbers over the 3-year period 1999 – 2001.Calculations of GHG emissions associated with field burning of agricultural residues are based on the average of production levels for major crops (e.g., sorghum, vegetables, ground nuts, cereals) over the 3-year period 2000 – 2002.
- *Regional livestock breakdowns:* The data quality of regional estimates of livestock numbers was limited and introduced uncertainties in the assessment of manure production for livestock rearing for different ecological zones.
- *Lack of data:* For some cereal crops such as sesame, sunflower, pluses, and vegetables, there were limited data available to estimate crop residue quantities. Roughly10% of crop residues are assumed to be burned in-situ. Also, there is high uncertainty for emissions associated with savannah burning to improve range productivity, as no data were available.

2.6.4 Results

Table 2-4 summarizes GHG emissions associated with agriculture in 2000. Relative to overall anthropogenic GHG emissions, the 57,611Gg CO_2e represents about 74% of total CO_2e emissions.

Figure 2-6 illustrates the breakdown in agriculture-related GHG emissions in 2000 by emitting activity. Enteric fermentation accounts for about 68% of all CO_2e emissions from the agriculture sector, followed by manure management, which accounts for 32% of

Table 2-4: GHG emissions from agriculture, 2000 (Gg)

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO2e	CO_2	CH_4	N_2O	NO_x	CO
Total Emissions from Agriculture	**57,611**		**1,923**	**56**	**17**	**353**
A Enteric Fermentation	38,851		1,850			
B Manure Management	18,590		72	55		
C Rice Cultivation	4		0.2			
D Agricultural Soils	0			0		
E Prescribed Burning of Savannas	3		0	0		
F Field Burning of Agricultural Residues	164		1	0	17	353
G Other	0		0	0		

Notes:
Grey-shaded cell indicate not applicable.
Only emissions of CO_2, CH_4 and N_2O were included in the determination of total CO_2e levels

agricultural CO_2e emissions. All other categories (i.e., rice cultivation, prescribed savannah burning, and field burning of agricultural residues) are small in comparison, together accounting for about 0.3% of agricultural CO_2e emissions.

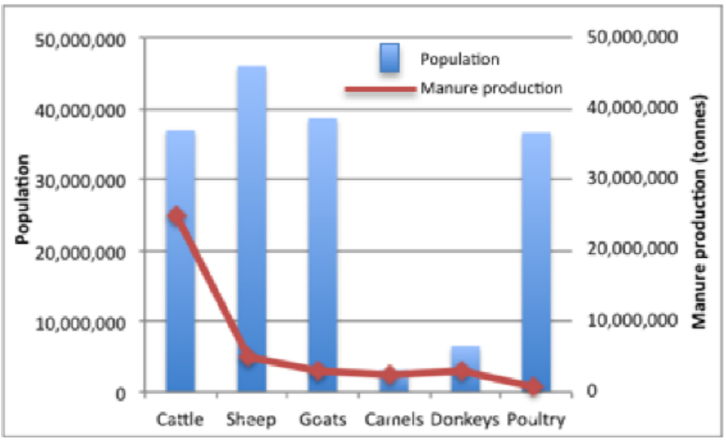
The high levels of methane emissions associated with enteric fermentation are due to the large role that animals play in the economy of Sudan, particularly in rural areas. As shown in figure 2-7, there were approximately 168 million domestic animals in 2000, collectively producing over 35 million tonnes of manure. Methane emissions associated with these animals are characterized by the following:

- Cattle account for the largest source of methane. Most of the cattle population provides draft power and some milk under traditional farming systems. In fact, the traditional sector account for the overwhelming majority of these emissions, as the commercialized dairy sector is very small in comparison.
- Emissions from sheep, goats and camels are low. Sheep show the highest emissions followed by goats, camels and finally donkeys. Mules, buffalo, and swine are typically not found in Sudan.

Methane and nitrous oxide emissions from manure management are primarily associated with cattle, about 50%. Typically, cattle manure management is based on dry lot under range and paddock systems.

Of the remaining 0.3% of agricultural emissions, field burning of agricultural residues account for the largest share, about 96%. Rice production is very limited – only 5238 hectares are cultivated – and accounts for about 3% of remaining agricultural emissions. The remaining 1% of agricultural emissions is associated with the (fire lines) burning of grassland savanna, a practice that is common in Sudan.

Figure 2-7: Livestock population and manure production estimates, 2000



Note: Based on data available from the Ministry of Animal Resources and Fisheries

2.6.5 Recommendations

The experience gained in updating the agriculture portion of the GHG inventory leads to the following recommendations for the next update.

- *Develop livestock data systems:* There is a need for the development of new livestock population data systems. Such a system should be structured on the basis ecological zones and include information on type, age, body weight change and seasonal distribution of animals
- *Adopt alternative measurement methods:* Ground-based survey methods should be augmented to employ remote sensing techniques, low aerial surveys, and satellite imagery. Such information will be useful to validate livestock production and category distribution; assess pastoral conditions and stocking capacity in different ecological zones; and determine seasonal methane emissions relative to animal type and pastoral activity.
- *Promote inter-ministerial cooperation:* The Ministries of Agriculture, Animal Wealth and the Higher Council for Environment and Natural Resources should cooperate for a wide range of data collection, including data on livestock, crop residue burning, soils etc. In addition, the GHG inventory updating process should be institutionalized with clear definition of responsibility and accountability.
- *Enhance the IPCC methodology:* Effort is needed to enhance the general IPCC methodology on N_2O emissions for countries like Sudan that display highly diverse ecological zones, micro climates, and agricultural systems. Also, since soil carbon and nitrogen cycles are tightly integrated, both carbon and nitrogen should be considered together so that various aspects of the carbon and nitrogen cycle and CO_2 and N_2O production can be more accurately defined.
- *Strengthen local technical capacity:* Additional in-depth training of national experts on the inventory methodological guidelines and software is needed. In addition, local research and scientific studies are needed to develop emission factors and other parameters that are appropriate for Sudan's conditions.

2.7 Land Use Change and Forestry

Land and forests play a substantial role in terms of their economic value and support of local livelihoods. The forestry sector contributes to about 12% of GDP, primarily from annual exports of gum Arabic, and provides numerous direct and indirect benefits such as environmental protection, soil amelioration, work opportunities for rural population, building material and wood fuel.

2.7.1 Sectoral overview

Land use and forestry features that are most relevant to the development of the GHG inventory are briefly described in the bullets below.

- *Social value:* In rural areas where 66% of the population lives, wood is the main source of fuel for cooking and construction materials for buildings. In addition, forests are important natural rangelands for grazing, for wildlife and for obtaining forest food in the form of tree leaves, fruits and tubers.
- *Encroachment:* Forests have been facing encroachment by agriculture, urbanization, and unsustainable wood fuel extraction for several decades. By the end of 1997, forest reserves comprised of only 8.3 million hectares, less than 17% of the target of 46.3 million hectares called for in the Comprehensive National Strategy 1992–2002.

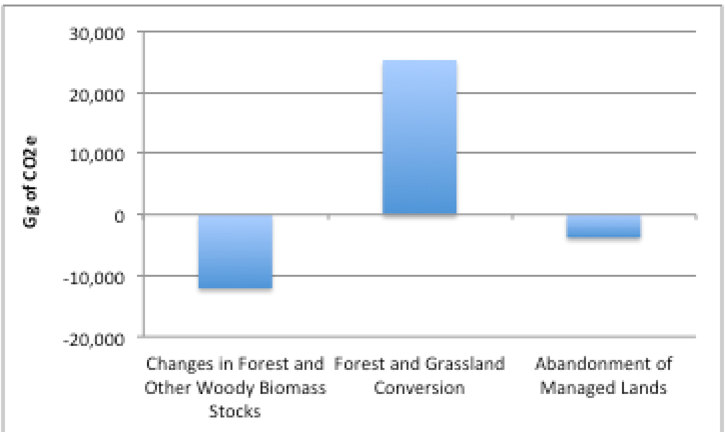
- *Sustainable forestry:* Recognition of the need to confront the decline in forest area has led to several sustainable forestry initiatives, particularly the adoption of community-based forestry management practices and switching from firewood/charcoal to LPG. These initiatives are expected to protect forest cover in the long-term.
- *Industrial wood consumption:* The industrial sector typically accounts for less than 10% of the total wood consumption. Over 98% is consumed as firewood at industrial/commercial facilities with the remainder taken up by brick kilns, the lime industry, sawmills, and other wood-based industries in the country.

2.7.2 Data sources

There are several sources for the secondary data used to estimate GHG emissions associated with land use change and forestry, as listed below. The reliability of these data is considered high.

- Annual reports of Forests National Corporation for the years, 1998, 2001, and 2003;
- Sudan Forestry Sector Review, 2007;
- FAO report (Forest Resource Assessments for 2000 and 2005);
- Reports of Ministry of Energy, 2000; and
- Range and Pasture Administration

Figure 2-8: Breakdown of CO_2e emissions associated with LUCF activities, 2000



Note: Based on data available from the Sudan FNC and FAO

2.7.3 Assumptions and key uncertainties

Default factors from the IPCC's 1996 Guidelines were assumed to be adequate for most categories. The sole exception concerning annual tree growth rates based on national data. Key uncertainties for the LUCF portion of the GHG inventory are as follows:

- *Soil data:* There were significant limitations regarding soil data availability due to the diversity of ecological zones and the historic lack of national data collection efforts.
- *Biomass conversion:* There was difficulty in collecting biomass data concerning post-grassland/forest conversion levels, the fraction of biomass that is burned in-situ, and the carbon fraction of above–ground biomass burned in-situ.
- *Managed lands:* The annual rate of above-ground biomass growth and the carbon fraction of aboveground biomass were difficult to obtain due to poor data availability and/or quality.

2.7.4 Results

Table 2-5 summarizes GHG emissions associated with LUCF in 2000. Relative to overall anthropogenic GHG emissions, the 9,392Gg CO_2e represents about 12% of total CO_2e emissions.

Table 2-5: GHG emissions from LUCF, 2000 (Gg)

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO2e	CO2 Emissions	CO2 Removals	CH_4	N_2O	NO_x	CO
Total emissions from Land-Use Change & Forestry	**9,392**	**23,924**	**-15,906**	**59**	**0**	**15**	**520**
A Changes in Forest and Other Woody Biomass Stocks	-12,125	0	-12,125				
B Forest and Grassland Conversion	25,298	23,924	0	59	0.4	15	520
C Abandonment of Managed Lands	-3,781	0	-3,781				
D CO2 Emissions and Removals from Soil	0	0	0				
E Other	0	0	0	0	0	0	0

Note:
Only emissions of CO_2, CH_4 and N_2O were included in the determination of total CO_2e levels

Figure 2-8 illustrates the breakdown in LUCF-related GHG emissions in 2000 by emitting and removal activity. The conversion of forests and grasslands accounts for all CO_2e emissions from the LUCF sector. This is mostly due to the deforestation and degradation of forests and rangelands associated with unsustainable biomass extraction in rural areas.

Regarding CO_2 removals by sinks, changes in forest and other woody biomass stocks that are under the management of the Forest National Corporation account for about 76% of all sequestered CO_2. The remaining 24% of all sequestered carbon is associated with the abandonment of agricultural lands.

2.7.5 Recommendations

The experience gained in updating the LUCF portion of the GHG inventory leads to the following recommendations for the next update.

- *Develop data and information systems:* The development of a LUCF-based database information system is needed based on systematic scientific research and field surveys.
- *Promote institutional cooperation:* Improved data access and availability across national institutions is needed to enhance the quality and timely preparation of the GHG inventory.
- *Strengthen national capacity:* Additional in-depth training of national experts on inventory methodologies for the LUCF sector is needed.

2.8 Waste

Waste management in Sudan is not well advanced and is typically addressed in traditional ways regardless of whether the waste is solid, liquid, industrial or domestic in nature. This has led to health hazards in both rural and urban areas. Currently, waste management is not adequate, waste streams are unsegregated, waste collection is not systematic, and solid waste disposal sites are shallow, poorly designed and mostly unmanaged. Open burning is a common practice within cities.

2.8.1 Sectoral overview

With rapid urbanization and changing consumption patterns, solid waste management has become a major challenge in most urban centers in Sudan, particularly the larger ones. Apart from a few municipalities that have introduced innovative waste management approaches, modern waste management techniques, such as source separated, door-to-door collection, recycling facilities and sanitary land filling, are limited to small pockets in urban areas. In general, municipal governments typically lack the necessary skills and resources to manage wastes properly. Specific waste management features that are most relevant to the development of the GHG inventory are briefly described in the bullets below.

- *Wastewater management:* There are only two wastewater treatment plants, both located in Khartoum state and serving only 5% of the population. Other wastewater treatment systems include septic tanks, lanterns and pits. Plans are process to build two new wastewater treatment facilities.
- *Solid waste management:* Less than a third of estimated 4.3 thousand tonnes per day of municipal solid waste generated in Khartoum is collected. Most of this collected waste is dumped in shallow, unmanaged landfills with little engineering integrity, with the rest disposed in open, ad hoc sites.

2.8.2 Data sources

There are several sources for the secondary data used to estimate GHG emissions associated with land use change and forestry, as listed below. The reliability of these data is considered high.

- Central Bureau of Statistics;
- Khartoum Cleaning Company

2.8.3 Assumptions and key uncertainties

Default factors from the IPCC's 1996 Guidelines were assumed to be adequate for all categories. Key assumptions and uncertainties for the waste portion of the GHG inventory are as follows:

- *Solid waste:* Several assumptions underlie the development of emission estimate from solid waste management, namely only urban populations are applicable; all municipal solid waste disposal sites(SWDS) are shallow/unmanaged; per capita MSW generation is unchanged from the rate used in the Initial National Communication (i.e., 0.789 kg/capita/day); and the MSW fraction disposed to SWDSs is 75%.
- *Municipal wastewater:* Several assumptions underlie the development of emission estimates from municipal wastewater management, namely only urban populations are applicable for methane emissions; the degradable organic component(DOC) share is 0%;
- *Industrial wastewater:* Industrial wastewater data was available only for Khartoum; data from Khartoum was used to estimate industrial wastewater in other regions based on data regarding the type and number of industries in each region.
- *Human waste:* Several assumptions underlie the development of emission estimates from municipal wastewater management, namely the entire urban and rural population was considered for nitrous oxide emissions; the share of pregnant women in the population is 20%; protein consumption for adult males is 50gm/day, 45gm/day for adult females, 80 gm/day for lactating females, and 1.2gm/day for children; average weights of children are 12.5 kg (less than 5 years of age) and 33 kg (between 6 and 15 years of age).

2.8.4 Results

Table 2-6 summarizes GHG emissions associated with waste management in 2000. Relative to overall anthropogenic GHG emissions, the 2,015Gg CO_2e represents about 12% of total CO_2e emissions.

Figure 2-9 illustrates the breakdown in waste sector GHG emissions in 2000. Solid waste disposal on land accounts for over two-thirds of CO_2e emissions. Wastewater handling of commercial, residential and industrial waste streams accounts for the remaining 30% of CO_2e emissions from the waste management sector.

2.8.5 *Recommendations*

The experience gained in updating the waste sector portion of the GHG inventory leads to the following recommendations for the next update.

- *Increase public awareness:* There is a need to encourage and support more people to do household composting and establish larger composting facilities in partnership with the private sector. Similarly, most of the inorganic waste such as plastics, metal and paper can be recycled by private sector.

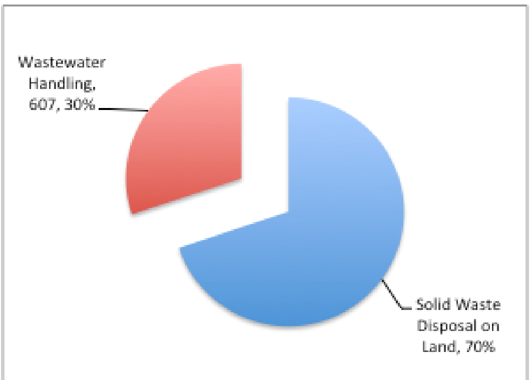
Table 2-6: GHG emissions from waste management, 2000 (Gg)

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO2e	CO_2	CH_4	N_2O	NO_x	CO
Total Emissions from Agriculture	2,015		76	1	0	0
A Solid Waste Disposal on Land	1,408		67			
B Wastewater Handling	607		9	1		
C Waste Incineration	0	0	0	0		
D Other	0		0	0		

Note:
Grey-shaded cell indicate not applicable.
Only emissions of CO_2, CH_4 and N_2O were included in the determination of total CO_2e levels

- *Enhance municipal capacity:* The capacity of municipalities and the amount of resources they invest in solid waste management is very limited. Additional staffing and the allocation of resources will be necessary to improve solid waste management and the quality of data collection.
- *Support decision-making:* Policymakers at the municipal, state and federal levels need to be made aware of the economic, environmental, and public health benefits of proper waste management practices, including segregation, collection, recover/re-use, recycling, and the need for sound engineering designs of landfills or incineration facilities.
- *Strengthen institutional cooperation:* There should be a designated focal institution, which acts in support of other national agencies and ministries to collect and update waste generation and treatment data on a regional basis.

Figure 2-9: Breakdown of CO_2e emissions associated with waste management activities, 2000



2.9 Uncertainty Assessment

An overall uncertainty assessment was undertaken to help prioritize efforts to improve the accuracy of future inventories. As noted in the previous sections, uncertainties are associated with data access/constraints and potential unsuitability of the IPCC's generic emission factors.

Some of the current estimates, such as CO_2 emission factors for energy production and consumption activities have small levels of uncertainty. On the other hand, other portions of the inventory rely on factors, which are typically not collected in Sudan such as per capita protein consumption and conversion factors for crop residue calculations. For these and other categories, there is a systematic lack of information, which increases the uncertainty surrounding the estimates presented in this chapter.

Table 2-7 summarizes the uncertainty assessment for the GHG inventory. Based on expert judgment of specialists participating in the development of the inventory, the confidence in the results for each source/sink category was evaluated relative to the uncertainty associated with data quality and emission factor suitability. Less than 10% uncertainty was considered to be low; uncertainty between 10% and 50% was considered medium; and uncertainty greater than 50% was considered high.

Based on the sector-specific recommendations in the previous sections, attention to three key areas will help reduce uncertainty in future GHG inventories in Sudan. First, enhancing the availability of detailed and high quality activity data will increase confidence in the inventory results. This will necessarily involve a government commitment to establishing systematic database systems. Second, improving the accuracy of local emission factors to calculate emissions from a variety of sources is vital. Many of the default emission factors are classified as having high uncertainty relative to Sudan conditions. Finally, addressing these areas through additional capacity strengthening and development of dedicated observation networks is essential.

Table 2-7: GHG inventory uncertainty assessment, 2000

Sector	Activity	Uncertainty Assessment		Confidence in Inventory results
		emission factor	data quality	
Energy	Energy industries	low uncertainty	good quality	High
	Manufacturing industries	low uncertainty	medium quality	Medium
	Transport	low uncertainty	medium quality	Medium
	Other sectors	low uncertainty	medium quality	Medium
	Fugitive emissions	low uncertainty	medium quality	Medium
Industrial processes	Mineral products	low uncertainty	medium quality	Medium
	Chemical industry	high uncertainty	poor quality	High
	Metal production	low uncertainty	medium quality	Medium
	Other production	low uncertainty	medium quality	Medium
	Halocarbons & sulfur hexafluoride	low uncertainty	medium quality	Medium
Agriculture	Enteric fermentation	high uncertainty	poor quality	Low
	Manure management	high uncertainty	poor quality	Low
	Agricultural Soils	high uncertainty	poor quality	Low
LUCF	Changes in Biomass Stocks	high uncertainty	poor quality	Low
	Forest and grassland conversion	high uncertainty	poor quality	Low
	Abandonment of managed lands	high uncertainty	poor quality	Low
Waste	CH4 emissions from SWD sites	medium uncertainty	poor quality	Low
	Wastewater handling	medium uncertainty	medium quality	Medium
	N2O emissions - human waste	medium uncertainty	good quality	Medium

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3 Vulnerability and Adaptation

Sudan is one of the most vulnerable countries in the world to climate change. Rain-fed agricultural systems, the dominant livelihood in rural areas and representing a large fraction of GDP, must cope with highly variable climatic patterns, rainfall extremes (either high or low)becoming increasingly more common as the climate changes throughout the country, with a trend of rising temperature that increases the rate of evaporation and worsen the situation with the occurrence of drought. The unreliable nature of rainfall, together with its concentration within short growing seasons, heightens the vulnerability of Sudan's rain fed agricultural systems to more frequent and intensive drought and poses critical and pressing challenges for timely and effective adaptation.

During the past several years, Sudan undertook and completed several major climate change assessments to better understand the range of adaptation opportunities. These assessments have focused on adaptation research, adaptation planning, and impact assessments for the water resource and coastal zone sectors. Together, these efforts have helped to clarify the range of adaptation strategies that show promise for building resiliency against future climatic changes. They are also providing the basis for national efforts to incorporate climate change adaptation into policymaking and investment decisions. As this chapter demonstrates, the motivation for adaptation is clear, and progress is underway to initiate and coordinate action. Some of the key findings are summarized in the sections below.

3.1 Adaptation research

There have been two major adaptation research initiatives that have taken place in Sudan in recent years. Over the period 2002-2005, as part of a project on Assessments of Impacts and Adaptations to Climate Change (AIACC), HCENR in collaboration with national researchers undertook an assessment in Sudan to explore the possibility that certain sustainable livelihood and environmental management measures could be considered as climate change adaptation options in planning of future adaptation strategies(HCENR, 2004).

Also, since 2009, Sudanese researchers have been involved in a regional project designed and implemented by non-governmental organizations. Known as the Community Based Adaptation in Africa (CBAA) project, it sought to help vulnerable communities to adapt to climate change and share lessons learned from project activities with key stakeholders at local, national, regional and international levels (Zakieldeen, 2009).

3.1.1 Assessments of Impacts and Adaptations to Climate Change

This research effort, implemented by HCENR, was part of a global adaptation research project that consisted of 24 regional studies on vulnerability and/or adaptation, financed by the Global Environment Facility (GEF) and implemented by the United Nations Environment Program (UNEP), Global Systems for Analysis, Research, and Training (START) and The Academy of Sciences for the Developing Worlds (TWAS).

3.1.1.1 Research design

There were two main objectives for the adaptation research effort in Sudan, namely to show ways in which small-scale, community-based initiatives can increase community resilience to climate–related shocks such as drought; and to show how such measures can be effectively implemented and supported for lasting impacts. Three case study projects were considered, all of which were focused in rural, arid Sudanese communities within a specific ecological/agricultural system (see Box 3-1). Case studies were selected on the basis of their success in achieving rural development goals. Their major features are summarized in the bullets below.

- *Focus:* Case studies were focused on specific rural development projects that were implemented during the 1980s up through the present. The main focus of the projects varied across the case study sites, with the core of activities focused on rangeland rehabilitation, water harvesting, and livelihood diversification.
- *Methodological framework:* Each case study used a structured interview format within a sustainable livelihoods framework to explore the impact of "local" knowledge (e.g., traditional, indigenous, autonomous, informal) and/or "external" knowledge (e.g., formal, technical, directed) in the ability of the community(ies) to cope with climate-related stress.
- *Research approach:* Each case study compared a community's resilience to climate extremes, before and after project activities. Commissioned Sudanese researchers conducted the structured interviews over a six-month period, backed up by one-on-one consultations with key households/individuals. The interviews focused on the impact of project measures on local resilience to drought impacts, and the reasons underlying the success of the project.
- *Adaptation policy relevance:* The research effort sought to identify the role of project measures in building community coping mechanisms and adaptive capacity, their policy and institutional enabling factors, their potential in climate change adaptation, and recommendations for how they can be integrated into adaptation policy and planning.

Box 3-1: Overview of the AIACC case studies

- *Khor Arbaat:* This site is located in the Red Sea State in northeast Sudan. The region is isolated with harsh terrain, highly variable rainfall, recurrent drought, and a dispersed population. The research evaluated the livelihood strategies introduced by the SOS Sahel Project (1993-2000) such as income diversification and alternative income generation activities.
- *Gireighikh Rural Council:* This study area is located in central Bara Province, North Kordofan State. The region has endured two droughts during 1967-193 and 1980-1984, the latter being particularly severe. The research evaluated the impacts of rangeland rehabilitation activities (i.e., wind-break installation, sand dune stabilization, tree and shrub planting) as well as other measures such as small-scale irrigated vegetable gardens, pest management practices, and water well installation.
- *North Darfur:* This study area is located on the northern transitional margin of the Inter Tropical Convergence Zone. The drought years of 1983-1985 greatly affected demographic and socioeconomic conditions, leading to incresing poverty, famine, and tribal conflicts. The research evaluated the impacts of autonomous water harvesting and terracing techniques.

3.1.1.2 Major findings

The major themes that emerged from a synthesis of the results are summarized in the bullets below.

- *Natural resource management is an adaptation strategy:* Strategies and measures for the sustainable management of natural resources support broad improvements in livelihood security and household and community capacity to cope with climate impacts.
- *Rural financing schemes are essential:* The capacity to locally finance coping mechanisms livelihood diversification activities that can pre-emptively lower climate vulnerability is key. In this sense, savings in tradable assets (e.g., livestock, agricultural produce) are critical, as is access to micro-credit to temporarily substitute for the lack of tradable assets.
- *Access to basic materials is essential:* Low-tech materials such as basic tools and farm equipment are on the critical path for sustained effectiveness of project interventions. Higher-tech inputs such as improved drought-resistant seeds, access to farm and earth-

moving equipment for the development and improvement of local infrastructure are also important.

- *Building human capacity is critical to strengthening coping and resilience:* Specifically, many of the things that enabled improved coping capacity within households and communities also required improved human capacity – from animal health care skills, to mechanical skills for the maintenance of machinery, to soil management skills, to community organizational capabilities. As the breadth and depth of human skills and capacity grows, so grows resilience and adaptive capacity.
- *Social capital is a key determinant of resilience to climatic shocks and stress.* Family and informal social networks, community groups, self-help groups, effective local decision-making bodies and institutions were each identified as important resources for building and preserving the capacity to cope with climate impacts.

Hence, in a broad sense, the case study results demonstrate that integrated development measures – those that sought to enhance sustainable livelihoods at multiple levels – can significantly increase community coping capacity in the face of drought conditions. Specifically, the case study research revealed practical adaptation options that are effective to increase resilience to climatic shocks in Sudan's vulnerable communities, and should be considered as priority interventions within adaptation policymaking dialogues in Sudan.

3.1.2 Community Based Adaptation in Africa

This research effort was part of a regional adaptation research project that involved eight African countries (Kenya, Sudan, Tanzania, Uganda, Malawi, South Africa, Zambia and Zimbabwe). The project was initiated by the International Institute for Environment and Development (IIED) and involved major African NGOs in the eight countries as well as some international scientific and advisory institutions such as the Stockholm Environment Institute (SEI) and the Bangladesh Centre for Advanced Studies (BCAS).

3.1.2.1 Research design

The Sudanese Environment Conservation Society (SECS) was the host institution for the project and was responsible for research design. The effort consisted of three major objectives as summarized below.

- *Enhanced local capacity:* This involved improving the capacity to understand and adapt to climate change, through improved livelihoods and natural resource management, reduced vulnerability to climate change and enhanced capacity to cope with its impacts in the vulnerable African communities;
- *Enhanced regional capacity:* This involved improving the capacities of African scientists, research organizations, local and national NGOs, decision-makers and policy institutes to conduct research on vulnerability and adaptation, support climate change adaptation initiatives, and communicate research results to other stakeholders; and
- *New methods and tools:* This involved the development of products/tools for integrating climate information into development activities including workshops/dialogues with policy makers and other stakeholders.

The project applied a methodology called LOCATE (Local Options for Communities to Adapt and Technologies to Enhance Capacity) which combines top-down and bottom-up research approaches. Top-down secondary data was gathered (e.g., national climate change reports, national development reports, climatic trends) to conduct initial vulnerability assessment/mapping to identify and select priority communities. Bottom-up, location-based qualitative data were then used to confirm the presence of vulnerability hot-spots in consultation with the members of the community. The combined outputs of this process then formed the basis for the development of a Project Design Document recommending appropriate adaptation measures. Box 3-2 summarizes the vulnerability and adaptation profile for the selected community.

> **Box 3-2: Overview of the CBAA project site**
>
> The village of Mykahaya in Um Rawaba locality in Northern Kordofan State was selected. The top-down vulnerability assessment revealed that livelihoods have been affected by frequent drought cycles and extreme fluctuations in rainfall and floods. The bottom-up assessment identified several aggravating socioeconomic, namely high poverty and illiteracy rates, lack of income diversity and agricultural inputs, and chronic conflict over resources between farmers and herders.
>
> Based on community feedback, the most vulnerable sectors were water, agriculture, and energy. Villagers understood that their current coping strategies were actually contributing to a deepening of their vulnerability to climate change, particularly regarding food security. Specific adaptation options that emerged focused on improvement of water harvesting, introduction of drought-resistant seeds, enhanced cropping patterns, increased income diversification, and increased awareness of sustainable coping strategies.

3.1.2.2 Major findings

The major themes that emerged from a synthesis of the results are summarized in the bullets below.

- *Awareness raising*: The project played major role in rising awareness about climate change at both the community and state level. The project also contributed to awareness raising at the national level through conferences, meetings and workshops.
- *Training*: Training packages aimed at diverse audiences were produced both in English and Arabic and were utilized for capacity building of NGOs as well as academia and policymakers.
- *Institutional linkages*: The project was able to develop and strengthen linkages between the community and government organizations such as the National Forest Corporation and the state-level ministries overseeing natural resources, water, and agriculture; linkages that were virtually non-existent prior to the project.
- *Methodological enhancement:* The project also sought to contribute to the development of adaptation research methods. As a result of applying the LOCATE method, the project was able to develop specific recommendations for refinement and dissemination to enhance and improve the approach, particularly regarding the monitoring and evaluation component.

3.2 National adaptation planning

There have been two major adaptation planning initiatives that have taken place in Sudan in recent years. Over the period 2003-2007, Sudan prepared and submitted its National Adaptation Program of Action (NAPA), which identified urgent and immediate adaptation initiatives. Also, since early 2011,a Sudanese climate change network has been established in Sudan to focus more attention on adaptation planning, including capacity building, awareness-raising among government institutions, and strategic outreach to media.

3.2.1 National Adaptation Program of Action

As a least developed country, Sudan was supported by the Least Developing Countries Fund (LDCF) and UNDP to prepare its NAPA. The overall goal of the NAPA process in Sudan was to identify (urgent)priority activities to promote adaptation to climate change within the context of the country's sustainable development priorities. The NAPA process emphasized stakeholder engagement, planning, awareness raising, capacity building and identification of potential adaptation projects for subsequent implementation through the LDCF.

3.2.1.1 NAPA process design

The NAPA was implemented in five States (Central Equatorial, River Nile, Gedarif, South Darfur and North Kordofan States) representing five different ecological zones. The process of preparation involved extensive consultations with stakeholders within the five states on the vulnerable sectors of water resources, food security/agriculture and public health. Initial efforts focused on the characterization of six major current climatic stresses that are typically experienced by communities on a recurring basis, as shown in Table 3-1. Drought was widely recognized as the major climatic shock for which urgent adaptation measures are needed.

Table 3-1: **Extreme weather and climate events in Sudan types, frequency, sectors affected, and impact categories (Source: Government of Sudan, 2007)**

Event	Occurrence	Vulnerable areas	sectors	Impacts
Drought	Frequent	North & Western Sudan (North Kordofan and Darfur), Kassala State and some parts of the rain-fed areas in central Sudan.	Agriculture, livestock, water resources and health.	Loss of crops and livestock (food shortage), decline in the hydroelectric power, displacement wildfire.
Floods	Frequent	Areas within the River Nile basin and low areas from extreme South to far North. Mountain areas along Red Sea.	Agriculture, livestock, water resources and health.	Loss of life, crops, livestock; insects & plant diseases, epidemic/vector diseases, decline in hydro power; damage to infrastructure & settlement areas
Dust storms	Frequent	Central and northern parts of Sudan	Transport (aviation and land traffic)	Air and land traffic accidents and health.
Thunder - storms	Infrequent	Rain-fed areas throughout all Sudan	Aviation	Loss of lives and properties.
Heat waves	Rare	Northern, central parts of Sudan besides the Red Sea State.	Health, agriculture & livestock.	Loss of live, livestock and crops.
Wind-storms	Rare	Central and north central Sudan	Settlements and service infrastructure	Loss in lives, property; damage to infrastructure (electricity and telephone lines)

The process resulted in the identification of 32 potential adaptation projects. Of these, five projects were given the highest priority by stakeholders and were further characterized relative to their scope, major activities, and costs.

The NAPA process represents the first and thus far only national adaptation planning activity undertaken in Sudan. It offers a useful model by which to design future adaptation planning. Each vulnerable sector was systematically characterized, including the institutional, policy, and planning frameworks in need of reform.

3.2.1.2 Implementing NAPA priorities

The implementation of a subset of the highest priority NAPA projects began in 2010, with completion scheduled for 2013. This work has only been possible with the financial and technical support from the GEF-LDCF and UNDP-Sudan. Two sectors are being targeted, food security/agriculture and water as these sectors are affected by climate change increasing vulnerability among small farmers and pastoralists. Projects activities are unfolding in the states where the NAPA process itself took place. These projects are an essential first step in equipping poor communities in Sudan who simultaneously are the most vulnerable to and least responsible for climate change. Partnership and community participation in environmental issues expedite implementation processes and achieve community ownership and control over common resources.

Diverse activities are implemented in the targeted states which include: micro-fencing using dead Leptediniapyrotechnica stems to build fences that reduce the sand encroachment, rangelands reseeding, village nurseries for rehabilitation of rangelands were the most important practices for increasing the resilience of the community, with high involvement of community members (particularly Women).

- Shifting from total dependence on biomass energy to Butane gas units for domestic energy was a good practice reducing tree cutting for cooking, reducing sand dune movement. The practice is resulting in retarding of removed of vegetation cover and also resulting in reducing involvement of women in wood collection, and reducing cooking time and availing women time to be used in micro fencing and horticulture activities.
- Provision of water from ground water, drilling wells at Bara basin at North Kordofan, and pumping water from Atbara River at the Nile State to increase cultivated areas and establish community managed horticulture provide a viable practice for enhancing community adaptation to climate change through support to household food security and income.
- Promotion of water harvesting is a good practice in mitigating the effect of temporal and spatial variability of rainfall and the high risks on inter-seasonal dry spells, leading to increased crop yields in (Butana area in Gedarif State and Nyala surroundings in South Darfur State.
- Introducing drought resistant and early maturing vanities of crops and vegetables seeds.
- Livestock activities through vaccination against epidemic, strategic supplementary feeding and improved species.
- Best practices are already being identified such as small-scale irrigated farming, water harvesting, and introduced drought resistant seeds. Impact on communities is resulting in increasing resilience, increasing income and improving livelihood up scaling of above models is already taking place.

Sudan hopes to implement all the remaining adaptation projects that were identified as part of the NAPA process. Moreover, Sudan is in the process of considering options for the development of a comprehensive national adaptation plan that addresses all vulnerable sectors, not only those considered in the NAPA process. Clearly, the cost for implementing a broader set of adaptation measures is well beyond the national resources at the disposal of the Sudanese government. Therefore, it is imperative for developed countries to honor the commitments enshrined in the United Nations Framework Convention on Climate Change (UNFCCC) and fund the entire cost of adaptation. Such costs include financial, technical and technological support as well as capacity building to confront a changing climate, which is already adversely affecting poor communities in Sudan.

3.2.2 Sudanese climate change network

This network emerged from the participation of the Sudanese Environment Conservation Society (SECS) in the program entitled: Capacity strengthening for Least developed countries for Adaptation to Climate Change (CLACC). The program is in place in 15 African and Asian LDCs countries. After a year of CLACC activities, members established a climate change network to give more focus to national adaptation planning through training and capacity building of members as well as government and media institutions. Within Sudan, this network is called the Sudanese Climate Change Network (SCCN).

3.2.2.1 SCCN process design

The process of developing the SCCN has been primarily focused on information exchanges at multiple levels. Local and international experts in climate change issues have been invited to address the network’s members. In addition, network members have organized events to share their experiences with the public on effective approaches to climate change adaptation as well as discuss international experience in assessing the vulnerability of communities.

Moreover, some government institutions have been engaged to share planning information useful to local NGOs working on adaptation. The most prominent example is information provided by the Forest National Corporation regarding the Gum Arabic project for small producers, information which has proven valuable to many vulnerable communities in gum Arabic belt area.

Since its establishment in January of the year 2011, the network has conducted several information exchange events. These included training workshops related to vulnerability and adaptation to climate change, with the topical focus ranging from general to highly specific in nature. The SCCN has also organized advocacy events for climate change adaptation issues, particularly to raise awareness among media outlets.

3.2.2.2 Implementing SCCN activities

The network provides its members with up-to-date climate change information particularly those related to current status of international climate change negotiations as well as Sudan's positions on different issues under the discussion. The level of interest in climate change issues is increasing and it became part of the agenda of some of the national NGOs. Many of the members manage to utilize the provided materials and methods for helping their vulnerable communities.

The network became quite known and it received invitations from relevant networks and organizations for leading training on climate change issue for specialized group *e.g.* media, disaster risk management. It also built a lot of good relationships with many international NGOs and was able to implement many activities in cooperation with them.

3.3 Water resource vulnerability and adaptation

With half of Sudan’s population living on only 15% of the land, mostly near the River Nile, water resources are extremely important to Sudan’s continued economic development and social cohesion. While there remains uncertainty regarding the regional nature of future climate change, there is ample evidence to suggest that Sudan’s precious water resources are likely to be severely threatened as climatic change unfolds.

Water resources are considered to be vulnerable to climate change primarily due to the potential intensification of an imbalance between water availability from rainfall and the River Nile and water consumption for agricultural, industrial, and other productive activities. That is, based on the outputs of some global circulation models which show declining future precipitation patterns, a serious risk looms that future water supply will not be able to keep up with future water demand.

The rest of this section provides an initial assessment of the vulnerability of water resources to climate change, and immediate needs to undertake proactive adaptation. The discussion below builds upon the most recent IPCC findings, as well as an HCENR assessment carried out by a team of Sudanese scientists and researchers (Abdalla, *et al*., 2011).

3.3.1 Water supply and demand profile

Water supply comprises four main categories, namely the River Nile, other surface water, groundwater, and unconventional water. Each category is briefly described in the bullets below. Table 3-2 provides a summary of current estimates regarding annual quantities available for productive activities.

Table 3-2: Water supply in Sudan (Source Abdalla, 2011)

Water Supply Source	Quantity (bcm)
River Nile (Sudan share)	20.5
Wadi Waters	5 to 7
Renewable Groundwater	4.2
Alternative water	~0.0
Total	29.7 to 31.7

- *River Nile:* This is Sudan's primary water supply source. The average annual flow as recorded at Aswan is 84 bcm, of which 20.5 bcmis allocated to Sudan and 55.5bcmto Egypt, according to the 1959 Nile Water's Agreement between the two countries. About 75% of the Nile's annual flow occurs during the rainy season from July to October and originates from the Ethiopian Highlands as the Blue Nile. The remaining 25% of the Nile flow has less seasonality and originates from Lake Victoria in Uganda as the White Nile. The Nile exhibits extreme annual flow variations, with flows exceeding 150 billion cubic meters (bcm) in 1878-1879 and around 42 bcm in 1913-1914. These extremes motivated the construction of storage dams, including Sennar and Roseires on the Blue Nile, the Girba dam on Atbara, the Gebel Aulia dam on the White Nile, and the Merowi dam on the main Nile.
- *Wadi waters:* There are a large number of small streams outside the Nile Basin called Wadis, which have highly sporadic, short duration flows. Combined Wadis waters account for 5 to 7 bcm per year. In northeastern Sudan, the largest Wadis are the Gash and Baraka, which originate from Eritrea, with each having an annual average flow ranging from 200 to 800 million cubic meters (mcm), which occurs between July and Sept. In western Sudan, the Azum and Hawar are the largest Wadis ,having an estimated annual runoff of 500 to 750 mcm, respectively, during July and September. About half of Wadi Azum infiltrates into groundwater while the other half flows to Chad. Finally, there are over 300 small Wadis throughout the Red Sea region and the Savannah Belt with irregular flood flows in August, lasting but a few hours or days.
- *Groundwater:* Best estimates suggest that renewable groundwater supply is about 4.2 bcm per year. In the Nile region, groundwater is found in underlying alluvium formations and is primarily supplied and naturally recharged by the river. During low flow periods of the Nile, the direction of groundwater flow reverses and the flux of water is back to the river, from the groundwater. Groundwater depth varies from 3 to 20 meters. Groundwater is also found in Nubian Sandstones, the Umm Ruwaba Formation and scattered alluvial deposits. Basement Complex Formations, despite their impermeable nature, may also contain groundwater in fractured or weathered zones. Groundwater depth in these other formations varies anywhere between 10 and 200 meters. The quality of groundwater is generally good in Nubian Formations and alluvial deposits, ranging from 100 to 800 ppm of dissolved solids. In the Umm Ruwaba Formation, these values are between 100 to 5,000 ppm in specific areas.
- *Unconventional water sources:* These sources of water primarily include desalinated water and treated sewage effluent. The overall quantity of these types of water is negligible in comparison to the above sources. This is due to the fact that they are at a fairly early stage of development. That is, desalination occurs on in Port Sudan and sewage treatment only in some parts of Khartoum. There is a good potential for the future

development of these alternative sources of water, particularly in desalination, recycling and water reuse.

Water demand is driven primarily by three main categories, namely irrigated agriculture, the residential sector, and livestock/other. Table 3-3 provides a summary of estimates regarding annual quantities consumed in productive activities in 2012 and forecasted consumption in 2027. The profile of current and future water demand is briefly described in the bullets below.

Table 3-3: **Water demand in Sudan (Source: Abdalla, *et al.*, 2011)**

	Quantity (bcm)	
Water Demand Source	**2005**	**2027**
Irrigated agriculture	14.2	42.5
Residential sector	0.8	2.8
Livestock/other	0.2	7.3
Total	15.1	52.6

- *Current water demand:* Irrigated agriculture is by far the major current user of water in Sudan, representing about 94% of annual demand. The main irrigated crops grown are cotton, sorghum, groundnuts, sugarcane, wheat and horticultural. Many of these crops are grown in large agricultural schemes, areas that are expected to reach about 2.3 million hectares in the near future. Human consumption in the residential sector is estimated to be roughly 5% of total consumption. The needs of livestock and other uses (e.g., industrial production) make up the remaining 1% of total consumption. Current water consumption levels are below existing water supply.
- *Future water demand:* Sudan's 25-year Strategy (2002-2027) outlines ambitious development plans. Irrigated agricultural areas are projected to reach about 3.2 million hectares (about 4% of the arable land), with population expected to swell to 56 million. For agriculture, future water demand by irrigated agriculture would need to be about 42.5 bcm by the year 2027 (Abdalla, 2001), assuming current performance characteristics, with 2.8 bcm for consumption in the residential sector, and 7.3 bcm for animals and other activities. If the evaporation from proposed hydropower reservoirs is added (6.6 bcm), then the total demand would be 59.2 bcm. Quite apart from any climate change considerations, future water demands to satisfy development goals are well in excess of water supply. Any adverse impacts of climate change on water availability will further exacerbate an already daunting planning challenge.

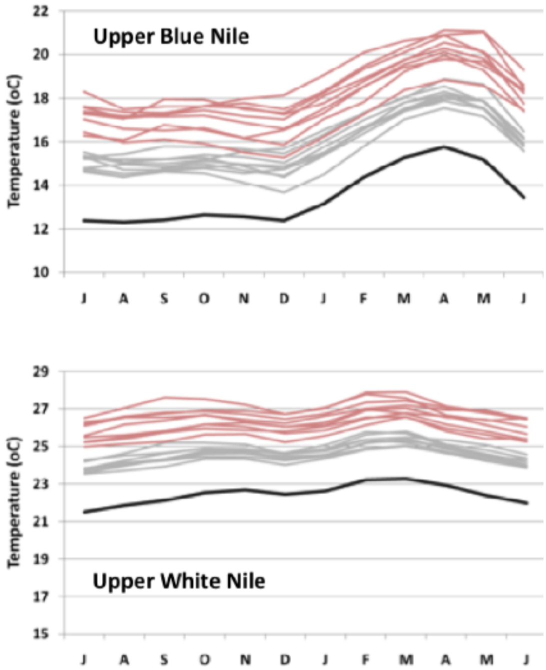
3.3.2 Major climatic hazards

There are two major climate change-related hazards facing water supply and demand in Sudan. These include changes in future temperatures that may adversely affect evapotranspiration rates at water storage location, as well as changes in rainfall patterns that may adversely affect surface water quantities flowing in the Blue Nile and White Nile as well as lead to drought in areas that practice rain-fed agriculture. To estimate future climatic change over the watersheds of major rivers and Wadis, a comprehensive analysis was conducted based on the three most extensively global emissions scenarios (i.e., A2, A1B, and B1) and downscaling of nine global circulation models (Abdalla, 2011) for 2050 and 2090. The results of the analysis are briefly described in the subsections below.

3.3.2.1 Change in temperature patterns

Figure3-1 shows average monthly temperature for each GCM run relative to the average baseline (1965-2005) period. Two projection years are shown, 2050 and 2090, for the Upper Blue Nile Basin (top chart) and the Equatorial region of the White Nile Basin (bottom chart). The baseline monthly temperature profile is indicated by the black lines. Projections for the 2050 period are shown by gray lines, one for each of the GCMs considered. Projections for 2090 for each GCM are illustrated by the red lines.

Figure 3-1: Monthly average temperature for the baseline and forecasted periods in Upper Nile regions



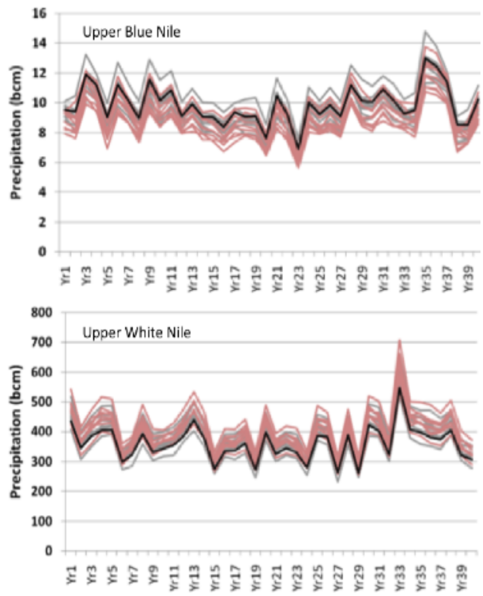
As can be seen in the Figure, monthly temperatures are projected to warm considerably throughout the 21st century in the region. In the watershed of the Upper Blue Nile, monthly temperatures are expected to rise between 1.5°C and 3.0°C by 2050 and roughly between 2.9°C and 5.8°C by 2090. In the Upper White Nile watershed, changes are similar; monthly temperatures are expected to rise between 1.0°C and 2.8°C by 2050 and roughly between 3.5°C and 4.5°C by 2090.

Hence, there is a clear and consistent tendency for considerably warmer conditions in the future over both the Upper Blue Nile Basin and White Nile Basin. This poses serious concerns regarding increased evapotranspiration over water storage areas that could lead to lower flows in the River Nile.

3.3.2.2 Change in rainfall patterns

Figures 3-2 shows average annual precipitation for each GCM run relative to an annual baseline (1965-2005). Two projection years are indicated, 2050 and 2090, for the Upper Blue Nile Basin (top chart) and the Equatorial region of the White Nile Basin (bottom chart). The baseline annual rainfall profile is indicated by the black lines. Rainfall projections for the 2050 period are shown by gray lines and the projections for 2090 are shown as red lines. As can be seen in the Figure, there is a tendency for drier conditions over the Upper Blue Nile Basin and wetter conditions over the White Nile Basin.

Figure 3-2: Annual rainfall for the baseline and forecasted periods in the Upper Nile regions



Hence, for the Upper Blue Nile, the combination of higher evapotranspiration rates associated with increased temperature, and lower annual rainfall suggests that water resources in this region will become increasingly vulnerable to climate change.

3.3.3 *Vulnerability of Sudan's water resources*

To assess the impact of the above projected changes in temperature and precipitation, a vulnerability assessment was conducted of the Nile and Sudan's other major river systems against the backdrop of two socioeconomic scenarios unfolding over a 40-year period covering 2010-2050, as summarized in Table 3-4(Abdalla, *et al.,* 2011). It was assumed that the lower and upper bound of climatic change that occurs over this period could reasonably be characterized as the projected temperature and rainfall conditions in 2050 and 2090. Key research questions of the study are summarized in the bullets below.

Table 3-4: Water supply and demand scenarios analyzed, 2010-2050

	Growth rate (%/year)	
Scenario	Population	Irrigated agriculture
No Growth	0.0%	0.0%
Modest Growth	2.0%	2.0%

- *Water demand:* How does projected water demand for productive activities compare to forecasted water supply?
- *Water supply:* What will be the estimated impact of climate change on future river flows of the Nile and major Wadis?
- *Water storage:* Will the water storage levels in the main reservoirs be adversely affected by climate change?
- *Hydropower generation:* Will the potential for hydro-based electricity generation be adversely affected by climate change?

To address these questions, a hydrologic simulation model was developed that used the future climate data discussed earlier as inputs to simulate water supply available in stream flow. Water demand for agricultural, residential, and livestock/other activities were represented and incorporated in the model to estimate future supply and demand balances. Finally, evapotranspiration effects were modeled relative to surface water storage levels and potential impacts on hydropower generation.

3.3.3.1 *Modeling framework*

The Water Evaluation and Planning (WEAP) Model was used to undertake the water resources vulnerability assessment. WEAP is an integrated water resources planning tool that represents current water conditions in a given area and can explore a wide range of demand and supply options for balancing future environment and development objectives under alternative climate scenarios. It has been widely used to model river basin overlain with water management network topology of rivers, canals, reservoirs, demand centers, aquifers and other features (Yates *et al.*, 2005a, 2005b).

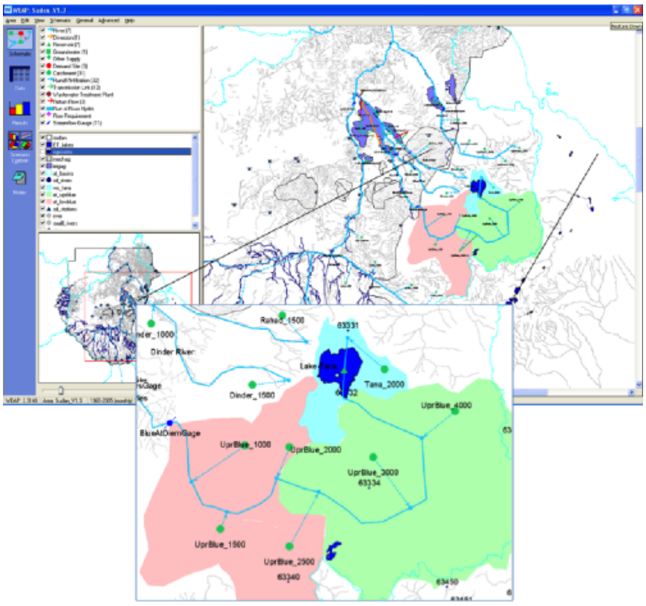
Figure 3-3 shows the overall domain of the study area, with the inset used to highlight the level of detail of the Blue Nile Basin. The upper portion of the Blue Nile basin is comprised of seven unique catchment areas that are used to characterize the hydrology of this region using downscaled GCM outputs to the appropriate banded catchment area.

WEAP modeling of climatic change on water resources involved the development of a large-scale water resources model that included climate-driven hydrologic models of the White Nile, Blue Nile, Atbara, and other rivers of the region. The model extended to the far southern headwaters of the Victoria Lakes region and northward through the SuddSwamp region of Southern Sudan, including the southeastern Sobat basin. The model also extends northward, including a more detailed representation of the arguably most important water supplies of Sudan- the Blue Nile and Atbara Basins. These basins contain the bulk of the irrigated agricultural and associated demands in Sudan and are sources of major hydropower generation.

3.3.3.2 *Impacts on total water demand*

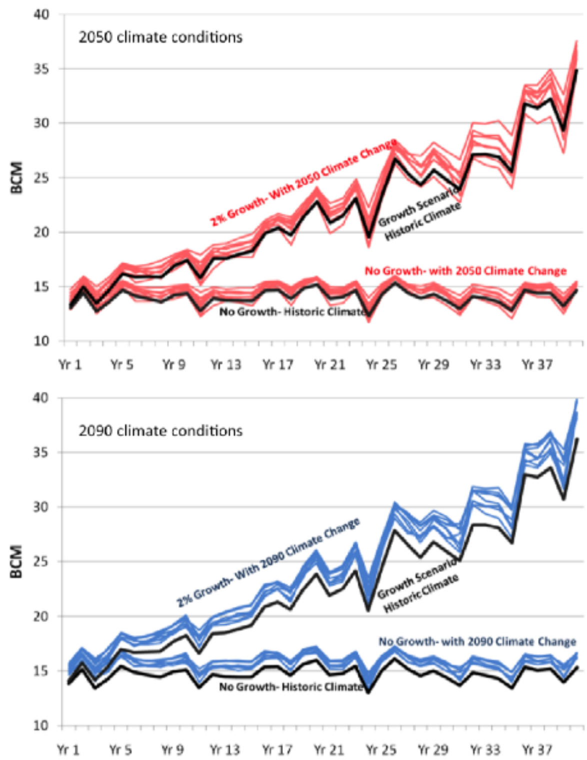
Figure 3-4 shows the projection of future water demand for both the projected 2050 and 2090 climate conditions in both the No Growth and 2% Growth scenarios. These figures highlight the fact that the assumptions regarding projections of future socio-economic growth strongly dominate the results over the assumptions of future climate change. The 2% growth in population and irrigated agriculture lead to water demands that exceed 30 bcm near the end of the 40-year period.

Figure 3-3: **Study area as represented in the WEAP model**



The various downscaled GCM outputs are not individually identified in the figures; rather they are presented as a set of individual ensemble members for both 2050 and 2090. For nearly all scenarios, warming leads to an overall increase in water demand relative to the reference cases. For climate conditions in 2050, some ensemble members lead to less overall demand, as increases in precipitation offset evaporative losses due to warming. On the other hand, with a 2090 climate, warming dominates the climate signal, as increases in precipitation do not overcome the evaporative losses.

Figure 3-4: **Total annual water demands under climate change conditions, 2% Growth and No Growth scenarios**



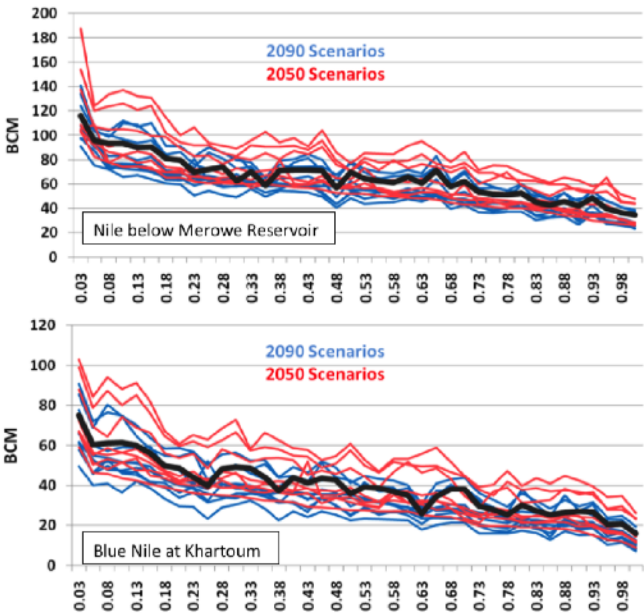
Hence, there is a clear and consistent finding that under all socioeconomic and almost all climatic scenarios, water demand will increase considerably. For 2050 and 2090 climatic conditions, water demand is expected to increase by up to 11% relative to baseline conditions. This poses serious concerns if it occurs against the backdrop of decreased river flows in the River Nile due to climate change. Since it is unrealistic to assume no future growth in Sudan, only the 2% Growth scenario was explicitly modeled to assess other impacts.

3.3.3.3 *Impact on River Nile flow*

Figure 3-5 shows flow exceedance curve for two points on the Nile for both the 2050 and 2090 projected climatic conditions. The horizontal axis of the figure shows the frequency with which river flow levels are exceeded; the vertical axis shows projected river flow levels. The top chart corresponds to the main stem of the Nile below the Merowe High Dam Reservoir north of Khartoum; the lower chart corresponds to the Blue Nile at Khartoum. The bold black line corresponds to historic average flow exceedance levels while levels under 2050 climatic conditions are represented by red lines and in 2090 by blue lines.

For the main stem of the Nile below Merowe, there are more scenarios with greater flows under 2050 conditions than 2090 conditions. On average, peak annual flows are about 20% less than historic levels under 2090 climatic conditions. For the Blue Nile at Khartoum, there is greater spread among the change in flow. There are several extreme low-flow scenarios on the Blue Nile, where the total annual flow never exceeds 60 bcm. On average, peak annual flows are about 30% less than historic levels under 2090 climatic conditions.

Figure 3-5: **Flow exceedance curves for two points along the Nile River under the 2% Growth scenario**



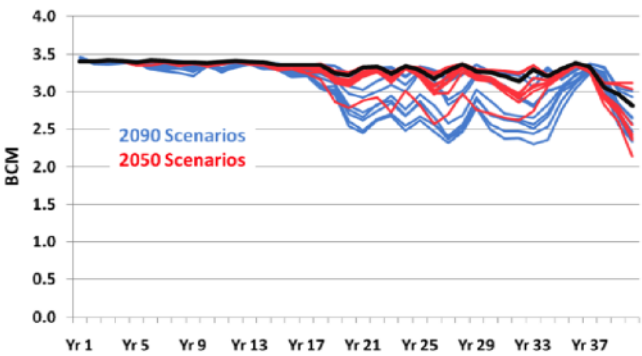
Hence, there is a clear finding that under many climatic scenarios, water flow in the Nile River will decrease considerably, between 20% and 30%. This circumstance, combined with the increased water demand discussed previously, suggests that risks of increasing water stress in Sudan over the next 40 years will need to be integrated into water planning and policymaking.

3.3.3.4 *Impact on water storage*

The total combined water storage in the main reservoirs in Sudan, including the Roseries, Senar, Girba, and Jebel Aulia reservoirs, is shown in Figure 3-6. The bold black line corresponds to the projected baseline levels.

By around the middle part of the 40-year evaluation period, storage becomes inadequate to meet the high demands, and the reservoirs are substantially drawn down. The drawdown is primarily driven by increases in water demand, but also due to the much warmer climate and the associated evapotranspiration rates. All but one of the 2050 scenarios shows similar storage to the reference scenario, while the 2090 scenarios show more dramatic drawdown.

Figure 3-6: **Total annual water storage in the Roseries, Senar, Girba, and Jebel Aulia reservoirs under the 2% Growth scenario**



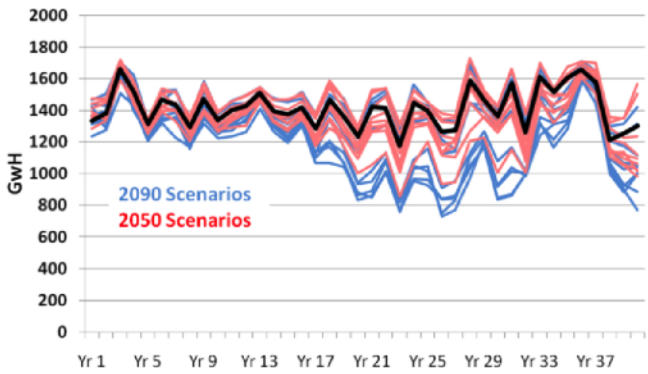
Hence, there is a clear finding that under all climatic scenarios, water storage will decrease considerably in Sudan, by about 40% starting around the year 2030. Efforts to increase water storage capacity are likely to face serious challenges due to greater temperatures and associated higher evapotranspiration rates.

3.3.3.5 Impact on hydropower generation

Figure 3-7 shows the total hydropower production for the same four reservoirs. The bold black line corresponds to the projected baseline levels of hydropower generation over the evaluation period.

For the 2050 scenarios, hydropower generation is near the baseline scenario, with releases made for downstream water demands. Several of the 2090 scenarios show fairly dramatic reductions in hydropower generation, with about a 35% reduction in total output, as the reservoirs simply do not store adequate water to generate enough electricity. Only a few of the scenarios show hydropower production exceeding the reference scenario, suggesting that the warmer conditions over the Blue Nile Basin in many of the scenarios lead to less overall water in storage.

Figure 3-7: **Hydropower generation in the Roseries, Senar, Girba, and Jebel Aulia reservoirs under the 2% Growth scenario**



Hence, there is a clear finding that under all climatic scenarios, hydropower generation will decrease considerably in Sudan. This will adversely impact national electrification efforts that seek to use a once-available non-GHG emitting resource.

3.3.4 Framework for climate change adaptation for Sudan's water resources

The results of the vulnerability assessment of Sudan's water resources suggest that significant steps should be taken to address the looming supply-demand imbalances that will arise due to climate change. Against the backdrop of the adaptation options outlined below, two fundamental capacity strengthening are essential. First, the capabilities of regional meteorological stations to monitor hydro-climatic variables should be enhanced in order to serve as effective inputs to proactive water planning. Second, the capacity of water planners should be strengthened in order to be able to implement modern concepts of Integrated and Adaptive Water Resources Management (IWRM/AWRM).

In the immediate near-term, government policy should be modified to promote the following adaptation actions regarding small-scale agricultural practices:

- *Water supply:* These include the introduction of new water harvesting/spreading techniques making use of intermediate technologies couple with the introduction of revolving micro-credit funds to support implementation of small water harvesting projects. Improved access to groundwater for both rural household and animal consumption should also be pursued through the installation of pumps.
- *Water demand:* These include the promotion of greater use of effective, traditional water conservation practices. There are good examples of successful measures already practiced

in certain areas; these should be extended to other areas through extension services and capacity strengthening for small-scale farmers.

For large-scale agriculture, government policy should be modified to promote the following adaptation actions in the immediate near-term:

- *Water supply:* These include the rehabilitation of existing dams as well as improvements in water basin infrastructure for increase water storage capacity, particularly in central and western Sudan. It also includes construction of new dams and water storage facilities in some valleys, particularly in western Sudan.
- *Water demand:* They also include the improvement of on-farm water management such as the use of modern irrigation systems (sprinkler and drip) and modernization of surface irrigation system through the adoption of canal lining, long furrow irrigation and optimization of field configurations. Finally, the reuse of treated wastewater from both municipal and industrial should be expanded.

3.4 Coastal Zone vulnerability and adaptation

Coastal zones in Sudan are threatened by climate change. With a length of about 750 kilometers, Sudan's Red Sea shoreline encompasses a spectacular diversity of relatively undisturbed ecological diversity, including coral reefs, mangrove forests, sea-grass beds and important feeding and nesting sites for a range of shorebirds. Portions of these areas are also becoming important centers for maritime transport, industrial development, and international commerce.

Climate change will further endanger Sudan's coastal zones through a range of adverse impacts on ecosystems, existing infrastructure, and future developments. Indeed, Sudan's vulnerability to the impacts of climate change on its coastline, given current socioeconomic conditions and projected population increases, is quite significant and raises important policy questions regarding current and future investment decisions. The rest of this section provides an initial assessment of the vulnerability to climate change of key coastal systems along the Red Sea, and immediate needs to undertake proactive adaptation. The discussion below builds upon the most recent IPCC findings as well as a recent PERSGA and HCENR joint assessment carried out by a team of Sudanese scientists and researchers (Nasr and Eltayeb, 2010).

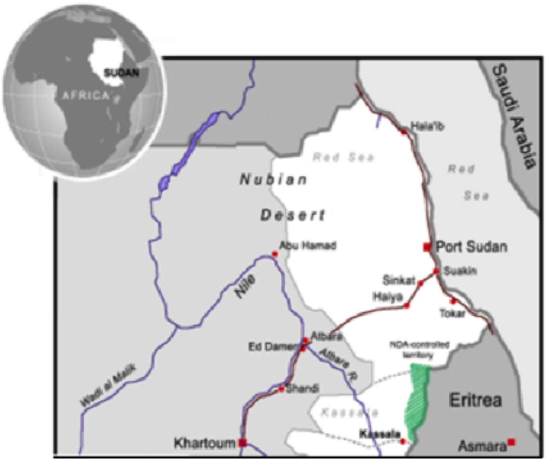
3.4.1 Coastal zone profile

Sudan's coastal zones are located entirely in its Red Sea State, a region located between latitudes 15°52′ North and 23°15′ North, and longitudes 33°15′ and 38°45′ (see Figure 3-8). The region covers about 218,887 square kilometers, borders Egypt to the North, Eritrea to the South, and is made up of eight administrative districts. The coastline itself is characterized by a large number of coastal lagoons and seasonal inlets, and is in close proximity to a number of Sudanese offshore islands that rise from the relatively deep water of the Red Sea.

The climate of Sudan's coastal zones differs sharply from its hotter and drier interior. Relative humidity ranges between 42-70%, with higher levels encountered in closer proximity with Eritrea. Mean annual rainfall ranges between 33mm/year in Hala'ib in the north (see Figure 3-8) to about 73mm/year in Tokar in the south; levels that are many times higher than those just west of the region

Red Sea surface temperatures are high, ranging from about 26.2°C to 30.5°Con average in the Port Sudan area. Average salinity levels range from 38% to 41% in the semi-enclosed sheltered bays and coastal lagoons (Nasr, 1982). These levels are greater than average levels found elsewhere in the world due to high rate of evaporation and very little precipitation, lack of significant rivers or streams draining into the sea, and limited connection with the lower water salinity of the Indian Ocean.

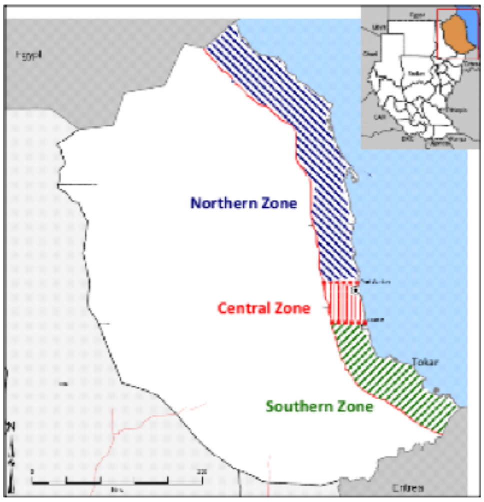
Figure3-8: **Sudan Red Sea coastline**



For vulnerability assessment purposes, the terrestrial environment of the coastal region can be characterized as consisting of three major zones, each of which is briefly described below and illustrated on Figure 3-9.

- *Northern Zone:* This zone consists of plains that stretch for about 300 km from Port Sudan to the Egyptian border. The plains range from about 10-30 km in width and contain patches of gravel and sand, as well as several rocky canyons, sand dunes, and low-lying hills. This zone is characterized by several small fishing villages along the coast, a rich variety of marine life, and sporadic saltmarshes and mangrove stands.

Figure3-9: Sudancoastal zones *(source: IMU-OCHA Sudan)*



- *Central Zone:* This zone consists of plains that extend for about 50 km from Port Sudan, the largest urban center along the coast, to Suakin. It is characterized almost entirely by flat sandy areas up to 30 km in width, with extensive saltmarshes in the lower reaches of valleys and sparse to dense mangrove forests. Small plots of rain fed millet and sorghum crops are also planted throughout the area, together with a few irrigated schemes at the base of the Red Sea Hills to the west. The plain is traversed by a pipeline, the Khartoum-Port Sudan railway, and contains the Port Sudan airport located inland about 15 km.
- *Southern Zone:* This zone consists of plains that extend from the small coastal town of Suakin to the Tokar Delta just north of the Eritrean border. It is characterized by flat sandy areas up to 20 km in width, yet is traversed by three large and poorly defined rocky canyons running from north to south. The vegetation in the rocky canyons consists of several plant species. The Southern Zone encompasses the Tokar Delta, a unique area consisting of fine silty soils that are nurtured by rainfall in the Red Sea Hills and Eritrean highlands and represents a rich cultivable zone for millet, sorghum, and other crops (FAO, 1999). This zone also contains the Tokar agricultural scheme.

3.4.2 Major climate change hazards

There are several major climate change-related hazards facing the Sudanese coastline, namely sea level rise, seawater temperature and salinity changes, and storm surge intensification. Each is briefly described in the subsections below. In addition, there are several other climatic hazards such a recurring drought episodes and flash flooding that are discussed in detail in other parts of this chapter.

3.4.2.1 Sea level rise

The IPCC estimates that the rising of average global sea levels are expected to continue at a significant rate for centuries, even if the climate system is stabilized (IPCC, 2001). The IPCC's Fourth Assessment Report posits an upper boundary for global mean sea-level rise of 0.59 meters rise by 2100, with a range between 0.1 and 0.9 meters depending on the combination of emission scenario and climate model used. The direct effects of sea-level rise on coastal zones will be increased water depths, changes in tidal variation (both mean tide level and tidal prism), altered water movement, and increased sea water intrusion inland(Short and Neckles, 1999).

In Sudan, observations confirm that local sea-level is already rising in the Red Sea. A review of limited data from Permanent Service for Mean Sea Level (PSMSL)for the Port Sudan area confirms that there has been a gradual increase in sea level, about 10-20 cm during the past century. Due to the unavailability of land survey data, it is unclear what role local uplift/subsidence plays in this estimate (Osman, 1984). Nevertheless, impacts from sea level rise should be quite noticeable along Sudan's coastline and any continuation or acceleration of sea level rise trends would jeopardize both natural systems and coastal development plans (El Raey, 2010). Moreover, erosion processes are expected to increase in coastal lagoons in the Central and Southern Zones, particularly the Tokar Delta.

Finally, abrupt or rapid sea-level rise constitutes a major potential problem facing coastal zones in Sudan. As the IPCC's most recent estimates do not include ice-sheet dynamics due to modeling limitations, the trends noted above may underestimate future sea levels. However, the continued melt of certain glacial types may lead to abrupt sea-level rise that could lead to sea level rise in excess of 10 meters in the period after 2100 (IPCC, 2007).

3.4.2.2 Changes in seawater temperature and salinity

Sea-surface temperatures are warming due to increased concentrations of greenhouse gases in the atmosphere (IPCC, 2007). Sea-surface temperatures (SST) play a vital role in coastal dynamics with respect to the interplay between temperature and sea levels as well as the health of many marine ecosystems. The IPCC estimates that thermal expansion will contribute more than half of the average sea-level rise as increases in sea-surface temperatures could reach up to 3°C by 2100(IPCC, 2007), changing the density and thus volume of the oceans.

Any increase in sea-surface temperature can lead to higher peaks of storm surges and a greater risk of coastal disasters. In the Red Sea, warmer sea-surface temperatures will lead to thermal expansion and will change the mean sea level along Sudan's coastline. Increased SST could also lead to higher peaks of storm surges, increased cyclone intensity, and a greater risk of coastal disasters. In addition, warmer waters will also undermine temperature-sensitive coastal ecosystem functioning.

Global climate change will also result in changes in seawater salinity (IPCC, 2007). Dissolved salt content influences how oceans react to warming such that there are regional differences and delays in thermal expansion depending on the salinity properties of a particular body of water (Berge-Nguyenet al., 2008).With the emerging consensus in the literature that tropic and sub-tropic regions have become and will continue to become slightly more saline (IPCC, 2007), such changes pose hazards to aquatic plants and animals in Sudan's coastal lagoons that do not tolerate high salinity.

3.4.2.3 *Intensification of storm surges*

The Eastern Mediterranean above the Red Sea area has been recognized as one of the world's active regions for cyclone activity (Krichak*et al.,* 1997). Several mechanisms like topography, convective processes, sea surface heat have been identified to be significant factors. The eastern Mediterranean region is characterized by the development of low pressure trough systems that can propagate to the Red Sea. In some cases the trough intensifies after establishing itself over the eastern Mediterranean and the development of a cyclone can take place. Nevertheless, the Red Sea area itself is not currently an area of cyclone activity and is not recognized as a region currently vulnerable to cyclone activity.

Some recent global climate model experiments suggest an increased likelihood of changes in tropical storms in the event of global warming (Royer et al., 1998;Elsner et al., 2008). Although the studies carried out so far are inconclusive on the likely changes in frequency of cyclones coming from the Indian Ocean, it is almost certain that an increase in sea-surface temperature will be accompanied by a corresponding increase in cyclone intensity. The IPCC has estimated a possible increase in cyclone intensity of 10-20% for a rise in sea-surface temperature of 2 to 4˚C. Any increase in sea-surface temperature can lead to higher peaks of storm surges and a greater risk of coastal disasters.

In Sudan, storm surges would lead to damaging flood conditions all along its coastline, particularly in high population areas like Port Sudan, as well as adjoining low-lying areas like the Tokar Delta agricultural areas. The destructive impact will be greater when storm surges, made higher due to increased sea levels, are accompanied by strong winds and large onshore waves. Recent GIS studies suggest that Sudan will experience roughly a 20% increase in its current storm surge zones (Dasgupta, et al, 2009).

3.4.3 *Vulnerability of Sudan's coastal zones*

Sudan's coastal zones are vulnerable areas given the increased certainty of sea level rise. The increasing concentration of infrastructure, industrial activity, and population render these areas vulnerable to impacts such as inundation, erosion, and flooding, and changes in sea surface temperature and salinity. Moreover, the intricate terrestrial and marine ecologies of coastal zones render these areas vulnerable to changes in seawater salinity levels and temperatures.

3.4.3.1 *Coral reefs*

Many shores and beaches of the Sudanese Red Sea coast are fringed by coral reefs and reef flats, which provide protection to shores from erosion by waves (see Figure 3-10). These reefs have been described as among the most diverse in the Red Sea (UNEP/IUCN, 1988), and supportive of a complex ecology. Although anthropogenic pressures on reef systems are generally moderate to low, a significant portion is estimated to be in poor health.

Corals are vulnerable to thermal stress and have low adaptive capacity. If sea-surface temperature increases 1 to 3°C, Sudan can expect to have more frequent coral bleaching events and widespread mortality especially because of coral systems' low adaptive, thermal adaptation or acclimatization by corals is unlikely (IPCC 2007).

Sudan has already experienced two catastrophic coral events associated with seawater temperature anomalies. The long-term prognosis for the survival of coral reefs with climate change, if summer seawater temperatures continue to rise, is not good. Some resilience can be assumed since reefs do exist and persist in this area of historic environment stressors such as extreme fluctuations in seawater temperature and high salinity (Goreau and Hayes, 2008) as well as frequent high turbidity. However, past bleaching events suggest that corals in the Red Sea may have probably reached their upper physiological temperature limit.

Figure 3-10: Coral reef in the southern Red Sea *(source: USAID photo gallery)*

3.4.3.2 Mangroves

Sudanese mangrove (*Avicennia marina)*forests are typically thin, ranging between 15 to 300meters in width and rarely exceeding 1-2km in length(see Figure 3-11). Sudan's mangroves have a high ecological value to the Red Sea and grow along major segments of the shore-line, on near-shore islets and fringing tidal inlets or creeks. The density and size of the stands increases towards the Southern Zone, which supports muddier soil conditions and receives more fresh water from surface run-off.

Figure3-11: Mangrove stands north of Port Sudan *(source: Nasr and Eltayeb, 2010)*

Mangroves play a vital role in the life-cycle of many valuable seafood species and provide a safe nesting, feeding and roosting site for many types of birds in Sudan. Mangroves also offer coastal production by reducing wave energy, from available data it is estimated that mangrove forest area is somewhere between the early FAO estimate of 500 km^2(FAO, 1992) and the more recent PERSGA estimate of 1,800 km^2(PERSGA, 2004) along the entirety of the Sudanese shoreline.

Sudan's mangroves have shown signs of decline in recent years (Bashir, 1998).Their vulnerability to external factors will likely increase with climate change-induced sea level rise. This due to the fact that root systems will be unable to take in oxygen and new trees will be unable to take root as seeds float in higher water (Gilman, et al, 2008). Additionally, any increase in extreme storms may induce erosion damage to the system.

3.4.3.3 Salt marshes

Sudan's salt marsh ecosystems are a hallmark of the country's coastal ecological and geological heritage and cover significant portions of the shore. Salt marshes in Sudan are highly productive areas found along the entire coastline at inlets and depressed areas (see Figure 3-12). They represent source of nutrition for fish, a roosting habitat for several species of shorebirds, and valuable shelter for migrant bird populations.

Typically, salt marshes exist at elevations just a few centimeters above/below high tide, can extend up to seven kilometers in width and contain a variety of vegetation that is highly resistant to salinity (e.g., *Aeluropuslagopoides, Sporobolusspicata*, and *Cyperusglomerata).*

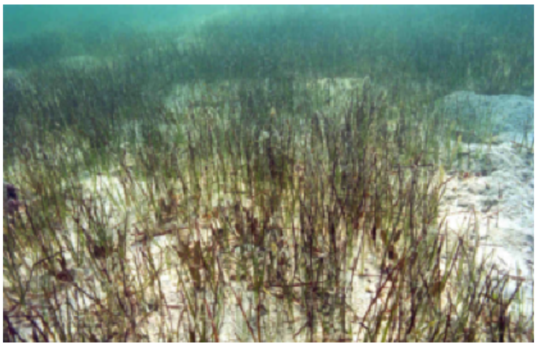
Figure3-12: Salt marshes north of Port Sudan ***(source: Nasr and Eltayeb, 2010)***

Coastal salt marshes in Sudan are vulnerable to sea level through several types of interrelated impacts. Flooding could serve to remobilize the fine sediments, increasing coastal turbidity and, in turn, affecting coral reefs, sea grass, and other marine biota. In addition to an increase in turbidity, the inundation of coastal salt marshes could create an extremely shallow sea along the coast. This, more shallow, body of water would be susceptible to strong heating and cooling and may exhibit associated density changes due to evaporation. Finally, as salt marshes are slightly above sea level, the lack of relief and altitude allows sea water to move inland during high tide, storm surges, and even more so with future sea-level increases. Any change sea level due to climate change will alter the evaporites that are at the core of ecosystem functioning.

3.4.3.4 Sea grass

Sea grasses in Sudan are found in shallow and sheltered waters especially landward depressed areas (see Figure 3-13). They represent direct food and shelter for many marine animals including water birds, fish and crustaceans, and the internationally important dugong and green turtles. They also form the basis of indirect food for many benthic organisms; their dead leaves fall, reach the bottom and are decomposed by bacteria to form detritus used by a variety of these benthic organisms. Commercially important fish and crustaceans use sea grass beds as nursery grounds.

Figure 3-13:Dense sea grass around Tokar Delta ***(source: Nasr and Eltayeb, 2010)***



Sea grass ecosystems have huge ecological importance for coastal areas of Sudan. They provide a stable coastal habitat, improve coastal water quality, and support fisheries production. The production of sea grasses also contributes to biodiversity (both plants and animals) as well as facilitates major nutrient recycling pathways for both inshore and offshore habitats. Sea grass detritus also provides nutrients and energy to salt marsh substrate, contributing to the development of storm-berms at seaward edges and supporting halophytic fauna and flora. In other areas, halophytic root systems help stabilize the substrate, which minimizes the effect of wind erosions and retains water in coastal soils (Phillips, 2002).

Sea grasses along the Sudan coastline are vulnerable to climate change in complex ways. A change in sea-surface temperatures could lead to altered growth rates, geographic distribution, and even impair physiological functions of the plants. A change in mean level, as it contributes to increased water depth, would lead to a subsequent reduction in light available for sea grass growth and could result in a 30±40% reduction in sea grass growth and productivity (Short and Neckles, 2002).

3.4.3.5 Key species

The marine environment along the Sudan coastline contains species that are currently diverse, healthy and abundant (PERSGA 1998). A brief review of key species that are considered particularly vulnerable to climate change is provided below.

- *Turtles:* The coastline also contains internationally recognized feeding and nesting grounds for the endangered green turtle (*Cheloniamydas*) and critically endangered hawksbill turtle (*Eretmochelysimbricate*;see Figure 3-14).
- *Birds:* it is estimated that there are 17 seabird species and 14 other water bird species found in Sudanese coastal waters such as the white–eyed gull *(Larusleucophthalmus;* see Figure 3-14), sooty gull (*Larushemprichii*), white-cheeked tern (*Sterna repressa*), brown noddy (*Anousstolidus*),and swift tern(*Sterna bergii*).
- *Marine mammals:* The Dugong (see Figure 3-14) is currently classified as a vulnerable marine mammal and is found around several Sudanese islands. Several species of dolphins are found including the common dolphin (*Dolphinus dolphin*), the Bottlenose (*Turspis truncates*) and the Humpback (*Sousa plumbea*).
- *Fisheries:* Fish communities are diverse, healthy and abundant along the Sudan coastline (PERSGA 1998). The Humphead Wrasse *(Cheilinius undulates),* currently considered endangered, is frequently encountered (see Figure 3-14). Angelfish *(Pomacanthidae)*, butterflyfish *(Chaetodontidae),* triggerfish *(Balistodiae)* are found at several locations while groupers *(Serranidae),*surgeonfish (Acanthuridae),nappers*(Lutjanidae),* and sharks are found throughout.

Figure 3-14: **Key species in Sudan's coastal zones** ***(from left: hawksbill turtle, white-eyed gull seabird, dugong, humphead wrasse coral reef fish)***

Each of the above species is vulnerable to climate change through the processes described earlier. For example, the variety of fish communities and the complex interactions they have with coral reef organisms will be adversely impacted by sea water temperature increases. The potential decline of mangroves due to rising sea levels will in turn impact the life-cycle of many valuable bird species that depend on these areas for safe nesting, feeding and roosting sites. Finally, potential increases in turbidity, water density, temperature, and salinity caused by sea level rise and other climate change phenomena will likely negatively affect sea grass growth and, in turn, may compromise the health of the dugong, other marine species such as turtles, and overall fish stock populations.

3.4.3.6 Built environment

Port Sudan is the Red Sea State's capital and is located at in the Central Zone of the coastal area. The coastal zone of Sudan hosts Port Sudan, a city that represents the only manufacturing base in the coastal region. The infrastructure of the Port Sudan area includes a major deep-water port, a pipeline transporting petroleum products to Khartoum, asphalt roads within and beyond the city, a railroad connection, hospitals, and a local airport. Its position has made it vital to the Sudanese economy as a transit point for oil exports and imports of commodities. Given that much of the infrastructure is located close to sea level, as well as with rising levels of investment and internal migration, the city is considered acutely vulnerable to future sea level rise impacts.

For the purpose of the assessment of the impact on the built environment, two plausible future sea level rise scenarios were developed. The first scenario is based on the upper bound of the observed sea level rise rates over the past century of about 2.0 mm/yr. This is consistent with an extrapolation of past trends evident in the area. The second scenario assumed a mean sea level rise rate of 6.0 mm/yr. This essentially conforms to a situation in which deglaciation rates increase, a key uncertainty in current modelling of sea level rise. Together, the scenarios are intended to bracket minimum and maximum expected rise in sea level and are tied to the findings of IPCC's Fourth Assessment Report. The sea level rise rates were then added to local high tide estimates (i.e., 0.27 meters above sea level, or half of the tidal range) to develop estimates of maximum sea level rise for the years 2030, 2060, and 2100. These levels are summarized in Table 3-5.

Table 3-5: Sea level rise scenarios for the Red Sea State

	Sea level rise over mean sea level in 2010 (meters)		
Scenario	2030	2060	2100
Scenario #1: Lower bound SLR rate of 2.0 mm/yr at high tide	0.32	0.38	0.46
Scenario #2: Upper bound SLR rate of 6.0 mm/yr at high tide	0.40	0.58	0.82

For the upper range of sea level rise, inundation risk is expected to affect a significant portion of land in the Port Sudan region. Primary hot spots at most risk include coastal beaches and the harbor, as illustrated by the various red-shaded areas in Figure 3-15. Inundation risk also affects other areas containing buildings, residential communities, and the Red Sea University, resulting in potentially substantial property losses in the absence of cost-effective adaptation measures.

3.4.4 Framework for climate change adaptation in Sudan's coastal areas

There are many levels at which Sudan is in need of adaptation in its coastal areas. Already subject to extreme temperature and changing climatic conditions, the coastal region will likely face more severe conditions with climate change as climate change impacts in its marine environment become increasingly evident.

Figure3-15: Inundation hotspots of the built environment in Port Sudan due to projected sea level rise *(source: Google Earth)*

3.4.4.1 Coastal adaptation goals and objectives

Hence, the overarching strategy for adaptation is the need to account for climatic risks in Sudan's policies, institutions and attitudes such that enabling conditions are established to respond appropriately. To pursue this, the Sudanese strategy for adaptation to climate has three major goals; first, build adaptive capacity in key vulnerable sectors; second, increase ecosystem resilience and reducing the risk of climate-related disasters; and third, mobilize and manage knowledge for adaptation policy and planning.

Developing a climate change adaptation policy around such aims will effectively integrate climate change risks into program planning within a cross-cutting adaptation framework.At the broadest level, this framework consists of the following objectives:

- Increase understanding of vulnerability of, and adaptation options for, the systems that have been identified in Sudan's coastal zones, namely coral reefs, mangrove forests, salt marshes, sea grasses, key species, and the built environment.
- Integrate/coordinate climate change adaptation objectives into planning frameworks so that existing codes/practices can be reformed to account for sea level rise, more frequent/intense storm weather events and their adverse impacts on the natural and built environment.

3.4.4.2 Major coastal adaptation strategies

Operationalizing the above goals and key objectives in Sudan's Red Sea State will require action in the face of uncertainty. That is, given the uncertainty inherent in the IPCC sea level rise scenarios and the qualitative nature of the vulnerability assessments undertaken thus far, an appropriate adaptation strategy for Sudan involves the introduction of a set of concrete "win-win" strategies that are consistent with both adaptation to sea level rise and sustainable development, and supported by international assistance. This would involve a strategic response coordinated across relevant ministries and sectors and consist of the following three major strategies:

- *New information systems:* This involves enhancing monitoring programs in natural and urban settings to detect biological, physical, and chemical changes and responses due to direct and indirect effects of climate change. This encompasses observation, analysis, and interpretation of trends in coastal water levels, elevation, shoreline change, wetland loss, and tidal influence on water supplies. The observation system should enable authorities in the Red Sea State to assess the responses of coastal landforms and biological systems to sea level rise and to the effects of any increases in storm activity.
- *Implement integrated coastal zone management (ICZM):* This involves an integrated approach to land use planning in order to increase the adaptive capacity and preparedness of coastal areas to respond to the threat of sea level rise. Projects under this policy action would support, for example, creation of ecological buffer zones, establishing protected inland zones to accommodate salt marsh, mangrove and sea grass migration, technology transfer, and establishing protected research reserves to improve understanding of how higher seas will impact ecosystems increasingly bordered by man-made infrastructure. Early versions of such plans have already been developed but without adequate consideration for climate change and have not yet been implemented due to institutional and regulatory barriers.
- *Building awareness:*This involves enhancing the awareness of coastal developers and real estate entrepreneurs through national and international workshops and conferences, training programs, online courses, technical assistance, and capacity-building.

3.4.4.3 Priority adaptation measures for Sudan's coastal zones

While each of the three strategies is a necessity for adaptation in Sudan's coastal zones, the most urgent is the first strategy, which focuses on the development of new information systems. This activity is fundamental to the other ICZM and awareness building measures.

Specifically, new information systems aim to enhance monitoring programs in natural and urban settings to detect biological, physical, and chemical changes and responses due to direct and indirect effects of climate change. This involves the observation, analysis, and interpretation of trends in coastal water levels, elevation, shoreline change, wetland loss, and tidal influence on water supplies. The observation system should enable the Red Sea State to assess the responses of coastal landforms and biological systems to sea level rise and to the effects of any increases in storm activity in the Red Sea. Specific elements include the following.

- Enhance inter-ministry integration and coordination of observation systems that detect trends in coastal water levels, coastal land elevation, shoreline change, wetland reshaping/loss, and tidal influence on water supplies and marine biological systems.
- Assess the installation of additional tide gauges in particular locations and software systems designed to coordinate data transfer between different vertical datums consisting of tidal, orthometric, and ellipsoidal datums;
- Develop a set of leading indicators of specific climate change impacts in the coastal environment and observe/record changes for those indicators. Indicators should be representative of specific geographic ranges or behaviors or population characteristics of certain species of plants, birds, and mammals sensitive to sea level rise and other climatic changes.
- Increase information of coastal systems through development of databases on coastal adaptation technologies and measures, preparation of planning studies, undertaking further sea level rise impact assessments, and raising awareness.
- Undertake an assessment of zoning, building codes, and other regulations to identify existing and future planning options and approaches within an integrated coastal zone management framework.

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4 Greenhouse Gas Mitigation

Article 4.1 of the climate change Convention requires all Parties, taking into account their common but differentiated responsibilities and their specific national and regional development priorities, objectives and circumstances, to formulate, implement, publish and regularly update national and, where appropriate, regional programs containing measures to mitigate climate change. However, with a status as a least developed country (LDC), Sudan is not obliged to pursue a GHG emission reduction target. Nevertheless, Sudan views the planning process to reduce GHG emissions as an opportunity to strengthen national capacity, promote sustainable resource management, facilitate technology transfer, and identify synergies between national economic objectives and sustainable development.

This chapter provides an overview of mitigation options and opportunities in both Energy and Non-energy Sectors. It also describes the followed mitigation methodologies and discusses issues related to the reduction of GHG emissions and enhancing carbon sinks.

4.1 GHG mitigation opportunities in the Energy Sector

The domestic consumption of refined oil products, across various demand sectors, account for all energy-related GHG emissions in Sudan. Since 1998, the use of fossil fuels has been increasing rapidly, about 8% per year (see Chapter 1). The intensification in fossil fuel use is particularly evident for electricity generation, which has been growing at an average rate of about 12% per year, with a significant share of power consisting of natural gas. Hence, the motivation for the GHG mitigation assessment is to better understand the GHG emission implications of these trends, as well as potential and relevant options in Sudan in its aim to meet future energy demands in a sustainable way. The summary below is based on a technical study by the national energy team (2010-2012).

4.1.1 Objectives, Data, and Methodology

The objectives of the GHG mitigation assessment in the energy sector are fourfold, as follows: to establish a Baseline Scenario of GHG emissions from energy-consuming activities; to identify a set of GHG mitigation options that are appropriate for Sudan; to quantify the GHG reduction benefits of those options, and to explore the changes needed in Sudan's policy, legislative and regulatory environment to achieve GHG reductions.

Most of the data required to undertake the assessment was acquired from the Ministry of Energy and Mining reports (1980-2009) and Sudan Energy Assessments (1980, 1995, and 2003). Additional data was obtained from experts who participated in the preparation of these reports as well as from household energy survey results in the different states of the country. Physical properties of fuels (e.g., GHG emission factors, energy densities)are based on IPCC default factors.

Basic parameters and assumptions regarding future development in Sudan (e.g., population growth, electric capacity expansion, transport sector characteristics, etc.) were sought from official sources and combined with expert judgment where such information was unavailable. Performance characteristics of mitigation technologies (e.g., combustion efficiency) were obtained from a range of international sources.

A bottom-up methodology was selected to assess GHG reductions benefits. Due to resource and time constraints, the assessment was limited to GHG reductions only (i.e., costs were not considered). The Long-range Energy Alternatives Planning (LEAP) system, an energy accounting model developed by the US Center of the Stockholm Environment Institute, was used to conduct the analysis.

4.1.2 Baseline Scenario

Table 4-1: Energy-consuming sectors, end-uses, and fuels

Sector	End uses	Fuels
Household	▪ Cooking ▪ Lighting ▪ Cooling ▪ Other appliances	▪ LPG ▪ Electricity ▪ Woodfuels (biogenic)
Transport	▪ On-road (cars, trucks, buses) ▪ Off-road (trains, air)	▪ Gasoline ▪ Diesel
Industry	▪ Sugar ▪ Textiles ▪ Cement ▪ Oil exploration & mining	▪ Electricity ▪ Residual oil ▪ Kerosene ▪ Diesel ▪ LPG
Agriculture	▪ Pumping ▪ Irrigation	▪ Electricity ▪ Diesel
Construction	▪ Buildings ▪ Roads	▪ Residual oil ▪ Diesel
Services	▪ Commercial ▪ Government	▪ Electricity ▪ LPG
Power supply	▪ Generation ▪ Transmission	▪ Diesel ▪ Residual oil ▪ Hydro

The year 2000 was chosen as the Base Year for the energy GHG mitigation assessment. This is the same year that was chosen for the updated GHG inventory as described in Chapter 2. The Baseline Scenario (otherwise known as a Business-As-Usual Scenario) for GHG emissions extended from the Base Year of 2000 through 2030. This 30-year planning period was considered to be sufficient to project the impact of only existing policies in Sudan on energy use and corresponding GHG emissions associated with that use (i.e., assuming no GHG mitigation policies or measures are introduced).

The overall framework for the development of the Baseline Scenario is summarized in Table 4-1. There are seven (7) distinct sectors that are projected to be responsible for the overwhelming majority of future non-biogenic GHG emissions in Sudan. These emissions are primarily associated with the combustion of diesel, gasoline, residual oil, and liquefied petroleum gas (LPG). Biogenic GHG emissions from woodfuel combustion in households for cooking, while expected to be significant throughout the planning period, are not included in the Baseline Scenario.

The results of the Baseline Scenario are shown in Figure 4-1 and 4-2. Energy consumption across the seven sectors is expected to reach just over 13 million tonnes of oil-equivalent (TOE) by 2030 (see Figure 4-1). Diesel and gasoline, used primarily in the transport sector, dominate future growth in fossil fuels and account for over 70% of energy use by 2030. GHG emissions associated with this energy use trajectory are expected to reach just over 24 million tonnes of CO_2-equivalent by 2030, a 6-fold increase from year 2000 levels (see Figure 4-2). The transport and electricity together account for most of the growth in GHG emissions in Sudan, with these two sectors responsible for around 70% of projected GHG emissions by 2030.

4.1.3 Priority measures to reduce GHG emissions in Sudan

A number of potential mitigation measures were assessed relative to their capacity to achieve long-term GHG emission reductions in Sudan associated with energy use. Of these measures, five (5) were selected for quantitative analysis by the national assessment team based on three main criteria; ease of implementation, consistency with existing sustainable development objectives, and potential magnitude of emission reductions under Sudanese conditions. Each of these priority measures is briefly described below.

Figure 4-1: Projected energy use in the Baseline Scenario

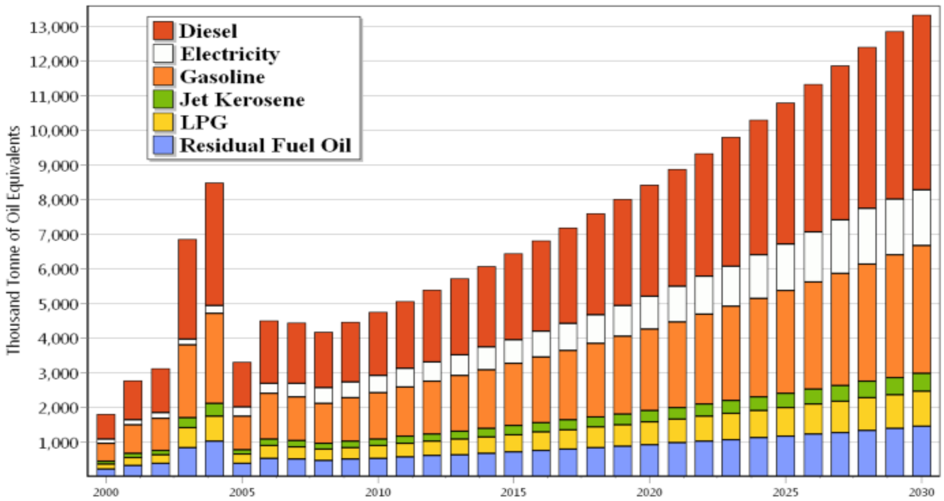
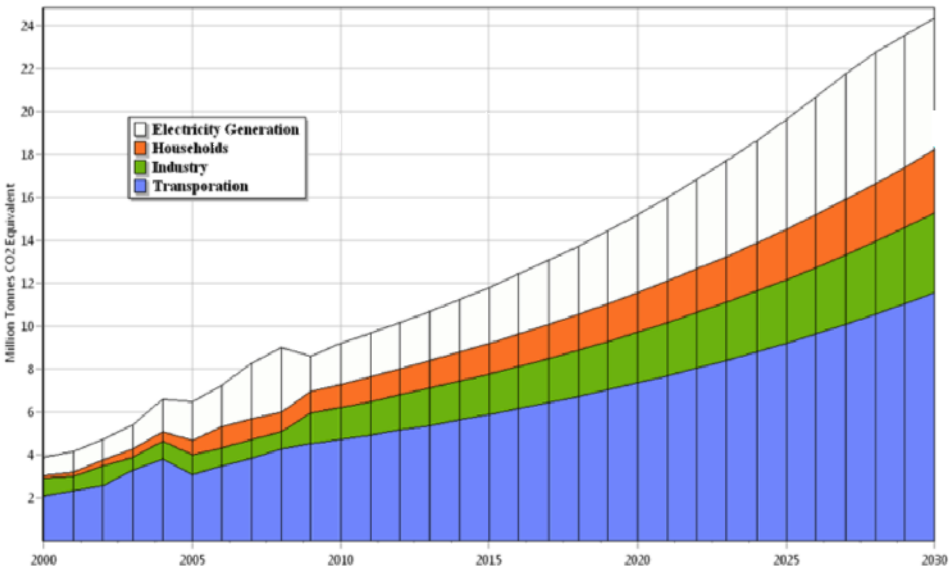


Figure 4-2: Projected GHG emissions in the Baseline Scenario



- *High efficiency air conditioning in the household sector:* Space cooling accounts for a significant share of annual electricity use in urban households. Typically, window-mounted air conditioning (AC) units are low efficiency and are rated between 12,000 and 24,000 BTU/hr. In year 2000, urban households consumed an average of 370 kWh annually for space cooling. By 2011, energy statistics indicate that this level grew over threefold reaching an average of about 1,230 kWh per urban household. By 2030, the average annual electricity use for space cooling is projected to be 3,110 kWh per urban household per year. An increase in the efficiency of space cooling can be achieved through a combination of price signals (i.e., taxation on imported AC units, full cost electricity pricing), technology substitution (i.e., switching to high efficiency evaporative cooling), and new building codes (i.e., passive solar housing design, advanced construction materials for new buildings). Phased in over the planning period starting in 2015, these policies are expected to achieve a decrease in energy intensity to 1,000 kWh per urban household per year by 2030, roughly one third of what it would otherwise be in that year.

- *Compact fluorescent lighting in household sector:* Lighting accounts for a significant portion of annual electricity use. Typically, households use low-efficiency incandescent lighting due to their lower costs compared to more efficiency alternatives. In year 2000, urban households consumed an average of 122 kWh annually for lighting. By 2011, energy statistics indicate that this level grew over three fold reaching and average of about 410 kWh per urban household. By 2030, the average annual electricity use for lighting is projected to be 1,036 kWh per urban household per year. An increase in the efficiency of lighting can be achieved through policies that promote the widespread penetration of compact fluorescent (CFL) and other high-efficiency lighting technologies (i.e., full cost electricity pricing, lower tariffs on high-efficiency light bulbs). Phased in over the planning period starting in 2015, these policies are expected to achieve a decrease in energy intensity to about 310 kWh per urban household per year by 2030, roughly one third of what it would otherwise be in that year.
- *Fuel switching in industrial subsectors:* Residual fuel oil is used heavily in the sugar, food, textile, cement and other industries in Sudan. In year 2000, these industries consumed about 66 thousand TOE annually of residual oil for heat production. By 2011, energy statistics indicate that this level nearly doubled reaching about 136 thousand TOE. By 2030, the total annual consumption of residual oil is projected to reach more than 300 thousand TOE. Fuel switching to LPG, a fuel with a carbon intensity roughly 17% less than that of residual oil, can be achieved through policies that incentive LPG use in the industrial sector (e.g., price subsidies, lowering of regulation barriers, encourage replacement of old and inefficient boilers). Phased in over the planning period starting in 2015, these policies are expected to gradually lead to a maximum of 50% of residual oil being replaced by LPG by the year 2023.
- *Increased use of public transportation:* On-road transport accounts for the majority of diesel and gasoline use in Sudan. In year 2000, about 600 thousand TOE of diesel and gasoline were consumed for the range of transport modes. By 2011, energy statistics indicate that this level more than doubled to about 1,400 thousand TOE. By 2030, the total annual consumption of gasoline and diesel for transport activities is projected to reach 3,500 thousand TOE. Shifting passengers from using mini buses and private cars to use public transportation can be achieved through import tariff reform (i.e., car import restrictions, increased taxes on private vehicles, lower import taxes on high capacity buses) and vehicle registration policies (e.g., new requirements for older vehicles, incentivize the establishment of new public transportation companies). Phased in over the planning period starting in 2015, these policies are expected to gradually lead to a 10% reduction in gasoline and diesel use by the year 2030.
- *Increased fuel economy of the light duty vehicles:* Improving the average fuel economy of light duty vehicle stock in Sudan can be achieved through traffic demand policies (e.g., special lanes for bus rapid transit to increase its speed, improved traffic flow through synchronized traffic lights, time-based one-way traffic directions, car movement restrictions to downtown areas), import policies (i.e., restrictions on the importation of low fuel economy light duty vehicles) and voluntary measures (e.g., awareness-raising of simple measures to improve performance such as maintaining proper tire air pressure, introduce solar films on car's glass windows to reduce AC usage). Taken together such measures can improve current fuel economy from the current fleet average of 14.3 liters per 100 km to 8.3 liters per 100 km. Phased in over the planning period starting in 2015, these policies are expected to gradually lead to a 30% reduction in gasoline and diesel use by the year 2030.

4.1.4 Potential GHG emission reduction levels

A summary of the projected annual GHG emission reductions in 2030, and cumulatively over the 2015-2030 implementation period, is provided in Table 4-2 for the five mitigation measures. Transport sector measures account for the majority of GHG emission reductions, achieving nearly a 15% reduction in overall Baseline Scenario emissions in 2030. Taken together, the measures achieve total reductions of about 4 million tonnes of CO_2e by 2030, relative to projected emissions in the Baseline Scenario in that year. Cumulatively, 32 million tonnes of CO2e are avoided by the measures.

Table 4-2: GHG emission reductions from priority GHG mitigation options

GHG mitigation measure	GHG reductions (million tonnes CO2e) In 2030	GHG reductions (million tonnes CO2e) 2015-2030	GHG reduction in 2030 as percentage of Baseline emissions in 2030
High efficiency air conditioning	1.22	8.25	5.0%
Compact fluorescent lighting	1.10	7.99	4.5%
Fuel switching in industrial subsectors	0.32	3.70	1.3%
Increased use of public transportation	1.10	7.62	4.5%
Increased fuel economy of the light duty vehicles	3.15	21.63	12.9%
Total	**6.89**	**49.18**	**28.3%**

The results of the GHG Mitigation Scenario are shown in Figure 4-3 and 4-4. Energy consumption across the seven sectors is expected to fall to just under 9.7 million TOE by 2030 (see Figure 4-3). This represents a reduction of 3.6 million TOE relative to the Baseline Scenario. Most of this reduction is accounted for by lower diesel and gasoline consumption due to measures in the transport sector. GHG emissions associated with this energy use trajectory are expected to reach about 17.5 million tonnes of CO_2-equivalent by 2030. This represents a 4.5-fold increase from year 2000 levels (see Figure 4-4). While projected national GHG emissions still show substantial increases relative to the Base Year, they are significantly lower than those that would result in the absence of any measures to reduce GHG emissions.

4.1.5 Conclusions and recommendations

A key potential mitigation option that was not quantified in the GHG mitigation assessment is renewable energy potential for electricity generation and mechanical power. The Government of Sudan has formulated a 25-year strategic plan for the period 2002-2027, setting goals for overall economic development. Given Sudan's immense renewable energy potential, these sustainable resources (i.e., solar, hydro, wind, geothermal) should play a supportive future role to achieve economic development goals.

Another aspect that was not considered in the GHG mitigation assessment was the role of biogenic GHG emissions. Biomass energy in the form of firewood and charcoal continues to dominate overall energy use and is contributing to the significant degradation of rural areas. There is an urgent need to implement action programs aimed at reducing Sudan dependence on biomass fuels. Such measures can yield important environmental benefits and also contribute to the carbon sequestration. Moreover, fugitive emissions from crude oil production started in the year 2000 were not included, since mitigation requires adequate study to pin point exact measures.

Figure 4-3: Projected energy use in the GHG Mitigation Scenario

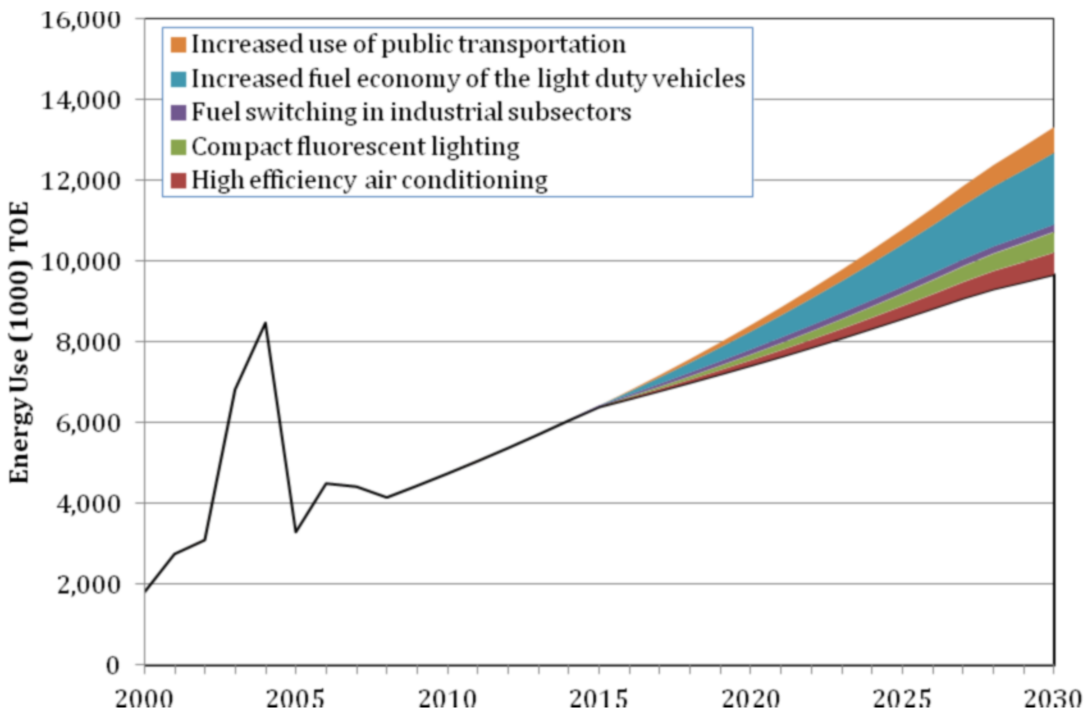
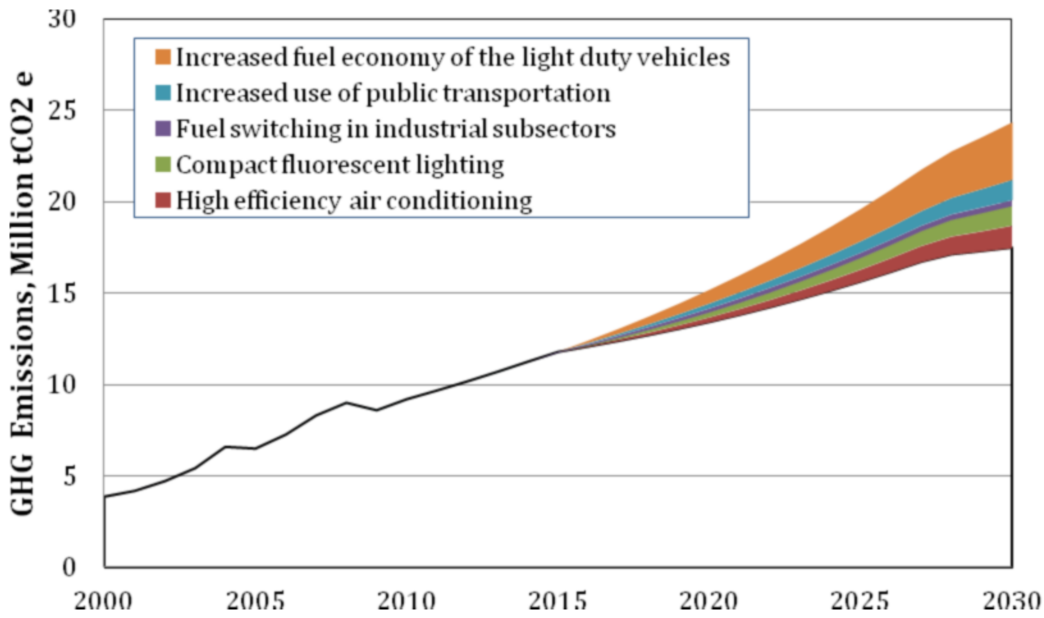


Figure 4-4: Projected GHG emissions in the GHG Mitigation Scenario



There are a number of recommendations that can facilitate future GHG mitigation assessments in Sudan. First, there is a need for greater institutional involvement and coordination. The data required for mitigation analysis is currently distributed across several key national institutions. A suitable mechanism to facilitate and implement coordination across these organizations needs to be formulated. Second, it is important to develop a database to develop an integrated inventory of available national data and resources currently spread out in various laboratories, ministries, universities and research institutes. Finally, additional funding should be solicited from international donors to assist in building awareness of critical GHG reduction projects and the development of project proposals.

4.2 Carbon sequestration opportunities in the forestry sector

Agricultural, pasture, and forested lands account for the major land uses capable of sequestering carbon in Sudan. Since the completion of a seminal project in the 1990s, which examined the carbon sequestration potential across various land types in Sudan, interest has been high among policymakers regarding the nation's ability to sequester carbon emissions in an arid Sahelian environment. This interest has intensified in recent years given the evolving debates in the Conference of Parties regarding the role of forestry options in stabilizing the climate system. Hence, the motivation for the carbon sequestration assessment is to better understand the costs and the benefits of embarking on ambitious carbon sequestration schemes that can be harmonized with national sustainable development objectives. The summary below is based on a technical study by the non-energy team, Abdelgadir, et al (2012).

4.2.1 Objectives, Data, and Methodology

The objectives of the carbon sequestration assessment in the non-energy sector are threefold, as follows: 1) to establish a Baseline Scenario of carbon sequestration from land use management activities; 2) to identify a set of sequestration options that are appropriate for Sudan; and 3) to quantify the carbon sequestration costs and benefits of those options.

The study area for conducting the mitigation analyses covers only the area between latitudes 10° to 22° north, comprising about 190 million hectares. The base year selected for the study is 2010, with a planning horizon of 30 years.

Most of the data required to undertake the assessment was acquired from national sources (e.g., Forest National Corporation, Range and Pasture Administration) as well as publicly available international sources (e.g., FAO's Global Forest Resource Assessment). Additional data was obtained from experts involved in land use management activities. Basic parameters and assumptions regarding future development in Sudan's forestry, agriculture, and rangeland sectors were sought from official sources and combined with expert judgment where such information was unavailable.

A bottom-up methodology was selected to assess carbon sequestration benefits. Both the incremental sequestration levels as well as the associated costs to achieve those sequestration levels were considered in the assessment. The Comprehensive Mitigation Assessment Process model (COMAP), a spreadsheet model developed by the Lawrence Berkeley National Laboratory for evaluating carbon sequestration options in the forestry sector, was used to conduct the analysis.

4.2.2 Baseline Scenario

Sudan has experienced significant political, economic and social changes, with the separation of its southern region into a new country, South Sudan, now a reality. However, the full nature and features of this separation are not yet clear relative to land use implications. This uncertainty, coupled with the unavailability or inconsistency in information/statistics, complicated the development of a Baseline Scenario for land use, making it difficult to quantitatively establish forested areas even in the very near future, and especially difficult to develop with any certainty through 2040, the end year of the assessment.

Nevertheless, future changes in land use were estimated based on the extrapolation of current trends and available sectoral plans. Without the area of South Sudan, there is currently a total of about 189 million hectares of agricultural lands, rangelands, and forests on which potential carbon sequestration activities could be implemented up through 2040. However, not all of this land is currently available or is expected to be available throughout the planning period.

A little over one third of this area is projected to be technically available, as briefly described in the bullets below.

- *Agricultural land use:* In Sudan, arable land constitutes about 80 million hectares, or about 27% of total available area on which potential carbon sequestration activities could be undertaken. While the majority of Sudanese farmers depend on rain-fed farming, a large modern mechanized rain-fed agriculture has been developed since the 1940s. Only 20 million hectares of arable land is currently used for crop production, with a little less than 4 million hectares devoted to intensive irrigated agriculture. Hence, there is a maximum of about 60 million hectares of agricultural land in Sudan that could be available for the implementation of carbon sequestration activities.
- *Rangeland use:* Grazing lands in Sudan constitute about 146 million hectares, or about 49% of available area on which potential carbon sequestration activities could be undertaken. Of this total, grasslands currently account for about 53 million hectares and woodlands that are characterized by scattered trees and shrubs account for the remaining 93 million hectares, a significant portion of which is considered forestland. However, Sudan's nomadic and transhumant communities rely on about 75% of grasslands and woodlands. Hence, there is a maximum of about 24 million hectares of rangeland in Sudan that could be available for the implementation of carbon sequestration activities.
- *Forestland use:* Forests constitute about 70 million hectares in Sudan, or about 24% of available area on which potential supplemental carbon sequestration activities could be undertaken. Unsustainable wood fuel use has led to a net deforestation rate of 0.5 million hectares per year for the period 2000-2008. Assuming this rate continues through 2040 and that only 50% of forests are available for managed plantations, there is a total of about 33 million hectares of forestlands in Sudan that is available for the implementation of carbon sequestration activities.

4.2.3 Priority measures to increase carbon sequestration in Sudan

Forestry options are considered the only priority carbon sequestration measure currently appropriate for Sudan. This is primarily due to the fact that forest management is highly strategic in Sudan and occurs within a broader national development context exhibiting strong links to sustainable wood fuel use, commercial gum Arabic production, industrial operations using wood products, and natural resource protection. A brief overview of the candidate tree species considered in the assessment is provided in the following bullets:

- *Acacia seyal:* This species is typically a thorny tree that grows between 6 and 10 meters high, has a pale greenish or reddish bark, and is tolerant to high pH levels (6-8). Natural growth extends from Egypt to Senegal. The species does best in heavy, clayey soils, stony gravely alluvial soils or humic soils. In Sudan, it also grows naturally in damp valleys. *Acacia seyal* is an important source for gum Arabic.
- *Acacia senegal:* This species is a small deciduous tree known by the common names Hasab, Gum Acacia, Gum Arabic Tree. It is native to semi-desert regions of Sub-Saharan Africa. It typically grows to a height of 5-12 meters, with a trunk up to 30 cm in diameter. The tree is the source of the world's highest quality gum Arabic. The species does best in clay plains and rocky hill slopes. In Sudan, it exists in the wild and is cultivated mainly on sandy hills.
- *Eucalyptus camaldulensis and Eucalyptus microtheca:* These species are native to Australia and typically grow to about 20 meters in height, occasionally reaching 50 m, with a trunk diameter between 1 and 2 meters. In open formations, they have a short,

thick trunk and a large, spreading crown. In plantations, they have a smaller truck with an erect, lightly branched crown. They are able to grow under a wide range of climatic conditions, from temperate to hot and from humid to arid zones.

4.2.4 Potential carbon sequestration levels and costs

Of the total land potentially available for carbon sequestration, only a fraction – not exceeding 1.4 million hectares – was considered as a practical limit for the assessment. A Sequestration Scenario was developed that considered the costs and benefits of four distinct carbon sequestration options. Three of the options correspond to afforestation/reforestation approaches in which certain types of land are afforested. The remaining fourth option corresponds to a forest protection approach in which existing forest reserves are protected from further degradation.

These sequestration options were developed in consultation with policy makers and forest planners, and thoroughly vetted with high- and medium-level managers in relevant institutions. Each is incremental to expected sequestration levels that would occur without any actions from current forest plantations. The options are also additional to each other, meaning that taken together they amount to 1.4 million hectares of incremental forested land. The options are briefly described in the bullets below.

- *Official reforestation: This* option considered afforestation in irrigated agricultural areas. Starting in 2010, an annual planting area of 20,000 ha/year is assumed to continue through 2040, totaling 600,000 hectares of newly planted area by the end of the planning period. Up to 70% of the planted species would be *Acacia seyal*, followed by up to 25% for *Acacia Senegal*, with the remaining 5% made of other indigenous species as appropriate. The new plantations would be managed in a 15-year rotation cycle, with the biomass stock density expected to reach 80 m^3/ha. After the trees reach 5 years in age, the agro-forested areas would be opened for livestock to graze the understory vegetation.
- *Community reforestation:* This option considered afforestation in rain-fed agricultural areas. Starting in 2010, an annual planting area of 20,000 ha/year is assumed to continue through 2040, totaling 600,000 hectares of newly planted area by the end of the planning period. The overwhelming majority of planted species would be *Acacia Senegal* in a 15-year rotation, with other *Acacia* species planted as needed. Since community forests typically display less wood production than commercial plantations, stock density is likely to reach only 50 m^3/ha by the end of the rotation. After trees reach 3 years in age, cereal crops would be able to be grown, with livestock grazing permitted after a minimum of 5 years.
- *Irrigated reforestation:* This option considered Afforestation in accordance with Sudan's Comprehensive National Strategy, which states that 5% of irrigated agricultural lands located in Nile-irrigated agricultural schemes or in areas irrigated by flooding of seasonal streams should be planted by forest trees. Starting in 2010, an annual planting area of 7,000 ha/year is assumed to continue through 2040, totaling 210,000 hectares of newly planted areas by the end of the planning period. *Eucalyptus camaldulensis* and *Eucalyptus microtheca* are the principal species to be planted, with a 6-year rotation.
- *Forest protection:* This option considered forest protection of the Khor Donia Forest Reserve in the Blue Nile region. The total area of the reserve is nearly 64 thousand hectares. About 25 thousand hectares have an adequate tree density of *Acacia seyal* and *Acacia Senegal* trees. The remaining 39 thousand hectares are essentially fully degraded. About 20 thousand hectares in total, or just over half of the degraded area in the Khor Donia Forest Reserve, would be protected through 2040 under this option.

Incremental carbon sequestration and the associated implementation cost effectiveness for the four additive options are summarized in Table 4-3. By 2040, it's clear there is significant potential for carbon sequestration in Sudan through afforestation measures. Combined, the four options cumulatively sequester around 71 million tonnes of carbon over the 30-year period. This is equivalent to the mitigation of nearly 260 million tonnes of CO2e, which is over 8 times the cumulative CO2e avoided from mitigation measures considered in the energy sector. Notably, these levels can be achieved cost-effectively in Sudan. Table 4-3 shows that the cost per tonne of carbon that could be sequestered in Sudan is about $2.2/tC ($182/ha), or roughly about $0.6/tCO2e.

Table 4-3: Carbon sequestration potential of sequestration options

Option	Land area planted (thousand hectares)	Carbon pool (million tC)			Incremental carbon uptake (thousand tC/ha)	Net present value of benefits (2010 US$)	
		Total Baseline	Total Sequestered	Incremental sequestered		$/tC	$/ha
Official reforestation	600	5.2	38.2	33.0	56	1.5	82
Community reforestation	600	5.2	30.1	24.8	41	1.3	107
Irrigated reforestation	210	2.2	13.8	11.6	55	6.3	692
Forest protection	20	0.5	1.6	1.1	55	0.2	17
Total	**1,430**	**13.1**	**83.7**	**70.6**	**49**	**2.2**	**182**

4.2.5 Conclusions and recommendations

As a developing country, Sudan is encouraged to increase the sequestration of greenhouse gases. Given its LDC status, Sudan is keen to consider sequestration only within its national priorities, such as poverty alleviation, providing basic facilities and health issues, as well as broad sustainable development priorities. With forestry, the study described above illustrates that there is a persuasive economic basis to seek to integrate carbon sequestration and national developmental objectives. The next step for Sudan is to identify and assess the specific legislative, regulatory, and policy initiatives needed to achieve the sequestration levels summarized in Table 4-3.

Such future evaluations should take place within the framework of a holistic evaluation of potential mechanisms, based on the national priorities and life cycle assessments and taking into account the macroeconomic impact of implementing the options. It is therefore recommended that a comprehensive study be undertaken to explore the changes needed in the policy and legislative environment to achieve full implementation of the proposed options. It is also recommended that the study address the macroeconomic benefits of ambitious forestry policies in Sudan (i.e., job creation, GDP growth). The results of the study should be able to assist policy-makers in the implementation of future national and sectoral strategies, and should contribute to the integration of carbon sequestration with environmental and development goals.

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5 Other Steps to Implement the Convention

This chapter provides other information relevant to the achievement of the objectives of the UNFCCC. The focus of the chapter is on education, training and public awareness programs, climate change research and systematic observation networks, and needed reforms to achieving the Convention's objectives. This information is based on two recent studies, conducted by the SNC project, of all relevant climate change activities taking place in Sudan within governmental agencies, academic institutions, and non-governmental organizations (Awad, (2010) and Sanjak, *et. al,*2010).

5.1 Education and training programs

The subsections below describe education, training, and public awareness activities within the major institutions within Sudan.

5.1.1 Governmental agencies

There are several key governmental organizations that have been involved over the past several years with various types of education and training activities. These organizations are briefly summarized in the bullets below relative to how climate change issues are incorporated into their operational roles, key activities, and networking initiatives.

- *Higher Council for Environment and Natural Resources (HCENR):* Established in 1992, this institution serves as a coordinating body for the development of national policies, strategies and legislation in the area of environment, ratification and implementation of multilateral environmental treaties (MEA) in Sudan, environmental management, building capacities of national institutions, dissemination and public awareness in the field of environment. HCENR is the focal point for the UNFCCC. It has organized several major climate change studies including the Assessment of Impacts and Adaptation to Climate Change (AIACC), the National Adaptation Plan of Action (NAPA), and National Communication Reports. HCENR's projects incorporate a substantial training component targeting professionals as well as the general public. In the future, the HCENR plans to conduct a technology need assessment, working collaboratively with other governmental agencies to address capacity and awareness building needs.
- *Sudan Meteorological Authority (SMA):* The SMA was established in 1890 for monitoring weather and undertaking climatic research. It provides short-term weather and climate forecasts for national planning, based on information collected from many monitoring station throughout Sudan. It also cooperates with regional and international organizations and is engaged with climate change science through field surveys, research, scientific articles, workshops, and seminars. It has developed strong links with international institutions such as the Intergovernmental Authority on Development (IGAD), International Climate Prediction and Application Center (ICPAC), African Center for Meteorological Application (ACMA), World Meteorological Organization (WMO) and International Development Research Centre (IDRC).
- *Forest National Corporation (FNC):* Established in 1902 as an executive body, the FNC exists to conserve, develop and sustainably manage Sudan's forest resources. The corporation is actively involved in reforestation programs, climate change adaptation and greenhouse gas mitigation programs. Workshops, seminars, scientific articles and field surveys are the main sources for exchange of climate change information. The FNC has a climate change department that is in close cooperation with the HCENR on training programs, national climate change strategy development, and technical studies. It has formal international links with the United Nations Forestry Forum (UNFF).

- *General Directorate for Planning and Agricultural Economics (GDPAE):* Situated within the Ministry of Agriculture and Forestry, GDPAE was founded in 1940 as an executive body for the development of Agricultural sector. Scientific articles, workshops, and seminars are the main sources for exchange of climate change information. The Directorate has no climate change strategy and programs but is developing a link with the HCENR as the climate change focal point. To date, GDPAE has organized a training and awareness workshop about the impact of climate change on agriculture.
- *National Ozone Unit (NOU):* The NOU was established in 1995,in collaboration between HCENR and the Ministry of Industry and hosted in the latter, as an executive body dealing with the daily administration of national efforts to phase out ozone-depleting substances. The unit is responsible for enacting and enforcing regulations/policies concerning the phase-out of HCFs, a GHG with a high global warming potential. The unit carries out field surveys, organizes workshops and seminars to collect and disseminate information. The NOUis under direct supervision of the HCENR and has good international links with the ozone secretariat, African Network for Ozone Depletion Substances (ODS), and the convention Secretariat.
- *General Directorate of Environment and Safety (GDES):*Located within the Sudanese Petroleum Corporation in the Ministry of Energy, GDES was established in 1999 as a small department and subsequently became an advisory board for environment and safety in 2003 and finally, a General Directorate in 2005. It is an executive body dealing with legislation in the field of environmental protection and safety in the oil industry. GDES is responsible to formulate legislation and performance standards. It is involved in climate change issues mainly through support of the development of updated GHG inventories and GHG mitigation analysis. The Directorate concentrates on field surveys, workshops, seminars and libraries as the main sources of climate change information. It has working relationships with the FNC and National Electricity Corporation (NEC). It has conducted joint training activities with HCENR, research programs with the University of Khartoum, and awareness workshops with the Sudanese Environment Conservation Society (SECS).

5.1.2 Academic institutions

At the primary school level, environmental issues and climate change are not typically addressed directly in educational curricula, though there is growing awareness of the need to increase the coverage of climate change issues more directly. The treatment of such topics are typically integrated within other sciences such as geography. Occasionally, it may involve the participation of pupils in drawings and essay contests dealing with environmental issues, of which climate change is part.

At the secondary school level, environment is an obligatory subject for obtaining a School Certificate of graduation. In addition, related topics such as environmental conservation and climate change are included within other subjects such as geography, physics, chemistry and biology.

At the tertiary school level, there are 77 institutions under the Ministry of Higher Education and Scientific Research (MHESR), including governmental and private sector universities/colleges. Most universities have only recently begun to integrate environmental studies into curricula. However, well-established universities like Khartoum, Juba, Gezira, Ahlia and Ahfad for Girls have had environmental components in their courses for some time. Some have established separate faculties for environmental and natural resource studies, including courses directly or indirectly related to the requirements of MEAs like the

UNFCCC. Examples of key departments within tertiary institutions that have made progress in integrating climate change into core teaching and/or research activities are briefly summarized in the bullets below.

- *Faculty of Forestry - University of Khartoum (UoK):* The faculty was established in 1994 as a result of upgrading the Department of Forestry in the Faculty of Agriculture. It is an academic and research institute offering BS, MS, and PhD degrees in Forestry. Aside from an undergraduate climate science course offered by the Meteorological Authority, there is no direct research dealing with climate change except at the dissertation level. The faculty works closely with the HCENR as members of Steering and Technical committees overseeing national strategy formulation, research and national communications. The faculty staff participates in workshops on awareness raising and technical studies on GHGs inventory, mitigation, adaptation organized by the HCENR.
- *Physics Department, Faculty of Science – Sudan University of Science and Technology (SUST):* This department offers undergraduate and post–graduate degrees in physics. Three members of the department's staff specialize in alternative energy, particularly solar energy, and its role as a GHG mitigation options. The Alternative Energy Program is carried out in collaboration with the Energy Research Institute of the Ministry of Science and Technology. Next year, the Department plans to launch a research program in the field of Alternative Energy jointly with Howard University in the USA.
- *Faculty of Environmental Studies – Omdurman Ahlia University:* The Faculty offers BS and MS degrees and maintains good links with HCENR in the field of climate change. At the undergraduate level, there is one course available on the socioeconomic impacts of climate change. At the postgraduate level, there is one course available on the science of climate change.
- *Center for Alternative Energy and Sustainable Development – Omdurman Ahlia University:* This is a research centre established in 2009 with the aim of conducting specialized research to develop alternative energy technologies that can contribute to sustainable development in Sudan. The center has developed a scientific relationship with the HCENR and has begun to develop joint research programs with Howard University in the USA.
- *Institute of Environmental Studies (IES) – UoK:* This is an academic and Research Institute offering post graduate degrees on Environmental Studies with number of its researchers involved in the issues of climate change such as GHGs inventory, mitigation, vulnerability and adaptation, and the UNFCCC negotiations. The IES has established strong ties within Sudan with the HCENR and the Remote Sensing Authority, and the SECS; at the international level, it has developed ties with the International Institute on Environment and Development (IIED). IES activities are targeting national climate change issues. The institute is planning to establish a climate change center in the future.

5.2 Public awareness programs

Public awareness activities have been implemented primarily by governmental institutions, NGO's, and the media. Major programs are briefly discussed below.

5.2.1 Governmental agencies

HCENR is the key governmental institution concerning the implementation of climate change awareness raising activities. Main initiatives:

- *Public events:* These include a variety of workshops, national conferences, and seminars that have been organized as part of its projects e.g. national communication process;
- *Information:* These include syntheses of research reports, special articles and project activities presented in public meetings, seminars and national conferences. They also include free brochures, newsletters and Elbeaa magazine on current climate change news.
- *Media:* Interviews of key HCENR staff and national experts regarding the UNFCCC and national climate change strategies/policies have appeared on television, radio, and print media
- *Targeted outreach:* Special workshops targeting specific groups (e.g. journalists) have been carried out to enable such strategic audiences to better understand climate change issues.

There are also several other government institutions that are playing a role in climate change awareness raising through workshops, seminars or other means. These include the Forest National Corporation, the General Directorate for Planning and Agricultural Economics, Ministry of Agriculture and Irrigation, Ministry of Water Resources, the Meteorological Corporation, the Ministry of Energy, Ministry of Industry, etc.

5.2.2 Non-governmental organizations

There are two major NGOs involved in climate change awareness raising activities. First, the Practical Action (PA) was established in 1966 at the international level in the UK and in 1988 at the national level as a civil society organization with a main vision concentrating on a world free of poverty and injustices in which technology is used for the benefit of all. PA first became involved in Sudan (as ITDG) during the mid-1970s, providing technical assistance to the regional government in building reinforced concrete boats for use as river transport on the Nile in south Sudan.

There are currently six members actively engaged in climate change awareness raising and capacity building of local communities and other stakeholders. Community-based adaptation projects with an emphasis on water harvesting projects are the main field activities of the organization. The organization has developed an excellent relationship with the Sudanese Environment Conservation Society (SECS), HCENR, Arab Alliance of Climate Change, Climate Action Network (CAN), Convention Secretariat, NGO's East Africa Desk and the Global Environment Facility (GEF).

Second, the Sudanese Environment Conservation Society (SECS) was established in 1975 as a civil society organization working in the areas of environmental awareness raising, demonstration of pilot initiatives in environmental conservation, lobbying and advocacy and environmental training. Six staff members are active in the area of climate change vulnerability and adaptation. For the past four years, the society has hosted activities associated with the international program entitled: Capacity Strengthening of Least Developed Countries (LDCs) for Adaptation to Climate Change (CLACC), an effort devoted to better understanding the impacts of climate change in urban areas and the economics of adaptation.

Under the CLACC program, SECS has organized a forum for Sudanese NGO's with the duel objectives of awareness raising and knowledge sharing regarding climate change issues. SECS also conducted a number of public awareness campaigns with support from HCENR highlighting the climate change issues. SECS in collaboration with HCENR celebrated many World Environmental Days and Arab Environment Days, the activities newspapers chief editors. SECS has a popular environmental program broadcasted weekly on the National

Radio Station (Omdurman Radio Station). The program started in 1994 and is still continuing broadcasting on all environmental issues including climate change.

5.2.3 Private sector organizations:

Recently, the private sector in Sudan has started to undertake serious steps towards implementing environmental and cooperative social responsibility policies and measures. Climate change has become an important area for some Sudanese companies. Three leading examples are cited below:

- Haggar Group is a group of seven companies working on food and beverages, engineering, oil services and other enterprises. In 2011, Haggar Group decided to conduct a GHG inventory of all its activities with the aim of implementing internal GHG reduction measures as well as working with other partners, e.g. civil society organizations, to offset GHGs and reduce the Group's overall carbon footprint. The result of the inventory showed total annual emissions of about 38,500 tCO2-e . Based on the results of this inventory, Haggar is currently working with one of the civil society organizations in north Darfour State on a project to offset GHGs emissions. This project addresses both GHG mitigation and adaptation by including components on forestry, improved stoves and water harvesting.

- DAL Group is one of the largest and most diversified private companies in Sudan. DAL Group operates across six business sectors - food, agriculture, engineering, real estate, medical services and education. DAL organizes a periodic Environmental Forum, which aims towards raising environmental awareness among business communities and promoting dialogue between business communities, government and other stakeholders, including research and civil society. The Environmental Forum hosts various esteemed speakers to address issues of global and societal concerns such as climate change, organic farming, sustainable development and others. A number of Forum sessions have been devoted to pertinent climate change issues such as the impact of climate change on food security and water, the clean development mechanism (CDM) and the role of business community in climate change adaptation and mitigation. In 2011, DAL launched the so called Go Green project, a tree planting initiative for its employees, in which 15,000 trees have been distributed for planting by its 5,000 plus employees. DAL also has a project called The Green Bakery, which contributes to GHG mitigation and improving the cost effectiveness of the traditional bakeries through promoting the use of LPG as a fuel instead of wood. The model has been extremely successful, creating cost savings for bakers as well as improving the work-place environment and the quality of their output.

- Kenana Sugar Company is the largest of six sugar companies in Sudan. Kenana has developed its unique diversified model by successfully integrating around the core sugar business other value added agro-industrial projects such as animal feed, bio-ethanol(50 million liters/year current capacity, expandable to 200 million liters/year by 2020), dairy products, poultry, meat, certified seeds and engineering goods and services. This is all poweredby a 75 MW bagasse-fired co-generation facility. Kenana is also working in the development of carbon offset projects targeting both the voluntary and CDM market to reduce emissions through cogeneration technology, waste management to reduce methane generation, and energy efficiency improvements.

5.2.4 Media organizations

As a result of the increasing frequency of extreme events worldwide and increased local interest, various media outlets have devoted more space in reporting climate change effects at global and national levels. Daily and weekly newspapers offer increasing coverage of a number of articles related to climate change and interviews with the local experts about the national context.

5.3 Key constraints and needs

The subsections below describe key constraints currently impacting education, training, and public awareness activities within the major institutions within Sudan, as well as a roadmap for change to overcome these constraints.

5.3.1 Governmental agencies

Sudan has a federal system of political governance. There are several levels within this emerging system that are perceived as broad constraints to collaborative action between the federal and state levels, including power sharing arrangements, and institutional coordination protocols. Within the particular area of climate change governance, key constraints include the following:

- *Unstable policy process:* Climate change is not well integrated in the national/state policy and planning systems, partly due to the continuous changes within government institutions related to climate change, lack of information and awareness.
- *Inadequate integration of MEAs:* At present, national development plans and strategies do not effectively incorporate MEA's such as UNFCCC.
- *Institutional fragmentation:* At the institutional level, there is a lack of awareness across institutions about the boundaries associated with the implementation of potential adaptation strategies, as well as training and public awareness raising activities.
- *Poor enforcement:* In most cases, laws and regulations are poorly enforced. This severely limits the effectiveness of strategies identified and approved to reduce GHG emissions and enhance resilience to climate change impacts.
- *Lack of capacity:* There is an overall lack of proper technology and number and qualifications of staff involved in climate change.

To address the above constraints, the following recommendations are offered that should be implemented in tandem with financial support from the Convention's Parties:

- *Pursue institutional reform:* There should be a reshaping of the vision and institutional roles of various government institutions working in conservation of natural resources at national and state levels. This should occur within the existing mandates of different ministries, with the addition of new terms of reference and substantial time period for policy implementation.
- *Enhance institutional capacity:* The capacity of key institutions such as the HCENR should be enhanced to improve coordination across national institutions, increase awareness among policymakers, develop/implement strategic training program, and meet other UNFCCC demands.
- *Pursue legislative reform:* Legal reforms should be enacted to facilitate the introduction of new laws and regulations aiming to reduce vulnerability to climate change, develop sustainable climate change information systems, and ensure compliance with obligations under the UNFCCC.
- *Develop robust information systems:* Systematic climate change knowledge and information systems need to be developed in order to meet Convention requirements for

GHG inventories, vulnerability and adaptation assessment, and GHG mitigation analysis. The creation of transparent and widely accessible internet-based data systems is imperative to meet this recommendation.

5.3.2 Academic institutions

Overall, the National Capacity Self Assessment (NCSA) concluded that root causes of all gaps and constraints for academic institutions comprise a lack of proper financing and the absence of a common vision and strong policies for the implementation of MEAs. Other key constraints are summarized in the bullets below.

- *Limited capacity:* Physical infrastructure is weak, lacking advanced facilities and information/communication technology to cope with emerging development issues; and human resources lack appropriate training.
- *Uneven research links and capacity:* Linkages between tertiary education and UNFCCC related education and research are not well established; and research is narrowly focused, as opposed to being multi-disciplinary, compatible with climate change as a strongly cross-cutting sector; staff interactions between universities and research institutions are informal rather than based on cooperative arrangements.
- *High faculty turnover:* Despite the low number of teaching staff and researchers that specialize in the field of climate change, staff turnover problems persist due to low salaries and lack of sufficient institutional support.
- *Information and policy limitations:* Higher education policies are not adapted to requirements of UNFCCC and do not adequately address sustainable development issues; there is little information on sustainable development in tertiary education; there is no standardized information system and database to promote institutional cooperation.

To address the above constraints, the following recommendations are offered that should be implemented in tandem with financial support from the Convention's Parties:

- *Develop multidisciplinary programs:* Universities should promote the integration of disciplines leading to multidisciplinary programs.
- *Establish specialized courses on climate change:* Advanced courses in environmental management should be developed on the topics of monitoring climate change impacts, introducing adaptive management, and mitigation in the agriculture and LUCF sectors. Such courses should incorporate indigenous knowledge and traditional practices as much as possible.
- *Reshape research priorities:* Research should be directed towards implementing sustainable development, and should include pilot projects that link researchers to communities and create partnering opportunities with the private sector, as well as research programs that foster the development networks between universities and research institutions.
- *Strengthen capacity:* Physical capacities related to infrastructure, communication and laboratory equipment for monitoring the different parameters related to climate change should be strengthened; Institutional capacity should also focus on training regarding achieving the Convention's objectives, including information technology and training of trainers courses.

5.3.3 Non-governmental organizations

NGOs in Sudan have been active in promoting conservation awareness and implementing valuable community-based natural resource management projects. If strategically supported, they could become effective lobbying and advocacy organizations regarding climate change in Sudan. Key constraints to realizing this potential are summarized in the bullets below.

- *Limited capacity:* The membership of NGOs typically consists of many young members, which, though full of enthusiasm, have limited technical capacity regarding climate change. Institutions capable of providing suitable training for such issues are largely lacking.
- *Weak institutional networks:* Coordination between NGOs and other institutions is limited, with many activities carried out within the framework of individual NGOs.
- *Limited resources:* Funding opportunities for climate change awareness initiatives and small scale adaptation projects is limited.

To address the above constraints, the following recommendations are offered that should be implemented in tandem with financial support from the Convention's Parties:

- *Build trust:* Efforts should be made to improve the relationship between government agencies and NGOs. Future collaboration should be based on commonly viewed areas of need, including climate change awareness raising and training projects. Government agencies should seek to create an enabling environment for greater involvement of NGOs.
- *Strengthen capacity:* Training packages should be formulated to build the capacities of the young members; the role of civil societies should also be enhanced through training, capacity building, and networking. New strategies should be developed to enhance funding opportunities.
- *Conduct needs assessment:* The development of a national survey to assess needs and requirements for implementation of article 6 of the UNFCCC is required. The results of such a survey can help to mobilize new partnerships for climate action.

5.4 Climate Change Research and Systematic Observation

The subsection outlines developments regarding research and systematic observation of the climate change in Sudan. The focus of the discussion is on existing/planned activities, gaps and any relevant steps taken to implement the UNFCCC convention.

5.4.1 Institutions

As discussed earlier in this chapter, climate change research is undertaken primarily in research institutions and universities, especially the older, government-run universities. However, several governmental institutes and centers run research pertaining to UNFCCC, most notably the Ministry of Science and Technology, which provides support for post-graduate fellowships for climate change. A comprehensive overview of institutions dealing with climate change is provided in Table 5-1. It is important to note that while universities and research institutions dominate climate change research activity, such research tends to be quite limited and not multidisciplinary in nature. Key features regarding research capacity are summarized in the bullets below.

Table 5-1: Universities, ministries, private sector companies, other governmental institutions, and NGOs active in the field of climate change

Type of institution	Name of institution
Universities and Research Institutions	▪ University of Khartoum (Institute of Environmental Studies, Institute of Development Studies and Research, Department of Geography) ▪ El Ahfad University ▪ El Nelain University ▪ Omdurman Ahlia University ▪ Sudan University of Science and Technology ▪ International University of Africa (Disaster management & Refugees Studies Institute) ▪ Energy Research Institute ▪ Industrial Consultancy Research Centre ▪ National Research Centre ▪ Agricultural Research Corporation ▪ The Desertification and Desert Cultivation Studies Institute of University of Khartoum ▪ University of Kordofan at El-Obeid
Government ministries	▪ Ministry of Science and Technology ▪ Ministry of Agriculture ▪ Federal Ministry of Animal Resources and Fisheries ▪ Ministry of Industry ▪ Ministry of Energy and Mining ▪ Ministry of Health
Other government Institutions	▪ Higher Council for Environment and Natural Resources ▪ Forests National Corporation ▪ Range and pasture Administration
Private sector companies	▪ AWASCO Company ▪ Petroedge Co. ▪ Khartoum Company for Water and Services
NGOs	▪ Practical Action (PA) ▪ Sudanese Environment Conservation Society (SECS)

- *Key research institution:* The Agricultural Research Corporation (ARC) is the most active research institute regarding the intersection between climate change and environment/natural resources. The El Hudeiba Research Station, one of the oldest stations of the ARC, has had a research program since 1972. In Kordofan, the ARC is the main actor for research through its two stations in El-Obeid and Kadugli.

- *Kordofan institutions: The* University of Kordofan at El-Obeid has initiated steps to establish a unit for remote sensing and geographic information system to address research related to climate change.

- *Darfur institutions:* Various research institutions in Darfur dealing with agriculture, animal production, forestry, rangelands, and wildlife could be capacitated to implement the different aspects of research and networking to address climate variability and climate change. Key institutions include the ARC, the Nyala and Al Fashir research stations, and the universities of Zalengi, Nyala and Al Fashir.

- *Red Sea and Kassala state institutions:* The research resources in these states possess limited technical capacities. Three main research stations have mandates relevant to climate change research, namely the Red Sea Fisheries Research Station in Port Sudan, the New Halfa and Kassala Research stations, as well as the State universities, (e.g. the Faculty of Marine Science in the Red Sea University).

- *Other institutions:* The Wildlife Research Center undertakes several areas of research, including wildlife ecology, biology, food habits, behavior, wildlife management, wildlife habitat, watershed management, diseases, and socio-economic studies. The most recent study was conducted in the Al Sabaloga Game reserve to evaluate climatic conditions and trends in variability, and its impact on wildlife and their habitats.

Regarding systematic observation, the Sudan Meteorological Corporation (SMC) is the sole institution in Sudan that is clearly mandated. The SMC has developed systematic observation records for temperature and rainfall through its eight monitoring stations distributed across the country. Table 5-2 provides an overview of the ecological zone in which the stations are located, together with the period of observation.

Table 5-2: Status of Systematic observations of the Sudan Meteorological Corporation

Station name	Ecological zone setting	Period of observations
Atbara	Desert	1908 - 2008
Khartoum	Semi desert	1901 - 2008
ElObied	Semi desert	1901 - 2008
El Fashier	Desert	1960 - 2006
El Gadarif	Low rain savanna	1913 - 2008
Kassala	Semi desert	1901 - 2008
El Damazin	High rainfall savanna	1962 - 2008
Malakal	High rainfall savanna	1913 - 2008

5.4.2 Level of Participation

As discussed in Chapter 3, Sudan participated in two recent global research initiatives regarding climate change adaptation. The first initiative was the "Assessment of impacts and Adaptations to Climate Change Project" (AIACC). The research involved a number of national and international researchers and was coordinated by the HCENR. The other research initiative was the "Community-Based Adaptation in Africa" (CBAA) project. Sudan was one of eight African countries participating in a project coordinated by the SECS.

Other research projects include collaboration between Lund University and the ARC, circa 2002, to conduct research on ecosystems analysis and potential of carbon sequestration in the tree-grass savanna at El Demokeya Research Forest in North Kordofan. Finally, there is a new project being launched called "Carbo-Africa" funded by the European Community which aims to quantify and predict GHG gases in Sub-Saharan Africa using a multidisciplinary integrated approach.

5.4.3 Key gaps

Numerous gaps regarding meteorological, atmospheric and oceanographic research and observation exist in the Comprehensive National Strategy, which are related directly or indirectly to climate change. These include protection and development of the rural environment for sustainable development, rehabilitation/preservation of ecosystems for sustainable and renewable energy resources, enhancement of environmental awareness among concerned groups, oceanographic research for the Red Sea coastline.

The major constraints for undertaking meteorological, atmospheric and oceanographic research is lack of resources, lack of a climate change information and database center, and inadequate training in the field of climate change. Table 5-3 summarizes key knowledge and research gaps related to climate variability in Sudan. Other specific gaps and constraints are summarized in the bullets below.

- *Weak policy integration :*Climate change and UNFCCC concepts are not well integrated in the national policy and planning systems due to limitations of the national management and data processing system.
- *Lacking data systems:* There is no sound programs/projects on research and systematic observations in most of the key sectors that are affected directly by climate change and variability such as agriculture, forestry and energy.
- *Weak legislative framework:* There is a significant lack of suitable policies, regulations, and legislation, together with an effective enforcement regime.
- *Poor awareness:* There is a lack of awareness at federal/state institutions, combined with limited capacity to monitor and evaluate the implementation of adaptation strategies and environmental management plans.
- *Inadequate technical capacity:* There is an urgent need for capacity building in the areas of information technology, networking, laboratory and field equipment for monitoring and evaluation. There is a need to upgrade institutional capacities to deal with climate change, which requires increasing awareness of policy-makers about climate change issues, introducing appropriate policies and regulations and revising institutional structures. Universities and research centers need support to include climate change issues in their programs.
- *Civil society organizations:* The role of civil society organizations should be enhanced through training, capacity building and networking, as well as government actions to create an enabling environment for greater involvement of civil society organizations.

Table 5-3: Knowledge and research and Gaps related to climate change in Sudan

Key area	Key gap
Risk/vulnerability assessments/mapping	Desk studies/field surveys
Metrological Stations coverage/data	Hard & Software
Improved cultural practices (rain-fed sector)	Research
Improved varieties (rain-fed sector)	Research
On farm water use efficiency (irrigated sector)	Research
Climate downscaling models	Capacities
Crop simulation models	Capacities
Water resources assessment	Desk studies
Out scaling good practices	Technology transfer
Policies	Capacities/analysis
Awareness	Media
Community participation	Socioeconomic/governance
Private sector (insurance, networking, information)	Services
Coordination/cooperation	Institutional
Early warning (flood/drought)	Institutional

5.4.4 Priority areas for climate change research and systematic observation

At this stage of Sudan's efforts to address priority research areas, only the energy sector has been addressed thus far. This reflects the growing importance that oil has assumed within national policy dialogues. Table 5-4 summarizes research priorities relative to climate change.

Table 5-4: Proposed National Research Program of Conventional Energy Affecting Climate Change:

Major Research Topic	Description	Impact on Climate & Priority
Sustainable Increase of oil and gas recovery from mature oil fields	1. Research on best technologies to suit Indigenous hydrocarbon resources recovery 2. Mitigation of environmental hazards such as produced water and oil field chemicals	Increase efficiency, reduce emissions and decrease of utilization of biomass in energy generation
Energy Conservation and proper Energy management and efficiency improvement	To reduce major losses in energy system resulting from transportation, storage (evaporation) and low conversion issues	Major emission and losses are encountered due to these issues and their elimination will reduce emission.
Advanced research in CO_2 capture and storage, biofuels from different wild plantations, etc	Produce carbon from biofuel from wild plantations.	New efficient & less emission fuels.

5.4.5 Conclusions

The main conclusions drawn from the above review of steps to implement the Convention are as follows:

Despite the great number of Sudanese Universities of different disciplines, few universities tackle the issue of climate change and variability as a stand-alone subject for undergraduate and postgraduate students.

Scientific research is conducted by different ministries in the Sudan, namely; Ministries of Higher Education and Scientific Research: in charge of national research centers and Universities, Ministry of Science and Technology: responsible for agricultural research, Ministry of Animal Resources: which oversees animal research activities, and Ministry of Industry: This oversees industrial consultants and research institutes.

Research related to climate change is minimal; what research is undertaken is mostly carried out by universities, especially older government-run universities.

Some governmental institutions conduct research pertaining to UNFCCC issues, notably the Ministry of Science and Technology.

Research is structurally weak and directed towards solving single discipline problems rather than solving complex, multidisciplinary problems pertaining to climate change

The Agricultural Research Corporation, together with selected universities, is the most active regarding climate change research.

Some NGOs are making important contributions to research on climate variability and climate change, particularly in the field of adaptation and coping mechanisms.

The National Meteorological Corporation keeps systematic observations for some of climate parameters, which can serve as important data for future climate change research.

Limited research has been undertaken to reflect the impacts of climate change on wildlife, an area that needs to be supplemented in future years.

National programs for research and systematic observation of climate change are confined to certain institutions like ARC, Forestry Research Centre, and National Research Centre. Even these institutions do not have dedicated systematic observation systems for climate change.

The participation of government intuitions in global research is limited to few good examples that have made important contributions.

The main gaps in meteorological and atmospheric research and systematic observations are as follows: lack of efficient climate change coordination, lack of a climate change information and database center, and lack of training in the field of climate change.

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