

ETHIOPIAN PANEL ON CLIMATE CHANGE

FIRST ASSESSMENT REPORT

WORKING GROUP II- CLIMATE CHANGE IMPACT,
VULNERABILITY, ADAPTATION AND MITIGATION

IV

WATER AND ENERGY

ETHIOPIAN ACADEMY OF SCIENCES



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About the Ethiopian Academy of Sciences

The Ethiopian Academy of Sciences (EAS) was launched in April 2010 and recognized by an act of parliament (Proclamation No. 783/2013) as an independent institution mandated to provide, inter alia, evidence-based policy advice to the Government of Ethiopia and other stakeholders. Its major activities include undertaking consensus studies, conducting convening activities such as public lectures, conferences, workshops and symposia on issues of national priority; as well as promoting science, technology and innovation.

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WATER AND ENERGY SUB-WORKING GROUP


WATER SECTOR- Climate change vulnerability, impacts and adaptation in the water resource sector of Ethiopia

Executive summary

Compared to many countries of sub-Saharan Africa, Ethiopia is endowed with abundant water resources. The annual flow from the 12 major river basins the country has is estimated at 124 billion meter cube (BCM). There are 11 freshwater and 9 saline lakes, 4 crater lakes and over 12 major swamps and wetlands. The total surface area of the major natural and artificial lakes is about 7,500 km². This surface area is considerably larger when small lakes and wetlands are considered. An estimated storage capacity of these major lakes is about 95.46 BCM. In addition, estimates of the groundwater resource of the country ranges from 2.6 BCM to 30 BCM.

All of the major rivers of the country are transboundary, and hence supply the downstream riparian countries with the much needed fresh water. For instance, the three major river basins (Abbay, Baro-Akobo and Tekeze), which carry some 76% of the annual flow of the country, account for about 85% of the Nile River waters in Egypt and Sudan.

A major challenge to water resources management in Ethiopia is the large spatial and temporal variability, both primarily driven by climatic variability. Mean annual rainfall varies from about 2000 mm over some pocket areas in the southwest to less than 250 mm in the Afar lowlands in the northeast and Ogaden in the southeast. Rainfall decreases northwards and eastwards from those high rainfall pocket areas in the southwest. This is reflected in the uneven distribution of surface and groundwater resources; northeastern and eastern areas of the country have limited freshwater resources whereas the western and southwestern parts of the country have abundant freshwater resources. In terms of temporal distribution, some 76% of the annual flow is concentrated in the months of July to October because of the heavy seasonality of rainfall. The variability in water availability indicates the need for water storage infrastructure for improved water security. The current *per capita* storage of water in the country is only 160 m³ which is only 20% of




South Africa's and 2.6% of North America's. Because of the limited water infrastructure in the context of the high hydrological variability, Ethiopia is considered to be economic and technical water-scarce country. Presently, the importance of water resources for all-round development of the country is widely recognized; there are ambitious water-centered plans in agriculture, energy, domestic and industrial water supply sectors.

The low level of development of water infrastructure exacerbates the country's vulnerability to climate change. Climate change is exacerbating the natural hydrological variability, and hence presenting another dimension to the challenge of water resources development and management. Although non-climatic drivers such as land degradation, land use change and agricultural water use play important roles, with changes in climate continuing for the coming century, the type and rate of impacts on water resources is likely to be unprecedented and overwhelming. All changes happening in rainfall and temperature have various effects on available water resources.

Stream flow, available soil water, groundwater recharge and water quality are all vulnerable to the projected changes in rainfall and temperature. For most of the major river basins of Ethiopia, many studies projected reduction of water yield. The reduction of water yield against the slightly increasing rainfall projected for much of the country indicates the effects of increased evapotranspiration loss of water due to the rising temperature. In general, most studies suggest that in terms of rainfall change wet areas will become wetter while dry areas will become drier. This means that southeastern, northeastern and rift valley areas will become drier; while southwestern, central and parts of western highland areas will become wetter. For instance, a study in the Blue Nile basin estimated a 14% reduction of runoff with a 3% increase in rainfall and 1.7°C rise in temperature; and 11% runoff reduction with 6% increase in rainfall and 2.6°C increase in temperature. The same study noted that higher low flows could be observed in the headwaters of the Blue Nile because of the likely increase of rainfall in this region, and it would be less likely that downstream communities suffer reduction of flow even with increased water demands and population growth.

On the other hand, downscaled projection studies to the local scale show that changes in runoff will be variable and inconsistent across different watersheds even within the same climatic regimes. There is a greater agree-



ment among studies on potential changes in the magnitude and frequency of extreme events across the country; as the climate continues to change, floods and droughts are most likely to become more severe in many parts of Ethiopia.


Ethiopia is currently implementing a Climate Resilient Green Economy (CRGE) initiative with the objective to protect the country from the adverse effects of climate change and to build a green economy. CRGE has three objectives: fostering economic development and growth, ensuring abatement and avoidance of future greenhouse gas emissions, i.e., transition to a green economy, and improving resilience to climate change. In addition to the fact that most of the strategic elements in the Green Economy strategy are water related (hydropower generation, irrigation and improving rain-fed agriculture), a separate water sector climate resilience strategy has also been prepared. The water sector strategy identifies ten climate resilience strategic priorities in four priority sub-sectors (power generation, energy access, irrigation and access to water, sanitation and hygiene). Effective implementation of these priorities is expected to enable adaptation to the progressive climate change by building resilience into the water resources sector. But financing implementation of the strategy will be a real challenge. Studies have already noted that the cost required for water management and water sector adaptation to climate change is very high due to the difficult hydrology of the country that is characterized by extreme events and high inter-annual and seasonal variability and very poor water infrastructure development.

In addition to financing, it is also important to note that there many factors, often categorized as physical, political, social and institutional, that could limit or complicate adaptation responses and climate risk management activities in the water sector. Furthermore, there are many knowledge gaps in the intricate relationships between climate change and water resources, and there are also a number of developmental issues that require policy attention as the country steps up investments to build resilience to climate change in the water sector.

1. Introduction

Water is an important natural resource upon which all living things depend. It is required in almost all forms of human enterprise, but water availability is inherently variable (Kiparsky et al., 2012). Water undergoes circulation between ocean – atmosphere and land, known as the hydrologic cycle. The hydrologic cycle is driven by exchange of solar radiation between the atmosphere and the earth's surface. The largest proportion of incoming radiation is used for heating the earth's surface (change in surface temperature) and evapotranspiration (Ludwig and Moench, 2009). With the changing climate, increasing surface temperature, change in rainfall pattern (intensity, amount and duration) and evapotranspiration rates will impact on the global hydrologic cycle with a subsequent influence on water availability for different uses (Rydgren et al., 2007; Estrela et al., 2012). There is a strong link between changes in climate and the hydrologic cycle (World Bank, 2009). Observations and climate projections provide abundant evidence that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change, with wide ranging consequences on societies and ecosystems (Bates, 2008). These impacts are mainly due to increases in temperature, evaporation, sea level rise and rainfall variability (Kundzewicz et al., 2007). Change in intensity, volume and timing of rainfall as a result of climate variability will affect the volume and frequency of stream flows. Consequently, this will lead to an increase in the intensity of floods and droughts, with substantial impacts on water resources at local and regional levels (Blanco, 2008).

Different basins and sub-basins respond differently to the same changes in climatic variables, depending largely on their physiographic and hydrogeological characteristics as well as the surface conditions (Arnell, 1992). Watershed characteristics are increasingly altered by human activities to meet the increasing demand for food and settlement. Projections indicate that over the coming decades, expansion and intensification of agriculture, growth of urban areas, and extraction of natural resources will likely accelerate to satisfy demands of increasing numbers of people with higher standards of living (DeFries and Eshleman, 2004). Land use change in semiarid areas has often resulted in dramatic modifications of the water balance (Favreau et al., 2009). Land use change affects also water demand and so, future water




requirements and availability are tightly linked to land use (Rockstrom et al., 2009). Population growth and the dynamics of climate change will also exacerbate desertification, deforestation, soil erosion, degradation of water quality, and depletion of water resources which in turn worsen the challenge of food security in developing countries (Delgado et al., 2011).

Particularly in developing countries like Ethiopia where livelihood of over 80% of the population relies on agriculture, expansion of agricultural lands and associated land degradation is a widespread challenge. Expansion of cultivated lands favors surface runoff generation from catchments and reduces groundwater recharge and hence results in low base flows (Hurni et al., 2005; Girmay et al., 2009; Tadele, 2009; Strzepek and Boehlert, 2010; Ogden et al., 2013). The consequences of land use change on water resources is wide-ranging that needs to be understood for proper management. These consequences include for instance, changes in water demands from changing land-use practices, such as irrigation and urbanization; changes in water supply from altered hydrological processes of infiltration, groundwater recharge and runoff; and changes in water quality from agricultural runoff and suburban development (DeFries and Eshleman, 2004).

The manifestation of climate change impact on water resources can be felt in several ways. Increased frequency and intensity of rainfall will produce increased soil erosion and sedimentation. Flooding will damage infrastructure, cause loss of lives and property as well as affect water quality as large volume of water polluted with contaminants is transported to water bodies. Drought as a result of change in rainfall pattern will lead to soil moisture deficits and affect agricultural production, water supply for domestic, industrial and agricultural purposes as well as ecosystem disturbances including wildfire and biodiversity invasion (Da Cunha et al., 2005; IPCC, 2007). Moreover, climate change will also affect the function and operation of existing water infrastructure including hydropower, water supply, flood protection, irrigation and drainage as well as overall water management practices (IPCC, 2007).

Ethiopia, like other sub-Saharan African countries, is vulnerable to the impacts of climate change. This is attributed to the low incomes, low technological and institutional capacity to adapt to rapid changes in the environment, as well as their greater reliance on climate-sensitive renewable natural resources




such as water and agriculture. Water supply sources for agriculture and other sectors are mainly surface water and shallow groundwater wells that undergo seasonal variability depending on climate (Urama and Ozor, 2010). In arid and semi-arid regions like the lowland areas of Ethiopia, soil moisture and groundwater table fluctuation are highly sensitive to rainfall variability at the annual scale in arid regions (Wang and Alimohammadi, 2012).

In Ethiopia, the importance of water resources for all-round development of the country is presently widely recognized than ever before. This is driven by the development needs of the nation and subsequent ambitious water-centered plans in agriculture, energy, domestic and industrial water supply sectors. These sectors are by and large dependent on rainfall and surface water and to a lesser extent groundwater. However, water sources like these are subjected to seasonal variability and necessitate storage infrastructure which are currently at a very low level of development in Ethiopia (World Bank, 2006; Awulachew, 2010).

Climate change affects not only water quantity and quality but also water demand and use. Water use in agriculture generally increases with increasing temperature. However, as water demand is also driven by non-climatic factors, there is no clear evidence for a climate-related trend in water use in the past (IPCC 2007; Estrela et al., 2012). Inefficiencies in water use particularly in agriculture have considerable influence on water demand. The efficiency of surface irrigation which is widely practiced in Ethiopia varies on average from 30-50% (Ayana, 2010). This indicates an unaccounted additional water demand of 50-70%. With growing demand for water in all development sectors and growing water stress due to climatic and non-climatic factors, such high inefficiency in water use needs to be improved.

Due to limited financial and technical capacity and capability, Ethiopia has been considered as economical and technical water scarce country (Awulachew, 2010). It means, even if the country is endowed with vast physical water resources potential, the resource could not be made available for use due to inadequate water infrastructure. This low level of development of water infrastructure exacerbates the country's vulnerability to climate change. Climate change represents a challenge for water resources development. The course of water resource development strategies need to consider means of



adaptation to the challenges.

Generally, in the midst of increasing urban and environmental demands on water, agriculture will be increasingly required to improve water use efficiency. Climate change will intensify the demands on efficient use of water in agriculture and other sectors. With rising temperatures and changing rainfall patterns, controlling water supplies and improving irrigation access and efficiency will become increasingly important. Climate change will burden currently irrigated areas and may even outstrip current irrigation capacity due to general water shortages (Lybbert and Sumner, 2010).

As indicated above, Ethiopia is making remarkable progress in the development of water resources infrastructure as a means of building sustainable and climate resilient green economy and as a measure of both adaptation to and mitigation of climate change. It is widely recognized that, in the face of climate change, adaptation (adjustment in natural or human systems to moderate harm in response to expected change) is a key mechanism for reducing negative impacts of current and future changes (Kiparsky et al., 2012). Alongside adaptation, the country has committed itself to work on mitigation of climate change (reducing greenhouse gas emissions) as expressed in its climate resilient green economy strategy and the five-year development plan, known as Growth and Transformation Plan (GTP) (MoFED, 2010).



2. Water Resources of Ethiopia

2.1. General features of Ethiopian river basins

Ethiopia has an area of about 1.13 million km² and this is bisected by the Great East African Rift Valley into the western highlands and the eastern highlands, each with associated lowlands. The Ethiopian highlands are extended Plateaus that covers on both sides of the rift valley. The topography on the southeast of the highlands descends and levels off towards the border of Somalia and Ethiopia. The most mountainous terrain is found in the northwest of the Rift Valley within the upper watersheds of the Blue Nile and Tekeze River basins (Romilly and Gebremichael, 2011).

Generally, the country is characterized by highly diverse topography, with elevation ranging from 125 m below sea level in the Denakil Depression called Dalol to 4620 masl at Ras Dashen in the Simen Mountains. In between, there are high mountains, plateaus, deep gorges, incised river valleys, and low-lying plains. Areas with elevations greater than 1500 m asl are considered as highlands, and it is in these areas that almost 90% of the population of the country lives (MoWR, 2001; Cheung et al., 2008). The remaining population lives in lowland areas (<1500m asl) surrounding the highlands.

As summarized by Ayenew et al. (2008) and MoWIE (2014), Ethiopia has three principal drainage systems, which start from the central highlands. The first and largest is the western system, which includes the watersheds of the Abay (Blue Nile), Tekeze and Baro-Akobo, all flowing west to the Sudan. The second is the rift valley internal drainage system, which includes the Awash, the Lakes region and the Omo-Ghibe basins. The Awash River drains to the northeast through the rift floor and remains entirely contained within the boundaries of the country and enters Lake Abbe near the Djibouti border. The Rift Lakes basin is a closed system located in central Ethiopia where several rift valley lakes are found. The Omo and Ghibe rivers flow to Lake Turkana in the Ethiopia and Kenya border. The third system is the Wabi-Shebele and Genale-Dawa rivers, which drain to the Indian Ocean through Somalia.

All of Ethiopia's major rivers originate in the highlands and flow outward in many directions through deep gorges. The Ethiopian landmass is hydrographically divided into 12 River Basins (Figure. 1).




Figure 1 River basins of Ethiopia

Climatologically, the south and southwest region exhibits tropical climate whereas the northeastern and southeastern lowland areas are characterized by arid and semiarid climates (UN-Water, 2008). The hydrology of the country is a direct reflection of the climate, the terrain and other physiographic characteristics.

2.2. Rainfall in Ethiopia

The water resources of Ethiopia are governed strongly by the amount and distribution of rainfall. The distribution of rainfall over the country is highly variable. Variations in rainfall throughout the country is highly influenced by differences in elevation and seasonal changes in the atmospheric pressure systems that control the prevailing winds (US Library of Congress, 2005;



World Bank, 2006; Cheung et al., 2008; Korecha, 2013; Reda et al., 2014). These factors are the drivers of spatial and temporal variability of rainfall distribution and water availability in Ethiopia.

Ethiopia has three distinct seasons which are commonly recognized in the country (viz. Belg, Kiremt and Bega), each with different rainfall distribution pattern and amount. The Belg season, approximately extends from March to the end of May, and is considered the small rainy season in most of the river basins; and it is generated by weather systems that originate over the Indian Ocean. The Kiremt season, approximately extend from June to the end of September. It is considered as the main rainy season. The seasonal oscillation of the Inter-Tropical Convergence Zone (ITCZ) is the predominant mechanism for the rainfall during Kiremt (Seleshi and Zanke, 2004; Mohammed et al., 2005; Korecha, 2013; Reda et al., 2014). Bega is the dry season and it extends from October through the end of February.

Mean annual rainfall ranges from about 2000 mm over some pocket areas in the southwest to about less than 250 mm over the Afar lowlands in the northeast and Ogaden in the southeast. Rainfall decreases northwards and eastwards from the high rainfall pocket areas in the southwest (NMSA, 2001).

Based on the annual rainfall distribution patterns over the country, three major rainfall regimes are identified (World Bank, 2006; Reda et al., 2014):

- The southwestern and western areas of the country are characterized by a mono-modal (single peak) rainfall pattern, with the length of the wet season decreasing northward (example, region Bahir Dar in Figure 2).
- The central, eastern, and northeastern areas of the country experience a nearly bi-modal (two peak) rainfall distribution. The two rainy seasons are called Belg (smaller rains from February to May) and Kiremt (main rainy season from June to September). Example of such distribution is the rainfall at Metahara station indicated in Figure 2).
- The southern and southeastern areas of the country are dominated by a distinctly bimodal rainfall pattern. The rainy seasons are September to November and March to May, with two distinct dry



periods separating them (example, Arba Minch in Figure 2).

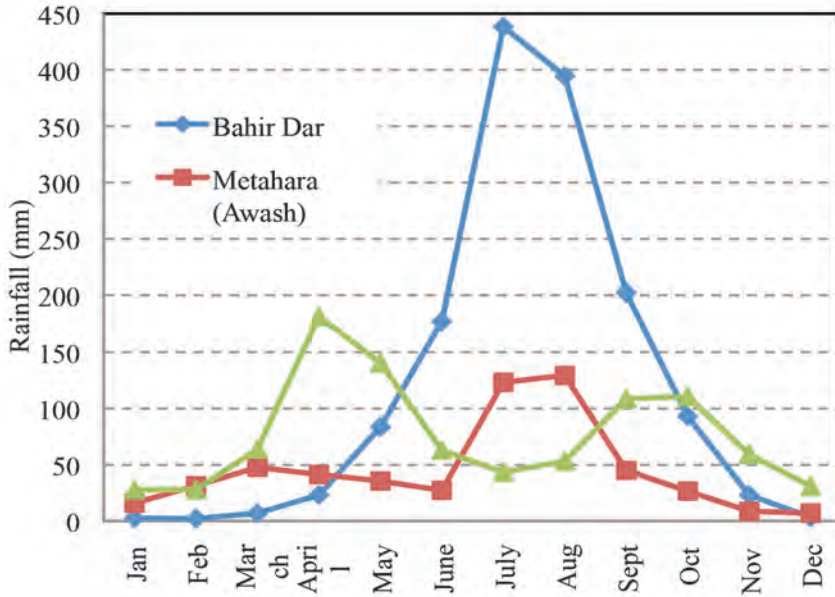


Figure 2 Typical rainfall distribution pattern in the different rainfall regions of Ethiopia

Rainfall distribution is extremely variable both in space and time. This variability is reflected in the uneven distribution of surface and groundwater resources of the country. Northeastern and eastern areas of the country receive low rainfall and have limited freshwater resources whereas the western and southeastern parts of the country receive high rainfall and have abundant freshwater resources. According to Seleshi and Zanke (2004) there is a decline in annual and Kiremt rainfall and rainfall days in the eastern parts of Ethiopia.

2.3. Water Resources Potential

2.3.1. Surface runoff


Most of the Ethiopian rivers originate from highland areas and flow into different directions to lowland areas including to the neighboring countries. This is the reason why Ethiopia has been considered as the water tower of Northeast Africa. The total annual surface runoff from the twelve river

basins amounts to about 124 billion cubic meter, BCM (Table 1). Although this represents an immense amount, its distribution in time and space is erratic. Out of the 12 river basins presented in Table 1, eight basins can be considered as wet basins (NOs. 1 - 8) as they generate considerable quantities of flow. The Lakes Basin (Rift Valley Basin) in which several lakes are fed by numerous rivers and streams and three other basins are considered as dry as they receive low amount of rainfall that cannot even satisfy evaporative demands (Awulachew, 2010; Fekahmed, 2012; Berhanu et al., 2014).

Table 1 Hydro-meteorological characteristics of the major river basins

Basin number	Basin Name	Area (km ²)	Temperature (°C)		Rainfall(mm)			Average Evaporation (mm)	Surface runoff (BCM)
			Min.	Max.	Max.	Min.	Average		
A	Blue Nile Basin								
1	Abbay	199,912	11.4	25.5	2220	800	1420	1300	54.4
2	Baro-Akobo	75,912	<17	>28	3000	600	1419	1800	23.2
3	Tekeze	82,350	<10	>22	1200	600	1300	1400	8.2
4	Mereb	5,900	18	27	2000	680	520	1500	0.7
B	Draining to Indian Ocean								
5	Wabi Shebelle	202,220	6	27	1563	223	425	1500	3.4
6	Genale Dawa	172,259	<15	>25	1200	200	528	1450	6.0
C	Draining to Lake Turkana								
7	Omo-Gibe	79,000	17	29	1900	400	1140	1600	16.6
D	Internally closed basins								
8	Awash	110,000	20.8	29	1600	160	557	1800	4.9
9	Rift Valley	52,000	<10	>27	1800	300	650	1607	5.6
10	Danakil	64,380	5.7	57.3	1500	100	400	Na	0.9
11	Ogaden	77,120	25	39	800	200	380	Na	0.0
12	Aysha	2,223	26	40	500	120	400	Na	0.0
									124

Source: MoWR (2010); UN-Water (2008); Abbay River Basin Master Plan (1999)



The remaining three basins, viz. Danakil, Ogaden and Aysha are dry basins. They are characterized by very low rainfall and hot temperature and hence high rate of potential evapotranspiration.

The values of maximum and minimum annual rainfall indicated in Table 1 reveal that there is high variability in annual rainfall amounts in the river basins. It is also evident that all basins are characterized by high evaporation demands. Potential evaporation rates are greater than maximum basin rainfalls in some basins for instance in Abbay, Genele-Dawa, Awash and Tekeze basins.

Except Awash River, all of the eight wet basins drain to the neighboring countries. As a result of differences in rainfall amount and distribution across the country, there is considerable difference in runoff amounts generated from the basins. The basins located to the western side of the Great Rift Valley, namely Abbay, Tekeze, and Baro-Akobo and Omo-Gibe receive considerably high amounts of mean annual rainfall. They account for about 83% of the country's annual surface runoff (102.4 BCM), while covering only 39% of the country's area. These basins host about 50% of the population of the country. Runoff from Abbay, Tekeze, Baro Akobo and Mereb represents the contribution of Ethiopia to the main Nile River which amounts to about 85.5 BCM. The most remarkable contribution in terms of volume of runoff comes from the Abbay River, the second largest basin next to Wabi Shebele in terms of area, and it is also commonly called the Blue Nile River. This river alone accounts for about 43% of the annual flow in the country. About 70-80% of the annual flow of almost all rivers in Ethiopia is attributed to the heavy Kiremt rains that occur between July and September (NBI, 2008).

The Wabi Shebele and Genale Dawa basins which drain the southeastern part of the country towards Somalia cover about 33% of the country and contribute only 7.6% of the total annual runoff. The Omo Gibe basin is located in the southwest of the country and drains into Lake Turkana of Kenya through Baro River.

Abbay, Tekeze, and Baro-Akobo rivers account for about half of the country's water outflow. In the northern half of the Great Rift Valley flows the Awash River. The Awash flows northeast wards and vanishes in the saline lakes near the border with Djibouti. The southeast is drained by the Ganale, Dawa and

Wabi Shebelle Rivers into Somalia, and the Omo River in southwest drains into Lake Turkana in the Ethiopia and Kenya border. There are also many rivers that drain into the closed rift lakes in central Ethiopia; what is known as the Rift Lakes Basin.

The very high variability exhibited by the climate components of the country over time and space is the main reason behind the spatial and temporal variability in the availability of water. The surface runoff potential varies across the basins depending on other climatic variables such as rainfall and temperature and topography. This is evidenced by the fact that the wet southwest and western part of the country, viz. Abbay, Baro Akobo and Omo-Gibe, produce about 76% of the annual runoff whereas the southeast, east, and north comparatively produce very small amount of surface runoff.

Figure 3 shows the general flow characteristics of some of the Ethiopian rivers which exhibit seasonality. As rainfall that produces runoff all over the basins is seasonal, the river flows are also seasonal. About 76% of total annual flow is generated during the months of July to October. This variability in water availability necessitates water storage infrastructure. However, the current per capita storage of the country is only 160m³ which is only 20% of South Africa’s and 2.6% of North America’s (World Bank, 2006; Awulachew, 2010).

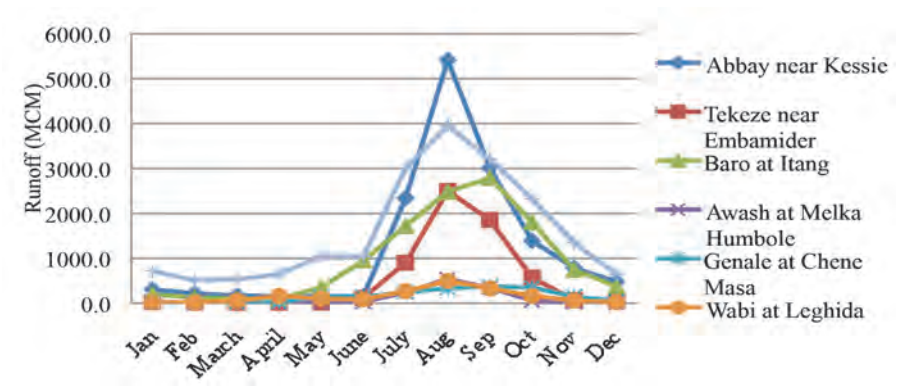



Figure 3 Mean monthly runoff hydrographs of some major rivers

To minimize the economic impacts of water shortages, greater water storage, both natural and manmade, large scale and small scale, will be needed. Given



both seasonal and inter-annual variability, significant over-year storage will be particularly important for Ethiopia (World Bank, 2006).

2.3.2. Lakes and wetlands

Ethiopia has 11 freshwater and 9 saline lakes, 4 crater lakes and over 12 major swamps and wetlands. The majority of the lakes are found in the Rift Valley Basin (Figure 4). The Central Ethiopian Rift valley is characterized by a chain of lakes and wetlands with unique hydrological and ecological characteristics. Most of the rift lakes are localized within a closed basin fed by perennial rivers and seasonal streams. Hills, ridges and volcano-tectonic depressions separate them. Large highland rivers are the source of sustained supply to the major rift lakes. The amount and distribution of highland rainfall strongly controls the level and size of these lakes (Ayenew, 2009).

The major lakes and their hydrologic characteristics are given in Table 3. The total surface area of the major natural and artificial lakes is about 7,500 km². This surface area is considerably higher when small lakes and wetlands are considered. An estimated storage capacity of these major lakes is about 95.46 BCM (Table 3). All of these lakes, except Tana, are found in the Rift Valley.

The streams feeding the rift valley lakes are increasingly being used for irrigation. Studies show that many of the lakes are undergoing considerable change in their levels and sizes (Chernet et al. 2001; Ayenew, 2002; Tamiru et al, 2006; Ayenew, 2007). As a result of their volcano-tectonic origin and increasing land degradation for agriculture most of these lakes are characterized by high concentration of dissolved solids. The high content of fluoride reaches 300 mg/l and affects the health of the population who live in the main Ethiopian Rift valley. Furthermore, high level of alkalinity and sodicity of most of these lake waters degrade structure and productivity of agricultural soils (Chernet et al., 2001). Excessive land degradation, deforestation and over-irrigation are increasingly aggravating sedimentation in lakes and increase in soil salinity (Legesse and Ayenew, 2006). Except Lake Ziway and Abaya, irrigation directly from the lake waters is not practiced in the rift valley due to quality constraints. Lake Abiyata has been exploited for production of soda ash and hence, experiencing anthropogenic induced changes.

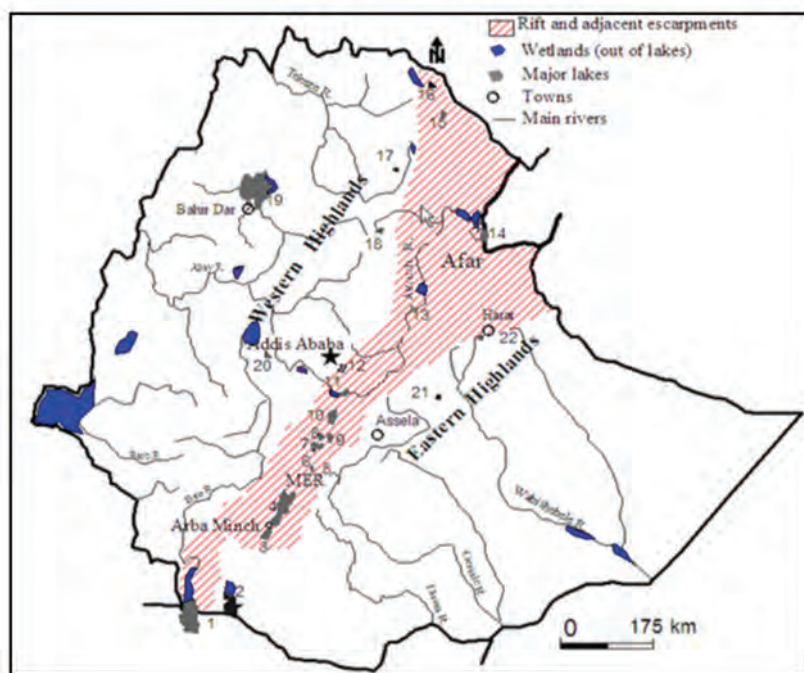


Figure 4 Location of Ethiopian Lakes and wetlands associated with the Great East African Rift and adjacent highlands.

Key to wetlands: 1 –Turkana, 2–Chew Bahir, 3–Chamo, 4–Abaya, 5–Awasa–Shallo, 6–Chitu, 7–Shala, 8–Abijata, 9–Langano 10–Ziway, 11–Bishoftu crater lakes, 12–Beseka, 13–Afambo–Abhe group, 14–Afdera, 15–Asale, 16–Ashenge, 17–Hayk–Ardibo, 18– Wonchi–Dendi, 19–Tana, 20–Lakes of the Bale Mountains, 21–Haramaya–Adele–Finkle (Ayenew, 2009)

Apart from their economic importance in terms of water supply for irrigation, recreation, fishery, and soda abstraction these chain of lakes harbor endemic birds, wild animals and provide ecosystem services. However, with increasing population growth, land degradation and related soil erosion and uncontrolled access to and use of these resources, sustainability of the lakes systems has become area of considerable concern that need attention. Several studies indicated that unwise water and land use systems from and around the lakes have led to changing conditions of the lakes especially in terms of their level, size, and water quality (Ayenew, 2004; Alemayehu et al., 2006; Legesse and Ayenew, 2006; Ayenew and Legesse, 2007).


Table 2 Hydrological characteristics of the major lakes of Ethiopia

Lake	Area (km ²)	Max. depth (m)	Average depth (m)	Volume (BCM)	Salinity (g/l)	SAR
Abaya	1160	13	7	8.2	0.96	15.7
Abiyata	180	14.2	7.6	1.61	16.2	653
Ashenge	20	25	25	0.5	-	-
Awassa	129	20	10.7	1.3	1.063	10.2
Bishoftu	86	87	55	0.1	-	-
Chamo	551	13	6	3.3	1.68	27
Hayk	35	23	23	0.8	-	-
Koka	250	9	9	2.25	-	-
Langano	230	47.9	17	5.3	1.88	-
Shala	370	266	8.6	36.7	21.5	267
Tana	3600	14	9	32.4	-	-
Ziway	440	8.9	2.5	1.1	0.35	3
Abe	450	37	36	2	-	-
Total	7500			95.46		

Source: Ayenew (2007); Mikhailovich et al. (2008); Rift Valley Basin Master Plan (2009)

SAR – Sodium Absorption Ratio - is an indicator based on several parameters specifically showing its suitability for irrigation. SAR of 10 is considered the maximum for irrigation

As can be seen from Table 2, the water quality of all lakes except Ziway, Hawassa and Tana is above the range of permissible level for irrigation. The management of freshwater lakes becomes a concern when they are overexploited. In this regard, Lake Ziway is the case in point. According to Ayenew (2004), the levels of some of the lakes have changed dramatically over the last three decades. Some lakes have shrunk due to excessive abstraction of water; others have expanded due to increases in surface runoff and groundwater influx from percolated irrigation water. Tiruneh (2007) has reported that the salinity levels of Abaya and Chamo lakes have increased by 60% and 67%, respectively, between 1964 and 2003.




With increasing water demand and use in agriculture and other water use sectors, the use of feeder streams as well as freshwater lakes will increase in the future. Under the changing climate, how these uses will affect the lakes and be affected by changing conditions of the lakes is an area of concern to be investigated and understood well.

2.3.3. Groundwater potential

Groundwater, the water beneath the surface, is recharged as part of rainfall and surface water bodies that infiltrates and percolates deep into the soil. Factors such as climate, topographic features, geology, land use and land cover affect the rate of groundwater recharge. It is an important source of water supply to springs, streams and rivers, lakes and swamps. This shows that groundwater is in intimate interaction with surface water. Groundwater has been exploited in other countries for domestic use, livestock and irrigation since the earliest times. Although understanding the occurrence of groundwater is difficult, successful methods of bringing the water to the surface was developed and groundwater use has grown consistently ever since (WHO, 1992). At present an estimated 70% of the world's population depends for its basic domestic water services on groundwater (MoWR, 2011).

In Ethiopia, groundwater is so far utilized mainly for drinking water supply, but there are developments in many parts of the country to implement groundwater based irrigation from shallow and deep aquifers. Although several areas with very shallow aquifers have recently been developed for agriculture by farmers and private initiatives, the level of groundwater use is still very low. On the other hand, it is well understood that groundwater is of paramount importance for Ethiopia to supplement the available surface water resources in providing drinking water to its population and for economic development (agriculture, livestock, industry, tourism) and in general to mitigate the effects of climate variability (MoWR, 2011). However, the low level of capacity in understanding and mapping the complex nature of the highly varying geology and aquifers of the country represents one of the bottlenecks to its development. Generally speaking, there are large gaps in knowledge, capacity and management systems in groundwater. Professionals especially in drilling, hydrogeology, water supply engineering



etc are inadequate or even lacking in some cases. Not only professional shortfall but also lack of drilling rigs, pumping and other relevant equipment are hampering the development of groundwater.

The groundwater potential of Ethiopia is variable from place to place based on several factors such as variations in geology, nature of structures, recharge condition, nature and duration of precipitation and other factors. Due to economic reasons test wells or sufficient pumping test data are not available to enable reliable determination of hydraulic properties of aquifers, other data such as recharge rate estimation are also not sufficient to determine the groundwater potential of the country (UN-Water, 2004).

Due to problems mentioned above, the groundwater potential of the country is not well known. Only few localized studies in the Ethiopian Rift Valley system have been made to understand the hydrochemistry and occurrence of groundwater (Kebede et al., 2005; Demellie et al., 2007; Ayenew et al., 2008a,b; Demellie et al., 2008). The mechanism of groundwater recharge, flow pattern and occurrence is reported to be complex. This is mainly attributed to the complexity of geological and geomorphological setup of the country.

An estimated amount of 2.6 BCM has been widely quoted. Following the results of recently completed assessment for parts of the country, there is consensus that the 2.6BCM figure is extreme underestimate and that it needs to be considerably revised. Best estimates in this respect range from 12-30BCM or even more if all aquifers in the lowlands are assessed (MoWR, 2011). According to rough estimates based on the information given in Table 3 and Figure 5, the annual groundwater recharge may reach up to 60 BCM.

Table 3 Aquifer categories and their yield

Zone	Name	Area (km2)	Average re-charge (mm)	Average volume (BCM)*
River basins	Abay	199,912	100	19.851
	Baro-Akobo	75,912	120	9.0864
	Tekeze (Atbara)	82,350	50	4.3885
	Wabishebelle	202,220	30	6.1623
	Genale-Dawa	172,259	30	5.0442
	Omo	79,000	100	7.721
	Rift Valley	52,000	50	2.745
	Awash	110,000	30	3.3996
	Denakil	64,380	10	0.6952
				Total 59.0932
				Recharge (mm/year)
Physio-graphic zones	Highlands of western and southwestern Ethiopia			250 - 400
	Eastern (high peaks) and central Ethiopian high-lands			150 – 250
	Much of northern and northwestern highlands, Central Main Rift, southern and far eastern high-lands			50 – 150
	Southern Afar and the extreme northern end of the western lowlands and much of far eastern and southern lowlands			< 50

*own estimation based on area and depth of recharge (for shallow aquifers).

Source: Ayenew et al. (2008a)

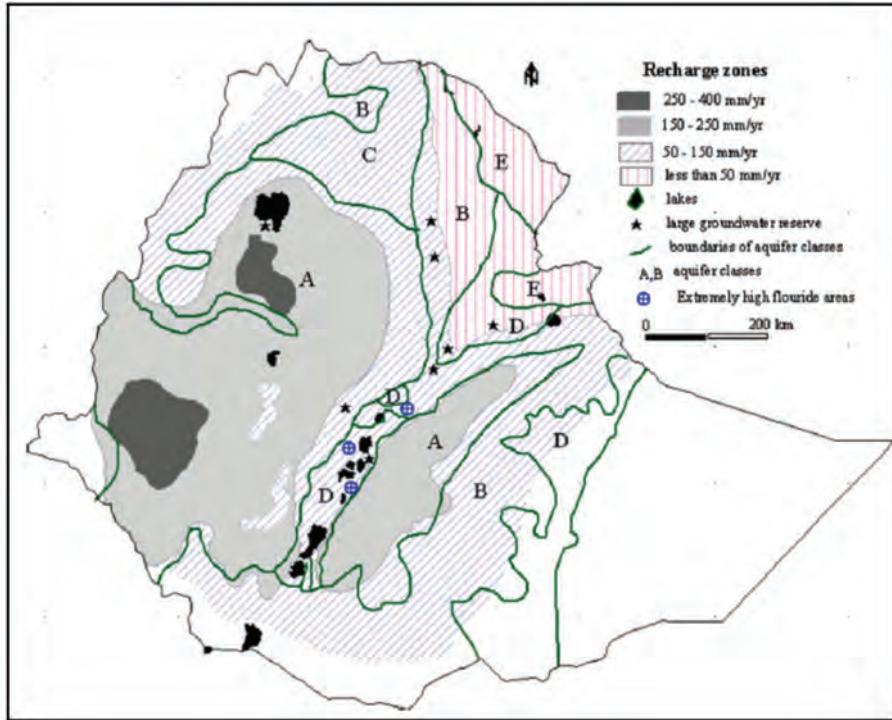



Figure 5 Groundwater recharge and availability map

Source: Ayenew et al. (2008a).

Note: A = wide spread good quality groundwater at a relatively shallow depth (dominantly highland volcanic aquifers recharged by high rainfall); B = large groundwater reserve with fair to bad quality often localized in lower elevation areas (rift valley and volcanics in pediment covered with thick sediments and intermountain grabens); C = low to moderate groundwater reserve with fair quality (highland trap series volcanic aquifer with less sediment cover and recharge); D = medium to high groundwater reserve in the volcanics and sediments recharged by rainfall and rivers in places with serious salinity problem; E = Low groundwater reserve with moderate quality recharged by seasonal floods and streams.

Given the low understanding of groundwater potential of the country, the role placed on groundwater in water-centered development plans is higher than ever before. Groundwater irrigation is given due attention to supplement rain-fed agriculture. The realization of planning targets in the water supply



sector will heavily depend on the development of groundwater. This suggests that there is an urgent need for developing the capacity of understanding and mapping groundwater for national development and management.


2.4. Water resources development

The availability of and access to freshwater is an important determinant of economic growth and social development. This is particularly the case in Ethiopia where more than 80% of the population lives in rural areas and are still heavily dependent on small scale agriculture for their livelihoods. Water has also a basic function in maintaining the integrity of the natural environment.

Ethiopia is characterized as on one hand a country with abundant water resources and on the other as one of the countries suffering from drought and unavailability of water in required quality and quantity for different use sectors. Agriculture, the dominant economic sector of the country is highly affected by variability of water availability. The magnitude of variability and the timing and duration of periods of high and low supply are not predictable; this equates to unreliability of the resource which poses great challenges to water managers in particular and to communities as a whole (UN-Water, 2008). Runoff characteristics of Ethiopian rivers as depicted in Figure 3, which shows that high water availability periods are limited to 3-4 months of the year depending upon rainfall distribution patterns of the basins. Despite this variability in water supply, the development of water storage infrastructure is at a very low stage. This demands understanding the groundwater system and developing more water storage structures in different parts of the country.

2.4.1. Irrigation

The development of irrigation and agricultural water management holds significant potential to improve productivity and reduce vulnerability to climactic volatility in Ethiopia. Irrigation can contribute to the national economy in several ways. At the micro level, irrigation leads to an increase in yield per hectare and subsequent increases in income, consumption and food security. Irrigation enables smallholders to diversify cropping patterns, and to switch from low-value subsistence production to high-value market-




oriented production, minimizing crop failure due to dry spells (Hagos et al., 2009).

Although Ethiopia has abundant rainfall and water resources, its agricultural system does not yet fully benefit from the technologies of water management and irrigation (Awulachew, 2010). Based on information from river basin master plans the irrigation potential of the country is estimated at about 3.7 Mha. With consideration of groundwater irrigation (1.1 Mha) and rainwater harvesting (0.5 Mha), the irrigation potential is estimated at 5.3 Mha (Awulachew, 2010; Gebremeskel, 2011).

Although traditional irrigation has long years of history, modern irrigation has started in Ethiopia in the 1960s in the Awash valley with the objective of producing industrial crops (Awulachew et al., 2007). For instance, sugar estate irrigation schemes of Wonji Shoa and Metahara were established in 1954 and 1966, respectively; Bilate was established in 1967 as well as Amibara and Nura Era in 1983. The country is presently committing huge investments to develop irrigation infrastructure of different scales with the aim to enhance agricultural production to feed the growing population, creating employment opportunity, expand export earnings and supply raw materials to agro-industries. Public investment, private, NGOs and farmers own initiatives are involved in the development of irrigated agriculture.

Regarding the extent of the area currently covered with irrigated agriculture, there is no reliable information and monitoring system. According to Hagos et al (2009) area under irrigation in 2005/06 was about 625,819 ha. Estimate made by Awulachew (2010) suggest that about 640,000 ha is under irrigation that includes 128,000 ha micro irrigation using rainwater harvesting, 383,000 ha small-scale, and 129,000 ha from medium and large-scale irrigation. This figure accounts 11.8% of the irrigable land which is still low as compared to the potential and development of other countries.

While the development trend in irrigation is promising, little attention is given to the management of existing schemes. The performance of existing irrigation schemes are low due to poor operation and maintenance services, problems related to improper planning and design, lack of incentive for proper management of water in state-run projects (Ayana and Awulachew, 2009; Awulachew and Ayana, 2011). Reports indicate that mismanagement



of irrigation water in intensively irrigated areas of the Awash Basin has led to considerable rise of salinity in almost 26% of the irrigated areas (Ayenew, 2007a). Lake Beseka, one of the saline lakes (current surface area around 55km²), is expanding dramatically due to groundwater rise driven by over irrigation in Wonji Shewa and Metahara irrigation projects (Ayenew, 2007b). The Growth and Transformation Plan (GTP) of the country envisages the development of irrigation to cover 1.8 million ha by 2015. Institutionalization of the management and operation of the irrigation sector is vital to ensure its efficient management and sustainability.

2.4.2. Water supply and sanitation


Ethiopia is considered as one of the countries with low water supply and sanitation coverage. However, from a very low base, the country is rapidly improving access to safe water supply and coverage. Table 4 shows the water supply coverage and its development targets.

Table 4 GTP water supply coverage and planned targets

Coverage (%)	Base year (2010)	Yearly targets				
		2011	2012	2013	2014	2015
Rural	65.8	73	80	86	92	100
Urban	91.5	93	95	97	99	100
National	68.5	75	81	87	93	100
Non-functional	20	18	16	14	12	10

Source: Gebremeskel (2011)

The fact that close to 85% of the population is living in rural areas under scattered settlements, provision of centralized water supply system is not possible. Instead localized systems have been developed and implemented. Most of the water supply schemes both in urban and rural areas are characterized by low levels of service and lack of sustainability. Although water supply systems in the larger cities have recently been improved, they need to be expanded to meet the demands of rapid population growth and the planned industrial zones. In rural communities, water supply systems have too often been installed without adequately training the communities to manage and maintain them (World Bank, 2006). Due to lack of technical



and financial capacities as well as unavailability of spare parts several water supply schemes implemented in rural areas are not functional (Girmay, 2012). Sustainability of schemes is an area of concern that needs serious attention.

2.4.3. Hydropower

With increasing population growth and development, the demand for energy is increasing. Expansion of manufacturing and agro-industries, improved living standards and service needs adequate and reliable supply of energy urgently. Close to 90% of the energy demand of the country has been covered from biomass (Solomon, 1998), which has been considered as one of the contributors to deforestation and land degradation. Ethiopia is making exceptional progress in developing its renewable energy resources as outlined in GTP and climate resilient green economy strategy. Among these sources, hydropower has received greater attention.

Hydropower is considered as clean energy and environmental friendly. According to EEPCO (2013) and MoWIE (2014), the theoretical potential of hydropower in Ethiopia is estimated to be 30,000–45,000 MW (160,000 GWh/year), with the estimated economically feasible hydropower potential ranging between 15,000 and 30,000 MW. With this huge potential, Ethiopia is the second in Africa next to the Democratic Republic of Congo. Although hydropower development for electrification goes back to 1930 (Table 5), very little percentage of the potential has been harnessed until recently.

Ethiopia is making significant progress in its socio-economic development. It has set development objectives of eradicating poverty through broad-based, accelerated and sustained economic growth and ultimately increasing per capita income of its citizens to the level of middle-income countries by 2025. This goal, as set out in the strategy of climate resilient green economy (CRGE), will have to be achieved by building the economy that is both resilient to the impacts of climate change and low in greenhouse gas emissions. It is evident that the demand for energy will increase with the development of different economic sectors. According to forecasts the energy demand will increase by 32% from 2011 to 2015 (MoWR, 2013). Development of hydropower is becoming essential to meet the energy demands of progressing development and it is also considered as one of the strategies to building CRGE. During

the first cycle of GTP, it was envisaged to develop the country's hydropower capacity from 2,000 MW (base year, 2010/11) to 8,000 MW (after 5 years, 2014/15).

Table 5 Hydropower chronology in Ethiopia

	Hydropower plant	Installed capacity (MW)	Year of completion
1	Akaki	6	1932
2	Tis Abay I	12	1953
3	Koka	42	1960
4	Awash II	36	1966
5	Awash II	36	1971
6	Fincha	134	1972
7	Melka Wakana	153	1989
8	Tis Abay II	72	2001
9	Gilgel Gibe I	184	2004
10	Tekeze	300	2009
11	Gibe II	420	2009
12	Gilgel Gibe II	420	2009
13	Tana Beles	460	2010
14	Finchaa Amerti Nesse	100	2012
15	Gilgel Gibe III	1,870	2014
16	GERD	6000	2017
		10,245	

Source: EEPKO (2013)

As can be seen from Figure 6, the development of hydropower installed capacity has increased enormously during the last 10 years. The development shows three distinct phases; namely, slow development phase (1932 – 2000), rapid development phase (2000– 2011) and shooting phase (from 2011 onwards).

Owing to the development needs and plans of the country, there are several hydropower plants in pipeline (Table 6). As it can be seen from the same table, the three River Basins, namely, Abbay, Omo Gibe and Baro Akobo, that generate about 76% of the annual surface runoff of the country, can be

considered as basins with vast existing, on-going and planned hydropower projects.

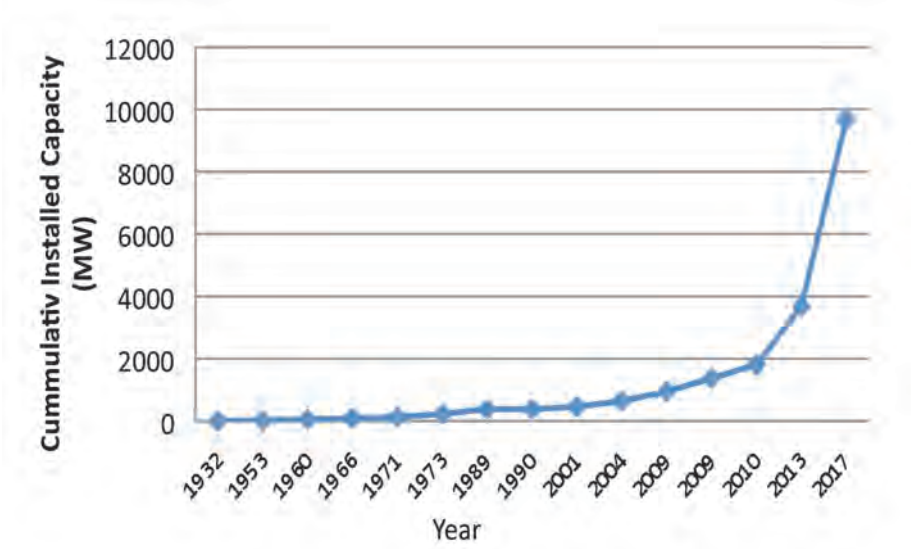


Figure 6 Development trend of hydropower in Ethiopia


Fifteen more hydropower projects with installed power capacity of 10,956 MW are under study (MoWIE, 2013). The status of these studies varies from reconnaissance to completed feasibility studies.

Table 6 Installed capacities of hydropower plants by basin in MW

	Basin Name	Existing	Construc- tion	Candidates	Total
1	Wabi Shebelle	153	-	88	241
2	Abbay	776	6,000	6,095	12,871
3	Genale Dawa	-	254	346	600
4	Awash	106	107	6	219
5	Tekeze	300	-	450	750
6	Omo-Gibe	604	1,870	2,718	5,192
7	Baro-Akobo	5	-	2,705	2,710
		1,944	8,231	12,408	22,583

Source: MoWR (2013)

It is important to note that with increasing water development projects



in all sectors like irrigation, energy, water supply and sanitation as well as ecosystem services, the demand for water will increase. Meeting increasing demand for water under varying climate makes proper management and allocation of water among different use sectors increasingly important which otherwise would lead to conflicts and degradation of resources. Climate change and variability will likely pose additional stress on these demands as it influences water availability.

Soil erosion and sediment transport from degraded areas is a serious threat for the growing development of water infrastructure like dams and reservoirs. Rivers and streams that originate from highland areas are carrying enormous sediment during rainy seasons and flooding events. With the current intensity of land degradation, several dams and reservoirs will fall short of their useful lives unless soil and water conservation practice is implemented rapidly.

2.5. Water resources governance

2.5.1. Institutional development

Water governance generally refers to the wide range of social, economic, political, institutional, administrative systems and decision-making processes that are in place to regulate development and management of water resources and provision of water services (Hemel and Loijenga, 2013). Such systems are required to regulate the development and management of water resources and provision of adequate, safe and reliable water supply services to different use sectors including ecosystems. However, water governance in Ethiopia is seriously threatened by inadequacies and incompetence of institutional arrangements and legal frameworks (UNESCO, 2004).


Water resources management is a core issue for development in Ethiopia. Human and institutional capacities are essential for effective water resources management. Given the country's challenging hydrology, the need for such capacity is great; but capacity in this regard is low. Efforts to strengthen capacity are ongoing in Ethiopia and should be seen as a continued priority (World Bank, 2006).

The evolution of water resources governance institutions has a short history in Ethiopia. Decentralized traditional water management system has been

widely practiced in the country since ancient times. The role of government in water resources management has evolved with the need to develop modern irrigation systems and water supply schemes in the 1950s. The historical evolution of water resources management institutions as given by Ligdi et al. (2011) and author's review is presented in Table 7.

Table 7 Chronological development of institutions in the water sector

Year	Institution	Duties
1956	Water Resources Department	Established under the Ministry of Public Works & Communications; it was established to handle a multi-purpose investigation of the Blue Nile Basin. Over the years, it took on the river basin studies and water well drilling programmes
1962	Awash Valley Authority (AVA)	Took over the responsibility for all water resources development activities in the Awash Valley. Its mandate includes all aspects of water planning, development and operation including water rights administration.
1971	National Water Resources Commission (NWRC)	Established under the then Ministry of Public Works & Water Resources. The Commission's purposes and objectives covered the full range of water responsibilities. The Commission's powers were broad but were not fully exercised and implemented due to financial and organizational constraints as well as lack of commitment and willingness of public authorities to accept a national authority over water resources development and management
1975	Ethiopian Water Resources Authority (EWRA)	EWRA was established and placed under the Ministry of Mines, Energy & Water Resources. Three agencies, namely, Land & Water Studies Agency, Rural Water Development Agency and Urban Water & Sewerage Agency were established under the Authority.
1977	Valleys Agricultural Development Authority (VADA)	VADA had similar powers and duties as AVA except that its jurisdiction was limited to water resources whereas that of AVA included all resources, but its authority covered the whole country.



1981	National Water Resources Commission (NWRC)	A further re-organization in the water sector resulted in the establishment of NWRC. It was composed of the Water Resources Authority, Water Supply and Sewerage Authority (WASSA), Ethiopian Water Works Construction Authority (EWWCA), and the National Meteorological Services (NMS).
1993	Ministry of Natural Resources and Environmental Protection (MoNREP)	After about ten years of service, the NWRC was dissolved and the Authorities under its umbrella, except EWWCA, were made accountable to MoNREP which was established in 1993 and served only for about two years.
1995	Ministry of Water Resources (MoWR)	MoWR was established by proclamation No.4/95 as a federal institution for the water sector. At regional level, the water sector is the responsibility of the Water, Mines and Energy Development Bureaus or the Water Resources Development Bureaus. The MoWR was responsible for the overall planning, development, management, utilization and protection of the country's water resources, as well as supervising all water development activities carried out by other institutions. Large-scale water supply was also handled by the ministry through its Water Supply and Sewerage Department.
2005	Ministry of Water and Energy	Had similar duties as the current MoWIE

2013	Ministry of Water, Irrigation and Energy	<p>Water resources related powers and duties of the Ministry as stipulated in Proclamation number 691/2010 are:</p> <ul style="list-style-type: none"> • Promote the development of water resources and energy; • Undertake basin studies and determine the country's ground and surface water resource potential in terms of volume and quality, and facilitate the utilization of same; • Determine conditions and methods required for the optimum and equitable allocation and utilization of water bodies that flow across or lie between more than one Regional State among various uses and the Regional States; • Undertake studies and negotiation of treaties pertaining to the utilization of boundary and trans-boundary water bodies, and follow up the implementation of same; • Cause the carrying out of study, design and construction works to promote the expansion of medium and large irrigation dams; • Administer dams and water structures constructed by federal budget unless they are entrusted to the authority of the relevant bodies;
2007	River Basin Councils and Authorities	It was legalized by the proclamation No. 534/2007.

2008	Awash Basin Authority (ABA)	AVA which was established in 1962 was re-established to ABA. It has the mandate of promoting and monitoring implementation of integrated water resources management processes in an equitable and participatory manner in the Awash basin (FNG, 2008)
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As can be seen from Table 7, water management institutions have been undergoing frequent restructuring and characterized by instabilities. Possible reasons for such high turnover according to Fekahmed (2009) could be:

- Creation of institutions with short term objective rather than long term vision
- Establishment through ad-hoc decisions rather than detailed institutional investigation and analysis
- Less emphasis given to institutional sustainability
- Discrepancy between high expectation and low performance during the first few years of institutions
- Insufficient budgetary allocation and less attention given to capacity building

Currently the water sector governance structure encompasses federal level ministry, regional level water and energy bureaus and supporting zonal and woreda level water resources development offices.

Federal level: The Ministry of Water, Irrigation and Energy is the main federal government institution established by proclamation number 69/2010 to manage the water resources of the country. It has the mandate of formulating national water policy, strategy, legal frameworks, plans, and for establishing national standards pertaining to water resources, establish relevant institutions, commission studies, plan and develop water supply and sanitation schemes, irrigation, hydropower and other energy forms, and water resources administration, protection, monitoring and allocation.

There are other ministries and institutions at federal level that are involved directly or indirectly in water resources development. These are for instance: Ministry of Agriculture, Ministry of Health, Ministry of Industry, Ministry of Urban Development and Construction, Ministry of Environment and Forestry,



and Ministry of Finance and Economic Development as well as Electric Power Corporation, Addis Ababa Water Supply and Sewerage Authority, and Water Resources Development Fund Office. Subsidiary organizations to the Ministry of Water, Irrigation and Energy are: Water Works Design and Supervision Enterprise, Water Works Construction Authority, Water Well Drilling Enterprise, and River Basin Authorities (Awash, Abbay and Rift Valley Lakes Basin).

River Basin level: River Basin Organizations comprising a Basin High Council and River Basin Authorities, as legalized by proclamation No. 534/2007, are being established in order to ensure integrated water resources management at the basin level

Regional level: The Bureau of Water Resources Development (Bureau of Water and Energy) at the regional level is an executive organ responsible for the implementation of federal policies, strategies and action plans through adapting them to the specific conditions of the Regions. In addition, Water Bureaus exercise regulatory duties delegated to them by the Ministry. The organization of each Bureau differs from region to region. At regional level there are also institutions like Irrigation development bureaus, bureau of health, water works construction enterprise, and bureau of agriculture and rural development.

Zonal level: Zonal Water Resources Offices are the supporting arms of the Regional Water Bureaus and are mandated to provide technical support to Woreda Water Offices and Town Water Supply Offices. In addition, they are responsible for coordinating activities, consolidating plans and reports of woreda and relaying requests from Regional water bureaus and/or woreda water offices. In general, Zonal Water Offices, in regions where they exist, are the links between Regional Bureaus and woredas.

Woreda level: Woreda Water Resources Development Offices are responsible for the investigation, design and implementation of small-scale water supply schemes, whilst study and design of big schemes are undertaken by Bureaus of Water.



2.5.2. Legal grounds for water sector governance

The legal framework for water resources management in Ethiopia covers policy, strategy, proclamations, regulations and directives. The Ministry of Water Resources has issued the Ethiopian water resources management policy in 1999. The policy sets guidelines for water resources planning, development and management. The overall goal of the policy is to enhance and promote all national efforts towards the efficient, equitable and optimum utilization of available water resources of the country for significant socioeconomic development on sustainable basis.

The Ethiopian Water Resources Management Proclamation No.197/2000 is the basic legal instrument governing the management, planning, utilization and protection of water resources in Ethiopia. This proclamation has been supplemented by the Ethiopian water resources management regulations issued in 2005 under Proclamation No.115/2005. It elaborates on issuance and administration of permits for different water uses, construction works and waste discharge. With the legalization of the establishment of River Basin Councils and Authorities by proclamation No.534/2007, powers and responsibilities rested in MoWR to manage the waters of the basins is delegated to the respective River Basin Organizations (RBOs). Through these organizations, water resources planning and management function will be decentralized. It envisages phase-by-phase establishment of RBOs and describes the provision that RBOs will have a two- tier organizational set-up, i.e., Basin High Councils (BHCs) and Basin Authorities (BAs). While BHCs are the highest policy and strategic decision-making body, the BAs will serve as administrative and technical arms of BHCs.

As described in the proclamation, the objectives of the councils and authorities shall be to promote and monitor the integrated water resources management process in the river basins falling under their jurisdictions with a view to using of the basins' water resources for the socio-economic welfare of the people in an equitable and participatory manner, and without compromising the sustainability of the aquatic ecosystems. Apart from these government institutions, there are enterprises, NGOs and private organizations working on water resources development. These include: Water Works Design and Supervision Enterprise, Ethiopian Water Works Construction Enterprise, and others.



2.5.3. Challenges related to water sector governance


Although frequent restructuring of Water institutions with the objective of bringing about efficiency, effectiveness, linkages, coordination and collaboration is a common phenomenon in Ethiopia, there is still lack of effective coordination among stakeholders in general. Coordination among key stakeholders such as Federal and Regional Public water institutions, NGOs, multilateral and bilateral agencies and the private sector is still an issue that needs improvement (UN-Water, 2004).

Like many other government institutions, the water sector institutions at Federal and Regional levels are not properly and adequately staffed with the right number and quality of trained and experienced staff. The fact that there is a competition in the labour market for experienced and skilled professionals, existing salary scales in the civil service and incentive schemes have failed to attract the required professionals to the water sector institutions. Many experienced civil engineers, economists, hydraulic engineers, irrigation engineers, and others are leaving the sector for better pay elsewhere in the country, mainly the NGOs, private sector and international organizations (UN-Water, 2004).

There are significant institutional challenges that result in shortfall of plan implementation. These include: lack of standardized approach across agencies for mapping/monitoring existing projects; lack of project ownership; lack of institutional memory; and insufficient technical staff. Decision makers also do not have guidelines or systems for prioritizing investment decisions and project pipelines, which prevents efficient ranking and budgeting based on needs and resources (Awulachew, 2010).

WGC (2013) has made detail water governance capacity assessment for the Awash River Basin Authority (ABA) and identified the following major gaps:

- The authority is working on a local and operational level, not on regional/federal level;
- It is not cooperating or coordinating with other stakeholders/institutions;
- ABA is invisible and unknown to many institutions and stakeholders;
- Organizational structure is not suitable for effective water management



in the whole basin;

- Basin High Council is not operational;
- No clear focus or prioritization of activities;
- No good connection between departments;
- Insufficient baseline knowledge available of water system functioning;
- Lack of skilled staff, especially in basin studies, monitoring, permitting and finance;
- No good provision of information to stakeholders;
- No guidelines for enforcement of permits; and
- No guidelines for waste (water) discharge permitting

The study has proposed some measures to overcome these shortcomings of the Authority in water governance:

- Develop a Business Plan, where institutional set-up, financial mechanism and knowledge and skills (HR) are described;
- Develop a Basin Master Plan (with focus on water allocation, flooding, water quality and monitoring) to get an overview of the water system functioning, provide adequate information to others and interact with stakeholders; and
- Implement coordination/cooperation by initiating and running stakeholder platforms.

Generally, the water sector is suffering from major capacity constraints that exist at all levels of government in the sector. Institutions are weak, afflicted with insufficient and inadequate equipment, staff/skills shortages, poorly motivated staff and a general lack of funds (AfDB, 2005).

3. Observed and projected hydrological variability and changes

Hydrological variability is a natural variation that exists within the hydrological regime in the absence of any external forcing. Currently, however, hydrological variability is no longer steady because of the impact of climate change, land use change and other anthropogenic effects; and thus hydrology is changing (Kundzewicz and Robson, 2004). The natural hydrological variability is as important as hydrological change in areas where the range of variability is highly extended, like in Ethiopia (Cheung et al., 2008). Variability is more evident in rainfall than other hydrological variables in the country (Zelege et al., 2012). Nonetheless, hydrological variability and change are treated together in the hydrological variables discussed below. This section discusses observed variability and change in rainfall, streamflow, groundwater, soil moisture, evapotranspiration, water quality, soil erosion, lakes, droughts and floods.


3.1. Observed hydrological variability and change

3.1.1. Detection and attribution

Detection methods

The two most widely used tools in detecting hydrological changes are statistical approaches and modeling. Trend, regime shift, frequency analysis and flow duration curve analysis are widely used methods in statistical hydrological change detection (Dahmen and Hall, 1990; Kundzewicz and Robson, 2004; Westerberg et al., 2011). These detection methods consist of different methodological procedures to differentiate whether changes are driven by climate change or other anthropogenic effects; also there are procedures to differentiate the natural variability from climate change induced impacts (Burn and Hag Elner, 2002). Understanding the environment where data are collected, nature of the data, methods used in pre-analysis will help for application of appropriate change detection methods and procedures.

Changes in model calibration, in parameterization and simulation are some of the tests carried out in modeling for hydrological change detection



(Madsen, 2000; Kundzewicz and Robson, 2004; Seibert and McDonnell, 2009; Gebrehiwot et al., 2013). Modeling approach is easier in identification of climate change impacts than statistical approach; as it can adopt different IPCC scenarios and analyze changes in hydrological responses (Mishra et al., 2010). In addition, local people's knowledge is used in assessing climate change and land use change and their impacts on hydrology (Wilk, 2000; Gebrehiwot et al., 2014b).

Attribution of hydrological variability and changes

The whole natural system in the globe, including water, has entered into the new era called “Anthropocene”. Thus all natural systems are liable to be impacted by human induced changes. Climate change, land use change and population growth are the main attributes for changes of natural systems. Water, among other natural systems, is the most stressed resource with climate change impacts and other changes. Every part of the hydrological cycle is affected by climate change (Bates et al., 2008). Especially increased evapotranspiration because of increased temperature and thus affecting the patterns of rainfall are major climate change impacts in water stressed countries of Africa (Oestigaard, 2011).

Hydrological variables are more troubled by impacts of climate changes in sub-Saharan Africa than other parts of the world (Urama and Ozor, 2010). This is mainly because of low level of water management facilities. Long-term climatic change, land cover change, water resources development and population pressure contributing to changes in hydrology over Africa (Mahe et al., 2013). Analysis of observational records showed that most of the hydrological variables were impacted by climate change. The Eastern African region, where Ethiopia belongs, is already water scarce region. This region is also frequently hit by droughts and floods which are partly attributed to recent changes in the climate (Bates et al., 2008).

Hydrological changes induced by land use change and population growth are also prominent in eastern Africa and in Ethiopia (Urama and Ozor, 2010; Hurni et al., 2005). Though, land use change and population growth have enormous impacts on hydrology, climate change impacts are bigger with special effects on hydrological regimes in the region (Bates et al., 2008).



Uncertainties in data and data analysis

Uncertainty in data and data analysis plays a major role in identification and attribution of hydrological changes, such as what really is changing and how modest prediction can be made based on observed records. Uncertainty in hydrology could arise by many factors which could have particular or cumulative effect on hydrological change analysis (Di Baldassare and Montanari, 2009). Observational errors, weak representation of spatiotemporal variability, methodological errors and model uncertainties have impacts on studies related to hydrological changes. Errors in data acquisition and analysis lead to ill design of water management infrastructure and hydrological prediction.

Hydrological data collection is undertaken by the Ministry of Water, Irrigation and Energy in Ethiopia. Staff gauge readings are recorded twice a day, at dawn and at dusk. Rating curve equations are then developed using current meters readings taken three or four times per year and equations updated from discharge measurements. River channel cross-sections and the levels of the staff gauges are resurveyed after each rainy season from local benchmarks. Finally, discharge in volume per unit time is computed using updated rating curve formulae. The data collected are subsequently subjected to pre-processing and quality control. But, uncertainties and errors could still persist in the available database. However, practical applications of these procedures remain uncertain at all places and at all time. This in turn leads to the complexity of the uncertainty in data generation and processing.

Another data-related problem is the scarcity of data to represent the different eco-climatic conditions of the country, and adoption of western based models and tools (Griensven et al., 2012); these are two main sources of uncertainties in hydrological change analysis. Many of the reviews indicated below included plotting and inspecting, screening, missing data analysis and homogeneity testing to evaluate the correctness of data used in the respective studies.



3.1.2. Rainfall


General

Rainfall is highly variable both spatially and temporally in Ethiopia (Zelege et al., 2012) (Figures 7 & 8). The monsoonal rainfall has bi-modal distribution in the northeast, east and southeast part of the country; while unimodal rainfall distribution is found in the southwest and northwest of the country. The main rainy season, June-September (summer, Kiremt), remains largely common over the country. Moisture transport with the airmasses coming from Indian Ocean, the Congo Basin and the Red Sea are responsible for the rain that falls in Ethiopia (Viste and Sorteberg, 2013a). Annual average rainfall is about 1200 mm in the highlands of the country; while it goes below 100 mm towards the southeastern lowlands (Figure 7). About 74% of the annual rain falls during Kiremt (Cheung et al., 2008); while about 16% falls during February – May (Belg) and the rest 10% is distributed over the rest of the months.

Variability

The spatial variation of the rainfall distribution is mainly governed by the changes in the position and direction of the moisture carrying air masses. The inter-annual variability of rainfall also depends on the amount of moisture transported by the different air masses to the highlands (Viste and Sorteberg, 2013b). The intra-annual peaks follow definite pattern; summer is wet, whereas winter is dry. The inter-annual variability has no definite pattern, but having peaks every 6-10 years. Lowest peaks of rainfall were registered in 1984, 1990 and 2000. In the northwestern highlands of Ethiopia, the Kiremt rain becomes below average during El Nino times (Conway, 2005). The Belg rain shows higher variability than Kiremt rain over the country (Cheung et al., 2008).

The spatial variability is more pronounced given the country's wide range of topography, climatic and ecosystem regimes. Ethiopia has 6 rainfall regimes; where annual rainfall ranges from $< 100\text{mm yr}^{-1}$ to 2000 mm yr^{-1} (Figure 7) (Berhanu et al., 2013; www.ethiomet.gov.et, 2014). Rainfall decreases along the way from southwestern part of the country to northeastern and southeastern parts. Wagesho et al. (2012) found that rainfall showed



inconsistent pattern of trend among some of the stations in rift valley part of the country. The inconsistency could be attributed to orographic effects, climate change and data uncertainty.

Trends and other changes

There is a direct relationship between climate change and rainfall. The warming up of the atmosphere leads to enhanced evapotranspiration which in turn leads to changes in amount, intensity, duration and pattern of rainfall (Treberth, 2011). Mostly, the trend of rainfall records in Ethiopia showed non-significant changes in the last half-a-century (Figure 8) (Conway, 2005; Cheung et al., 2008; Bewket, 2009; Shang et al., 2011; Wagesho et al., 2012; Mellander et al., 2013). Conway (2005) indicated that the annual rainfall over the northwestern highlands showed an increasing trend from 1905 to 1965, then decreasing trend till 1984 and started increase after 1985 to 1990s.

Some variables like the inter- and intra- annual variability, rainfall duration and intensity are the most important rainfall variables in the country in relation to impacts of climate change (Haile et al., 2011; Mellander et al., 2013). Cheung et al. (2008) indicated that the Kiremt rains were decreasing in the southwest of the country; whereas Mellander et al. (2013) indicated *Belg* rains were decreasing in the same part of the country. Cheung et al. (2008) and Bewket (2009) found a slight decrease of the annual rainfall in the recent decades in the northern highlands of Ethiopia over the last half-a-century. The timing and the onset of rainfall are responsible for the observed changes in some variables of the rainfall and in some areas of the country (Cheung et al., 2008). For instance, the onset of rainfall is negatively related to rainfall intensity in the northwestern highlands of Ethiopia (Mellander et al., 2013).

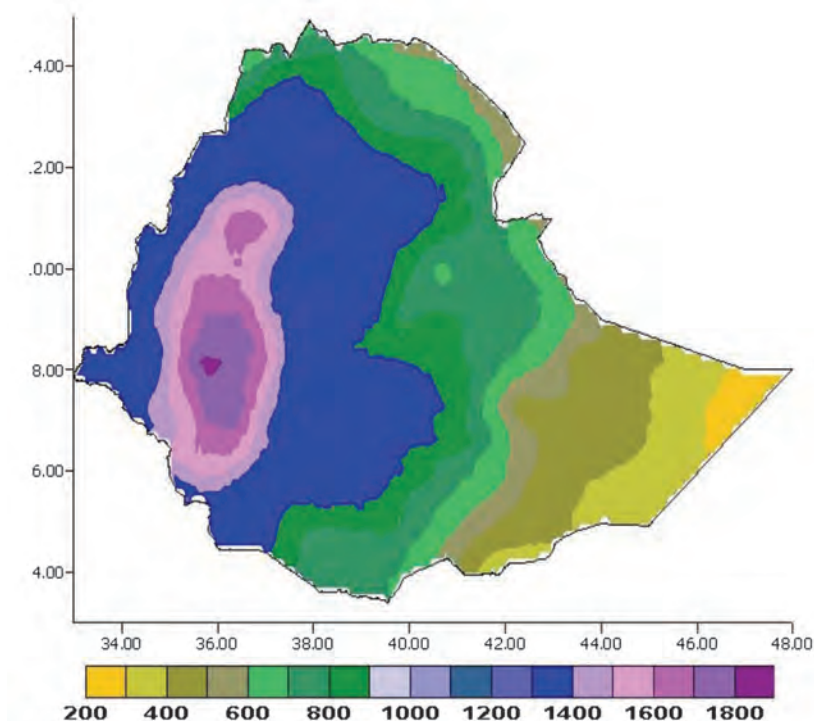


Figure 7 Different rainfall (mm yr-1) regimes across Ethiopia; y-axis and x-axis are showing longitude and latitude respectively.

Source: NMA (2013).

Rainfall is the most important limiting factor in agricultural production systems of low technology countries like Ethiopia. Rainfall variability has more severe effect on the national economy than drought and other hydrological impacts (World Bank, 2006). The variability of rainfall pattern is highly correlated with the GDP of the country. The temporal variability of rainfall has been a major cause for fluctuation and failure of cereal production over the last a few decades (Bewket, 2009). Admasu (2004) also indicated that rainfall variability is highly correlated with production of barley and wheat in the central highlands of the country.

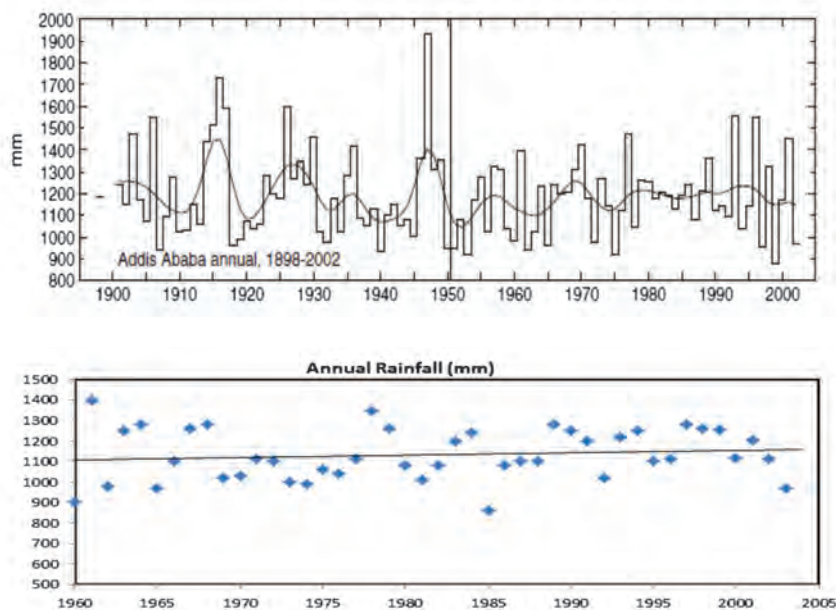


Figure 8 Trend of annual rainfall over Addis Ababa (upper panel) and over the country as summarized from 13 watersheds (lower panel).

Source: Conway et al., (2004); Cheung et al. (2008).

3.1.3. Stream flow

Gauging and records of stream flow

Ethiopia lies in high rainfall tropical and sub-tropical regions of Africa (Figure 9). Because of the high rainfall, there are many streams flowing from the uplands to the low lands. There are 12 river basins with a flow amount of $ca\ 124 \times 10^9\ m^3\ yr^{-1}$, where 75% of the flow comes from three rivers (Abbay, Baro-Akobo and Omo-Ghibe) (Figure 10, Table 8). The total gauge stations of streams are $ca\ 550$ in the 12 basins; where 80% of these stations are operational (www.mowr.gov.et/2014). However, most streams in the country are yet to be gauged. Denser gauge stations are found in the Abbay basin where 35% of the streams have hydrological records at daily basis. Most of the gauging stations are installed since 1960s when the US Bureau of Reclamation (USBR)

was collaborating for large scale water resource assessment. There were also few stations installed before 1960 at the outlets and major junctions of the main rivers. The Hydrological Department at the Ministry of Water, Irrigation and Energy is responsible for collection, archiving, processing and delivery of stream flow data.

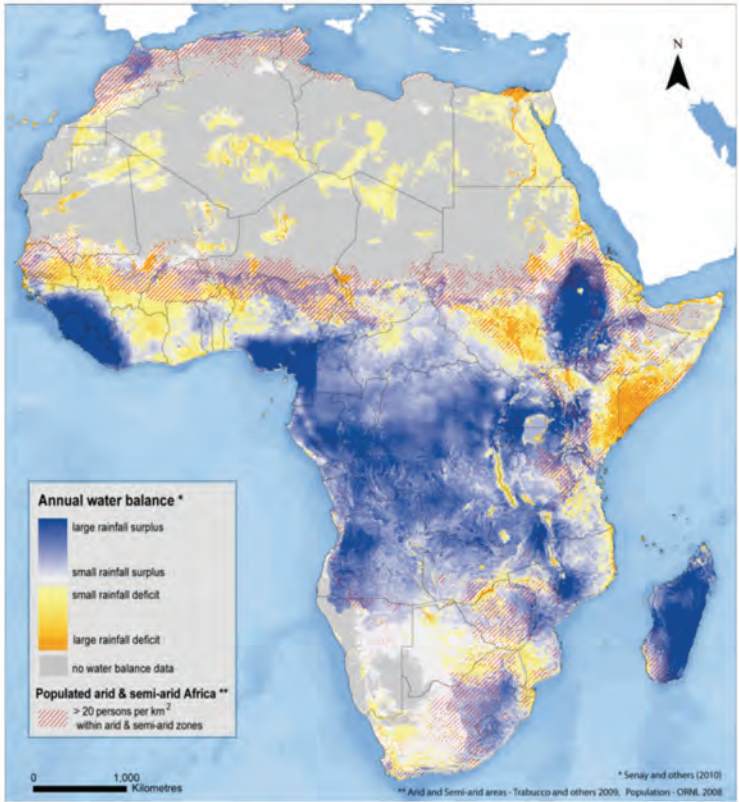



Figure 9 Rainfall/surplus water distribution across Africa

Source: UNEP (2010).

River Basins

Rivers originating from the mountainous highlands adjacent to the rift valley flow further to the periphery of the country. So, rivers from the northwestern



highlands flow towards southern and western periphery of the country; while rivers from the southeastern highlands flow towards southern and eastern periphery of the country. Major flow generating river basins, among the 12, are discussed as follows.


Abbay: The Abbay basin is located in the central, west and northwest part of the country (Figure 10). It lies between $7^{\circ}45'$ – $12^{\circ}45'$ latitude and $34^{\circ}05'$ – $39^{\circ}45'$ longitude. Abbay starts from Lake Tana (the biggest lake of the country) and flows towards Sudan and consists of the largest flow amount, ca 45% of the country's total flow. Abbay basin covers 18% of the area of the country. Abbay generates the biggest quantity of the Nile water (more than 62% [Mohamed et al., 2005]). There are 160 established gauge stations in the Basin; out of which 131 of them are operational.

Awash: The Awash basin starts around the mountains close to Ambo some 100 km to the west of Addis Ababa. It flows to the eastern part of the country across the Rift Valley floor to the northeast. Awash basin stretches from 4195 m asl at Ginchi area west of Addis Ababa to Lake Abhe at 210 m asl close to the border of Djibouti (Taddese et al., ILRI). Awash basin is the most utilized river basin of Ethiopia for the purpose of water resources development. Ninety seven gauge stations are found in the basin, out of which 72 of them are functional (www.mowr.gov.et/2014).

Baro-Akobo: The Baro-Akobo is located in the southwest. Despite sharing less area coverage within the country than Abbay, Awash, Omo-Ghibe, Genale-Dawa and Wabe-Shebele; it generates the largest specific discharge in the country. It flows towards South Sudan and joins the Nile proper. There are 32 functional gauge stations in the basin.

Genale-Dawa: The Genale-Dawa basin is located in the southern part of the country (Figure 10). It is the largest basin after Wabi-Shebele and Abbay (Awulachew et al., 2007). The flow starts from the second highest peak mountain of the country – Mount Batu (4385 m asl) in the Bale Massif. It flows to Somalia. The Genale-Dawa has 36 gauge stations which are operational out of 38 originally established.

Omo-Ghibe: The Omo-Ghibe flow starts from the southwest part of the country. This area generates the highest flow for all Omo-Ghibe, Abbay



and Baro-Akobo. It ends at Lake Turkana (500 masl) in Kenya after flowing south-wards. It flows from a 4200 m asl Mount Ghuge in the southwest. In the Omo-Ghibe basin there are 57 gauging stations, but only 46 of them are operational.

Rift Valley Lakes Basin: It is located in the central lowland part of the country. It is characterized by rich biodiversity. Most of the wildlife reserves and lakes of the country are found in this basin. The basin covers about 52 000 km². The elevation ranges from 500 m asl to 3000 m asl. This basin is more known for its rich groundwater resources rather than stream flows. However, the groundwater is fluoride rich. There were 70 gauge stations established in the beginning, but only 54 of them are functioning.

Tekeze: The Tekeze river basin is located in the northern part of the country, and it is one of the three rivers flowing from Ethiopia to the Nile. It is bordered by Mereb River (partly located in Eritrea) to the north and by Abbay to the south. Tekeze River starts flowing from the highest mountain of the country, Ras Dashen (4620 m asl) and drops to a lowland of 500 m asl before leaving to the Sudan. Tekeze drains the most rugged and dissected topography of the country, mainly in Gondar and Tigray. Among the 40 gauging stations established in the basin, all are functional except one.

Wabi-Sheble: The Wabi-Shebele is the largest basin in the country in terms of area coverage (202 700 km²) (Awulachew et al. 2007). It starts flowing from central part of Arsi-Bale Mountains to the dry lowlands of Ethiopian Somali Region and then to Somalia. Thirty gauge stations originally established and 20 more added and all the 50 stations are presently operational.

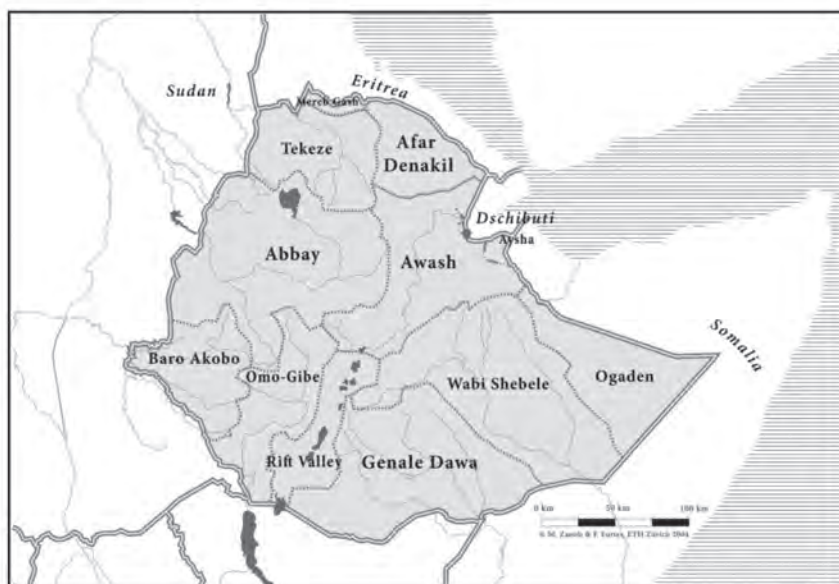


Figure 10 River basins of Ethiopia; separated by broken lines.

Table 8 River basins and their respective area, population and runoff characteristics

Rivers	Basin area (km ²)	Runoff (m ³ 10 ⁹ yr ⁻¹)	Runoff in depth (mm yr ⁻¹)	Sediment in m ³ 10 ⁶
Abbay	199,812	54.8	274.3	40
Awash	112,696	4.9	43.5	19
Aysha	2,223	-	-	-
Baro-Akobo	75,912	23.6	310.9	10
Danakil	74,002	0.9	12.2	-
Genale-Dawa	171,042	5.9	34.5	30
Mereb-Gash	5,900	0.6	101.7	1
Ogaden	77,121	-	-	-
Omo-Ghibe	79,000	16.6	210.1	120
Rift Valley	52,739	5.6	106.2	8
Tekeze	82,350	8.2	99.6	5
Wabe-Shebele	202,697	3.2	15.8	19


Source: www.mowr.gov.et/2014; Awulachew et al. (2007); Woube (1999).



Variability and trends of stream flow

Changes in stream flow depend on scale, location, climatic regime, and the method of detection. Variability and changes of stream flow over the past thousands of years in East Africa is highly related with the rainfall/climate changes associated with the El Nino Southern Oscillation (Gasse, 2000). Changes in rainfall force manifold changes of stream flow in the East African region. Expected changes of hydrology, which are increased runoff and reduced base flow (Melesse et al., 2010; Gebrehiwot et al., 2014a) are variable across scales and location in the country. Legesse et al. (2003) found a 30% reduction of simulated discharge with a scenario of 10% change of rainfall, while a 15% decrease in simulated discharge if air temperature increases by 1.5°C in southern part of Ethiopia. The effective rainfall or stream flow generation is highly dependent on the pattern of rainfall (Figure 11). A 500 mm cumulative rainfall has been found as an effective rainfall in generating streamflow in the highlands of Ethiopia (Liu et al., 2008).

Long term records of stream flow do not show any detectable trends in most rivers (Figure 12). However, some of the variables of stream flow like runoff coefficient and peak discharge have shown increment over the years (Senay et al., 2009; Gebrehiwot et al. 2014a). The increased runoff coefficient has resulted in increment of annual flow to downstream areas as well. Such changes are partially attributed to land degradation and land use change (Hurni et al., 2005; Senay et al., 2009). The common pattern of land use change is from natural vegetation to cultivated or degraded land. Urbanization caused an 80% increase of runoff coefficient between 1984 and 2002 in the upstream part of Awash basin; where the main urbanization refers to the city of Addis Ababa and its surrounding (Berhanu and Ayalew, 2013). Gebrehiwot et al. (2014a) found that few changes were detected in low flow, high flow and low flow index, which are following inconsistent direction of trend among 12 rivers in northwestern highlands of Ethiopia. Trend analysis in some of the streams in the Abbay basin showed decline of low flow from 1990s onwards (Melesse et al., 2010; Gebrehiwot et al., 2014a). Awash River showed reduction of flow amount between 1968 and 1997, mainly because of water utilization in the upstream (Berhanu and Ayalew, 2013).



Seasonal changes are more pronounced than annual changes – such changes are more important in areas of low technology agrarian community like in Ethiopia. For instance, stream flow reduction in spring (*Belg*) season contributed to more than 75% of the annual changes in Abbay annual flow between 1912 and 1987 (Conway and Hulme, 1993). A specific discharge of $0.6 \text{ m}^3 \text{ s}^{-1}$ has been found as a 10-year recurrent low flow in the streams of northern Ethiopia (Melesse et al., 2010). Different pattern of trends were observed along different classes of time scales in the last half a century (Melesse et al., 2010; Gebrehiwot et al., 2013; Gebrehiwot et al., 2014a).

Historical trends and variability are better explained when community knowledge is incorporated in hydrological analysis. Forty-two (1960-2002) years hydrological records in Koga didnot show any detectible changes; but, community knowledge revealed that the change of the hydrologywas masked by a wetland located just above the gauging station. This suggestion was drawn from a community knowledge analysis (Gebrehiwot et al. 2010).

Stream flow across scale and location

Variability and changes in flow regimes are more pronounced at small spatial scales than big rivers (Melesse et al., 2010. Hurni et al. (2005) found that the long-term trends of stream flow/runoff are highly influenced by land degradation and population growth at plot and micro-watershed levels. As forested landscapes werechangedinto cultivated lands, runoff increased by 5-40 times. Farm level or small scale watersheds showed changes in stream flow, which are not consistent across locations in the country (Hurni et al., 2005; Bayabil et al., 2010). In semi-arid parts of the country, soil conservation activities induced reduction of runoff and increased baseflow (Hurni et al., 2005). Bayabil et al. (2010) also indicated that topography plays a key role in changes of runoff at small scale than land use and climate.

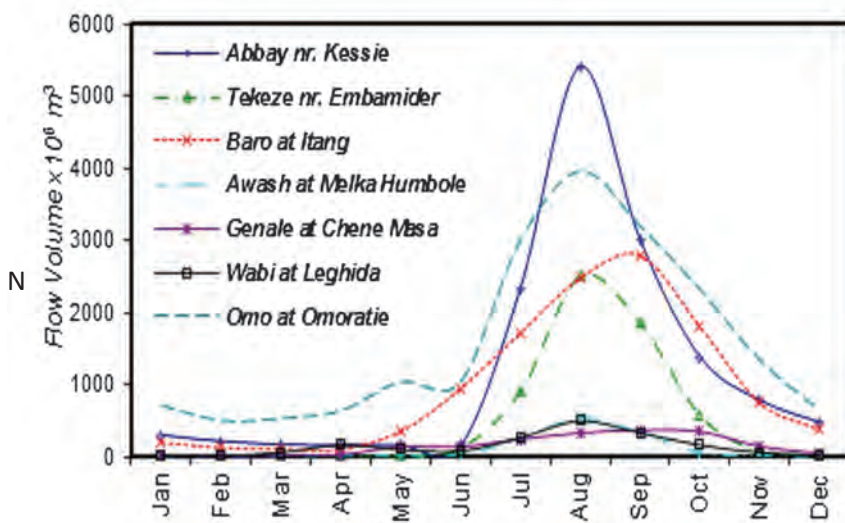


Figure 11 Spatial and seasonal variability of stream flow across Ethiopia

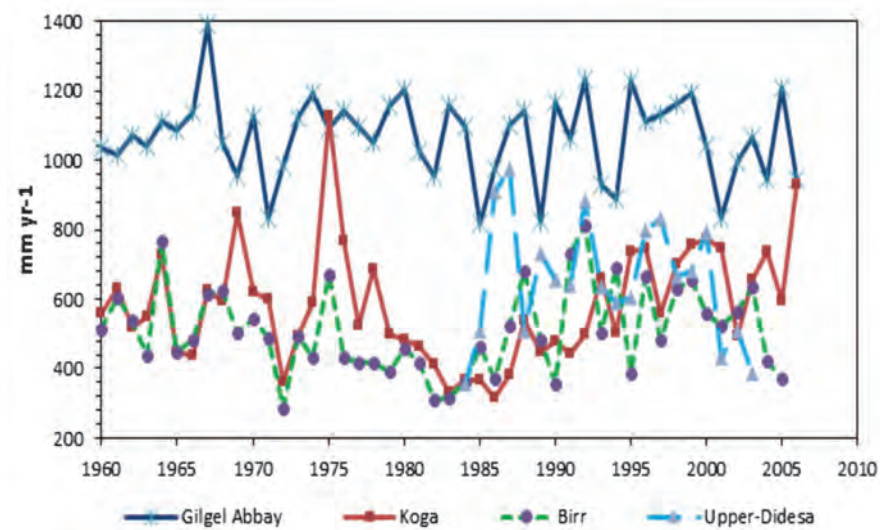



Figure 12 Time series flow data for some rivers in the northwestern highlands of Ethiopia

Source: Gebrehiwot et al. (2014a).

The variability of flows across basins is high. Among the 12 basins; Abbay, Baro-Akobo, Omo-Ghibe and Tekeze show higher seasonality than Genale-




Dawa and Wabi-Shebele (Figure 11). Johnston (2012) revealed that the northwestern highland rivers showed significant flow difference before and after 1960; where as Abbay's flow decreased by 10%, Baro-Akobo's showed no change, and Tekeze flow decreased by 30% after 1960. The middle part of Awash basin showed increment of annual flow in some of the tributaries while reduction was evident in annual flow in some others (Berhanu and Ayalew, 2013). The reduction of annual flow in some parts of the basin could be because of the considerable expansion of upstream water resources development.

On the other hand, spatial and inter-annual variability are widely observed than trends over time; this has been seen in some of the gauged streams in the northwestern highlands of Ethiopia (Figure 12). Stream flow is variable across stations, similar to the variability of rainfall (Figure 11). The spatial distribution of stream flow follows the rainfall regime classification indicated above. Higher flow amount is from the southwestern part of the country, and 75% of total annual flow of the country is observed from Abbay, Omo and Baro.

2.1.4. Groundwater

The distribution of available groundwater across Ethiopia is not well known (Figure 13). The groundwater of the East Africa region is governed by the hydrogeology matrix in and out of the rift valley system and adjacent highlands (Kebede et al., 2007; Ayenew et al., 2008). The rift valley system divides Ethiopia in to three broad topographical features – the northwestern highlands, the southeastern highlands and the rift valley lowland. The age of Ethiopian groundwater is classified as modern – not older than 3000 yrs (Kebede et al., 2007).

The total annual groundwater recharge of the country is estimated to be more than $28 \times 10^9 \text{ m}^3$ (www.mowr.gov.et/2014). The rift valley systems are endowed with deep groundwater availability (GWMATE, 2011) (Figure 13). Fifty percent of the recharge of groundwater of the rift valley system comes from the highlands (Kebede et al., 2007). There is high recharging rate in the highlands of Ethiopia where permeable rocks are found; however, the aquifer is shallow because of the fast discharge to the rift valley system (Ayenew



et al., 2008). This phenomenon is responsible for creation of springs at the boundary of the faults at the foot of mountains. Recent studies around Addis Ababa revealed deep groundwater resources in the highlands and escarpments of the Rift Valley.

East Africa, including Ethiopia, is next to Southeast Asia and North Africa in groundwater depletion (Doll et al., 2014). However, in many reports, groundwater is yet to be exploited to optimum level (Awulachew et al., 2007). Because of land degradation in the highlands, the trend of recharge of groundwater is reducing; because of this, springs are drying up in downstream areas. Recently, watershed management programs in the highlands are creating conducive environment for the recharge and some springs have reappeared. Long lasting well-water production is related with fault lines and permeable sediments, both in the rift valley and in the highlands (Ayenew et al., 2008). The big gap in knowledge about the distribution and extent of groundwater hinders to draw the trend of groundwater utilization. Megetch-Seraba, in northern Ethiopia, is the largest project so far known designed to irrigate 4 000 ha of land through pumping groundwater (www.mowr.gov.et/2014).

The best identification mechanism to know the chemical composition of groundwater is computing mean residence times (MRT) (Sani et al., 2012); however, MRT has not been well studied either in the highlands or in the rift system. Most of the highlands groundwater quality is calcium-magnesium carbonate water, while sodium carbonate is found in most of the rift valley lowland groundwater (Ayenew et al., 2008). Large amount of dissolved salt and alkaline water are common in the rift valley groundwater (British Geological Survey, 2001). The alkalinity is because of the high concentration of fluoride. Fluoride concentration goes up to 60 mg/l in some groundwater samples (Ayenew et al., 2008).

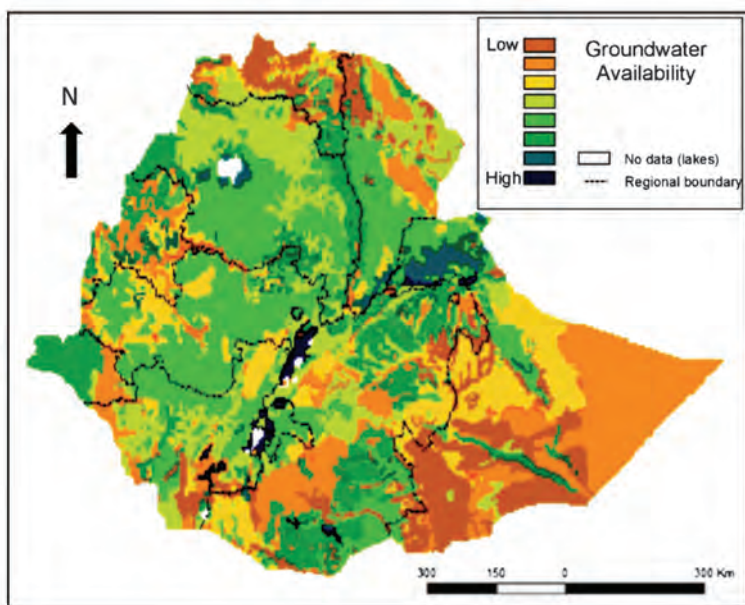


Figure 13 Groundwater availability in Ethiopia.

Source: Reproduced from British Geological Survey (2001).

3.1.5. Evapotranspiration

Knowledge of the extent of evapotranspiration is essential for physical and agricultural water management. There are no details of evapotranspiration estimates for different landscapes in Ethiopia as compared to rainfall and streamflow. The available estimates are scarce and depend on secondary sources (remote sensing analysis, calculations based on other climatic variables). Satellite data analysis using SEVIRI in East Africa region, including Ethiopia, showed good estimate of reference evapotranspiration when validated with ground-measurements ($R^2 = 0.73$) (Sun et al., 2011).

There is high spatial variability in evapotranspiration in the country like the climatic variables indicated above (Figures 14 & 15). There are six potential evapotranspiration regimes (Figure 14). The mean annual potential evapotranspiration ranges from 2350 mm in the lowlands to 620 mm in the highland mountains (Berhanu et al., 2013). Evapotranspiration follows the vegetation eco-regions and topographic elevation of the country (Demel,

2002). Potential evapotranspiration is much higher than rainfall in most lowland parts of the country. For instance 1800 mm of annual potential evapotranspiration is estimated in most (lowland) parts of the Awash Basin where the annual rainfall is less than 850mm (Berhanu et al., 2013).

Temperature is the main climatic variable used in the analysis of the trend of potential evapotranspiration. Trends and changes of temperature are better studied than evapotranspiration over the country. Temperature has been increasing in many parts of the country, as it has been the case in many places in the world (www.ethiomet.gov.et, 2014). Mean annual temperature increased by more than 1°C in the years between 1960 and 2006 (McSweeney et al., 2010). Mekasha et al. (2014) investigated the trend of temperature from 1967 to 2008 for 11 stations across the country; and they found that daily maximum temperature increased in all stations except two stations, while daily minimum temperature partly increased and partly decreased. In addition, the frequency of coldest nights, those causing frost, decreased in the years between 1960s and 2000s (ACCRA, 2011).

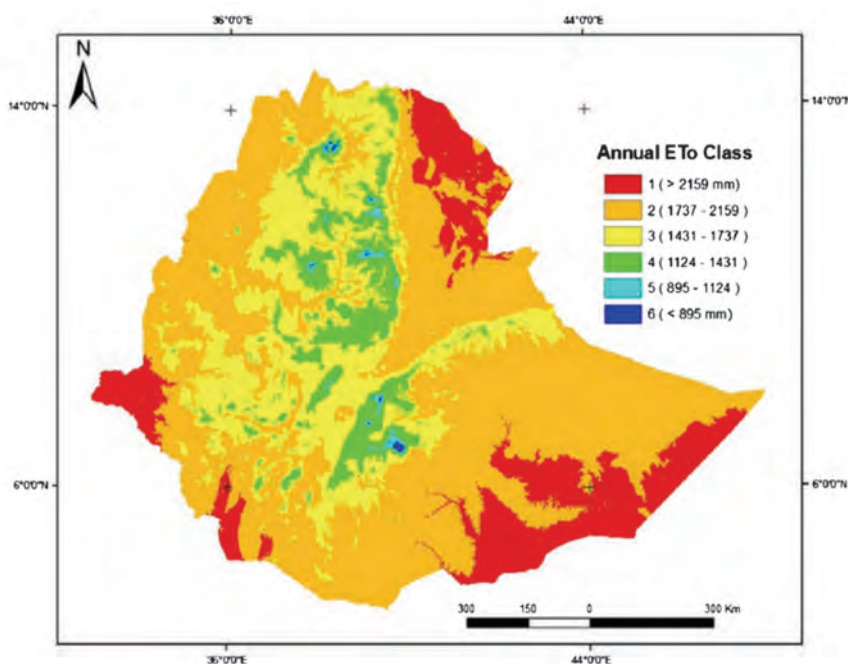


Figure 14 Potential evapotranspiration (mm yr⁻¹) regimes across Ethiopia

Source: Berhanu et al. (2013).

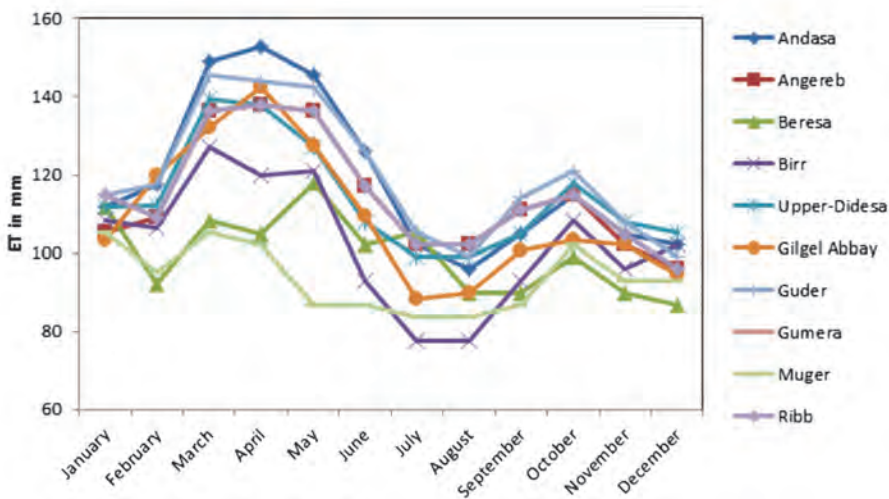


Figure 15 Season variability of potential evapotranspiration insome of the rivers in the Abbay Basin.

3.1.6. Soil erosion, sedimentation and soil moisture

Historical background to soil erosion research and conservation

Soil erosion has been happening for centuries in Ethiopia (Derbyshire et al., 2003). However, it has been accelerated ($> 42 \text{ t ha}^{-1} \text{ yr}^{-1}$) since a century ago following the fast growth of population and enhanced deforestation (Hurni, 1988). Soil erosion is widespread all over the highlands of the country, which covers some 43% of the land mass. The Ethiopian highlands are inhabited by about 88% of the total population and 95% of regularly cultivated land is found here (Bewket, 2007). The high population pressure and steep hillside cultivation are the major causes of accelerated soil erosion.

Farm level soil erosion

Small scale watershed (farm level) soil erosion has been drawing the biggest attention in the last decades in soil erosion research and conservation activities. Soil erosion and conservation activities were given more emphasis for land degradation mitigation which is impacting agricultural production in

the highlands of the country. The Soil Conservation Research Program (SCRCP) was initiated in 1981 by the Swiss Agency for Development and Co-operation at small scale watersheds/farm plots to support the assessment and conservation endeavors which were started by the Ethiopian Government (SCRCP, 2000). SCRCP did a comprehensive assessment of soil erosion on test plots and small watersheds, mainly in agricultural landscapes for decades. There were 6 stations throughout the country, where 4 of them have more detail data. From the records of soil erosion from these stations it seems that the trend of soil erosion has not been changing (Figure 17); however, the cumulative eroded soil increased, and this is very critical as the highlands have thin shallow soils.

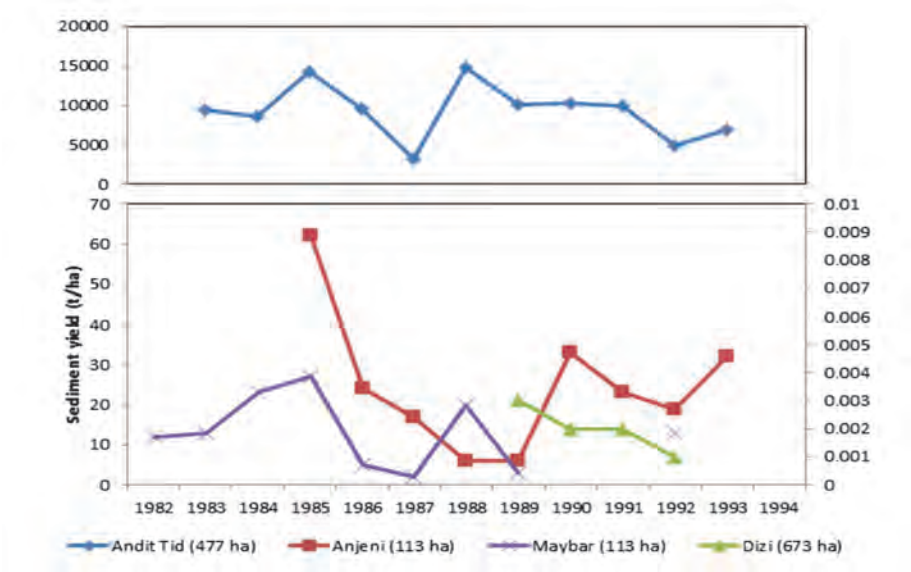


Figure 16 Time series of sediment load from experimental watersheds of Soil Conservation Research Project (SCRCP); Dizi’s trend is shown in the secondary axis
Source: SCRCP (2000).

Stream/river erosion and sediment load

Soil erosion and sedimentation from gullies, stream banks and big river channels has not been accounted for in many research documents and

reports. However, it is estimated to be a serious cause of land degradation in the country (Tebebu et al., 2010). Though the sources and impacts are not well known, there are records of suspended sediment for the major rivers at different river discharge gauge stations (Table 8). Table 8 shows the annual average soil loss and suspended sediment for two different time steps for major rivers of the country.

3.1.7. Soil moisture

Soil moisture is an important environmental factor for agricultural activity in mid- and high-altitude areas of the country. Soil moisture variability is highly dependent on the pattern and level of rainfall, humidity, temperature, and physical properties of the soil. Soil moisture reaches up to 80 cm deep in sandy loam soil texture in the highlands of Ethiopia (Kamara and Haque, 1987). The trend of soil moisture has been increasing in areas where water harvesting and soil conservation structures are constructed (IWMI, 2009); while the trend of soil moisture is decreasing in areas where soil degradation is advancing (Hurni et al., 2005). On the other hand, because of the recent increase in implementation of soil and water conservation practices, soil moisture has been increasing in many parts of the country (Figure 17) (Herweg and Ludi, 1999; Haile et al., 2006).



Figure 17 Soil moisture improvement after soil conservation practices in Abraha-we-Atsebeha watershed, northern Ethiopia.



3.1.8. Water quality

Groundwater is the source of water supply in many parts of the country. The two most notable water quality problems are siltation and contamination of groundwater. Siltation and groundwater contamination are causing problems for accessibility and utilization of household water supply, irrigation, hydropower, and residual soil moisture. Contamination of groundwater includes flourdification and salinization. The trend of potable water usage has increased immensely in the last 20 years; from 13% to 52% of the population (www.data.UNICEF.org, 2014). One of the critical problems of groundwater is high concentration of fluoride in the rift valley system and some parts of the highlands.


Sanitation is the worst among all water developmental aspects in the country; Ethiopia is the least among developing countries. The overall sanitation coverage of the country was <5% in 1990; it grew to ca 25% in 2012 (www.data.UNICEF.org, 2014). However, there is an improvement in general when the trend of sanitation is considered. The country's sanitation improved from 2% in 1990 to 24% in 2012; it is from 1% to 23% when the rural sanitation improvement is considered (www.data.UNICEF.org, 2014).

3.1.9. Lakes and wetlands

Ethiopia has more than 20 fresh and crater lakes; more than 12 major wetlands (Awulachew et al., 2007). The figure is far higher in some literatures (Ayenew, 2009). Most of the lakes are distributed in the Rift Valley area. The wetlands are more concentrated in the southwest part of the country. Lakes and wetlands are the most threatened hydrological systems in the country.

3.1.10. Droughts and floods

Droughts and floods have been environmental problems in Ethiopia since historical times. Studies on Ethiopian lakes inferred the occurrence of droughts which ended the kingdom of old Egypt (Walker, 2011). Ethiopia, being in sub-humid to arid region, as well as experiencing high land degradation, is highly prone to droughts, floods and other natural disasters. Droughts and floods have been experienced in the last 30-60 years over Eastern Africa,



including Ethiopia as a result of extreme rainfall (IPCC, 2014). The magnitude of droughts and floods are becoming higher and more frequent in Ethiopia since the 1970s.

Droughts and floods are dependent on the variability of rainfall anomalies. Zaroug et al. (2014) linked the occurrence of droughts and floods in northern highlands of Ethiopia with the occurrence of El Nino and La Nina. They found that there is a likely occurrence of floods when El Nino is followed by La Nina, as well as a highly likely occurrence of drought when El Nino event occurs during April to June. Wagesho et al. (2012) also noted the strong connection of floods and increased global positive sea level temperature anomalies; while droughts were related to negative sea level temperature anomalies.

Droughts and floods are the biggest natural disasters in Ethiopia. Both droughts and floods are apparent and recurrent in the country. Drought has been known for causing disastrous famines. Millions of people were displaced, starved and died because of droughts and floods (World Bank, 2006). Droughts are often the causes of food deficit and starvation in Ethiopia. From 1950 to 2009, Ethiopia has been hit by 20 major droughts; the worst among all African countries. The worst drought was in the year 2002/2003, which affected 13 million people (20% of the total population) (Figure 18).

Floods are major problems in the low lying areas. Human and animal lives, agricultural lands, settlements and infrastructure are affected. The occurrence of floods is by far more frequent than droughts (1 drought event to 5 flood events) (www.gfdrr.org, 2011). However, the impacts of floods are far more less than impacts of droughts. For instance, since 1999, 3 droughts and 7 floods were registered; where droughts affected ca 20 million people and floods affected ca 0.9 million people (www.gfdrr.org, 2011). Because of the transformation in disaster management, consequences of droughts and floods have been checked partly. Ethiopia has started disaster management system since the mid 1970s (Abebe, 2009). Until the end of the 1980s, disaster management has been implemented through traditional-rehabilitation type; while after the 1990s it has developed into a participatory institutional strategy. Recently, floods and droughts, as well as other disasters are better managed than ever.

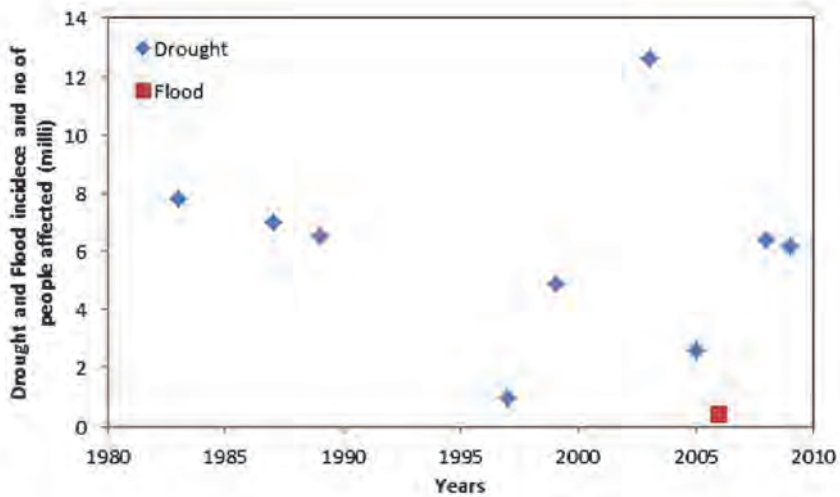


Figure 18 Events of droughts and floods with impacts on more than 100,000 people

Source: www.preventionweb.net/year


*Though the number of flood-affected people is low compared to drought-affected people, the number of floods is more frequent than that of droughts.

3.2. Drivers of change

Different anthropogenic and natural processes cause changes in water resources. Climate change is one among different drivers of change in water resources. Changes in water resources extend from local to global scales. However, changes are more complex in variable hydrological systems like in Ethiopia. The Ethiopian water resources are subjected to different types of change-drivers. These drivers are classified as non-climatic and climatic.

3.2.1. *Non-climatic drivers*

Non-climatic drivers of change of water resources include land degradation, land use change, agricultural water use, household water consumption, dams, and other water use infrastructure (UNESCO, 2011). Water resources are highly affected by these human induced global to local scale drivers. Many low income countries, such as Ethiopia have been enjoying a fast growing economy in the last decade and more likely to continue for decades



to come. The country has been attaining more than 10% annual economic growth in the past decade (World Bank, 2013). Ethiopia is now concluding a five year Growth and Transformation Plan (GTP) (2010-2015); and the next five year GTP is being developed (www.mofed.gov.et/08/03/2015). Water infrastructures are of the leading planned investments in the activities of the second GTP as well. Future water will be changed and modified in different ways by the development activities. Few studies have studied this issue.

3.2.2. Climatic drivers

The impact of climate change predominantly boils down to water resources. With changes in climate continuing for the coming century, the type and rate of impacts on water resources is likely to be unprecedented and overwhelming. All changes happening on rainfall and temperature have various effects on available water resources. Rainfall is the main source of water on the earth's surface while temperature change modifies the water release from the earth surface to the atmosphere. Both rainfall and temperature are changing and highly likely to continue changing in the years to come (IPCC, 2013) (Figure 19). Climate change impacts are impeding African countries' development with different but uncertain range. Climate change affects water and other natural resources directly; Ethiopia will face 1.25 °C change per 1 °C change over the globe (Figure 19).

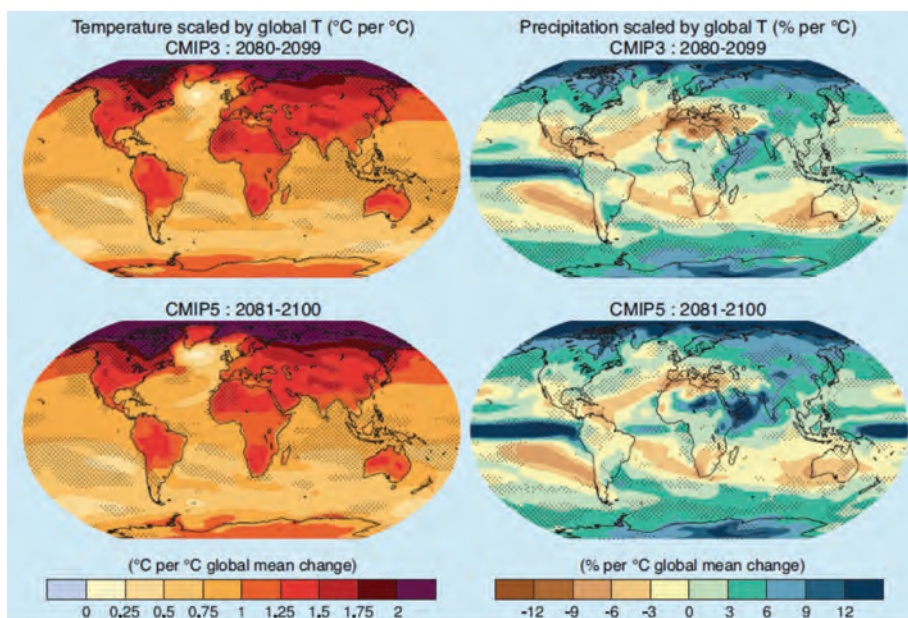



Figure 19 Global temperature and precipitation change in reference to a 0C change in temperature over the next century using Coupled Model Intercomparison Project Phase 3 (CMIP3).

Source: IPCC (2013)

Because of changes in rainfall patterns and temperature; stream flow, available soil water, groundwater recharge and water quality are changing. These changes will alter future water demand and consumption. Water demand and consumption will be critically impacted by anthropogenic drivers, as well. The changes in water resource variability are expected to be intense after 2025, especially in African countries (UNESCO, 2011).

3.3. Methodological developments in hydrological impact assessment

A two-stage procedure is followed in many studies of hydrological impacts of climate change. This is downscaling global and regional predictions (GCMs and RCMs) followed by hydrological modeling. There is other form of approach that considers development of different scenarios based on past and existing trends in the hydrological regime; then predicting the future



(Olsson et al., 2013). The later approach works for studies targeting impacts of non-climatic drivers.

Different future greenhouse gas emission scenarios are developed by IPCC SRES (IPCC Special Report on Emissions Scenarios) (IPCC, 2000). These scenarios are bases for using GCMS and RCMS for prediction of future impacts, including on water resources. Meanwhile, limitations of these scenarios upon downscaling for water resources impacts are well acknowledged (Wilby et al., 2004). Prediction based studies have considered calibration of GCM or RCM results with historical data to compromise with standardized emission scenarios (Conway and Hulme, 1993; Adger et al., 2003; Kim et al., 2008; Soliman et al., 2009; FAO, 2011;). In some studies better performance of models for averaged or summarized data resolutions is reported (Hasan and Elshamy, 2011; Gebrehiwot et al., 2013). However, summarized or averaged data need to be taken with caution for prediction of instantaneous flow events; as these ones need higher resolution data.

The uncertainties and variability in rainfall distribution are the main challenges for prediction models in Ethiopia (Conway and Hulme, 1993; Di Baldassare et al., 2011). Ensemble model predictions are supposed to address most of the uncertainties inherent in single model applications.

3.4. Projected risks, vulnerabilities and impacts in the water sector

People in the developing world are more dependent on the water resource variables which are highly exposed to impacts of climate change. This is because of low technology, weak institutional capacity, higher reliance on natural resources, and stressed water resources existing in the developing world (Urama and Ozor, 2010). In most African countries rainfall variability is the main driver for variability of streamflow and soil moisture (Adger et al., 2003). Streamflow and soil moisture are critical conditions for agricultural productivity. The variability of rainfall and streamflow itself varies across spatiotemporal scales in Ethiopia (Conway and Hulme, 1993).

3.4.1. Temperature and rainfall

Temperature and rainfall are climate variables that predominately affect water resources variability and availability. As Ethiopian economy is heavily dependent on rain-fed agriculture, understanding how climate change will affect temperature and rainfall variability is of paramount importance. Jury and Funk (2013) have used different climate models to analyze trends of temperature and rainfall over Ethiopia. According to their study, seasonal rainfall of March to June shows small reduction across the southern Rift Valley (3.5°–8°N, 38°–42°E) and steady decline of June to September rainfall across western Ethiopia. The fact that these areas are highly populated and characterized as high potential agricultural areas, the likely decline in rainfall is of great concern. Area average air temperature for Baro river basin shows steady upward trend (Figure 20). The average monthly rainfall shows only slight increasing trend (Figure 21). Studies conducted by Asfaw et al. (2013) in BaroAkobo Basin shows that increase in rainfall is likely to reach 24% between 2011 and 2050.

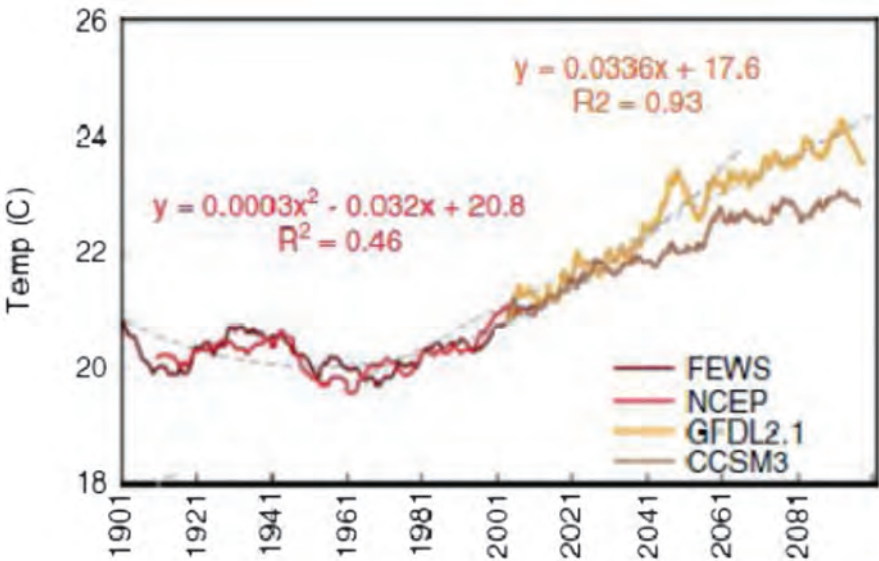


Figure 20 Observed and projected air temperature over Baro river basin

Source: Jury and Funk (2013)

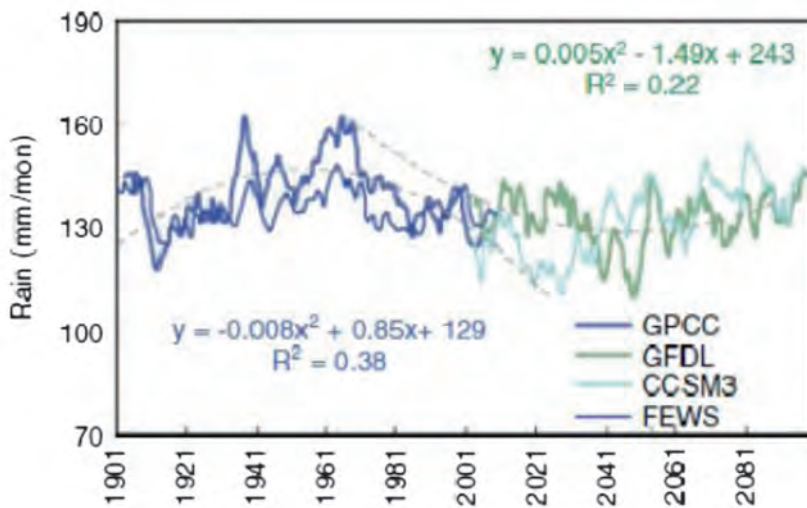
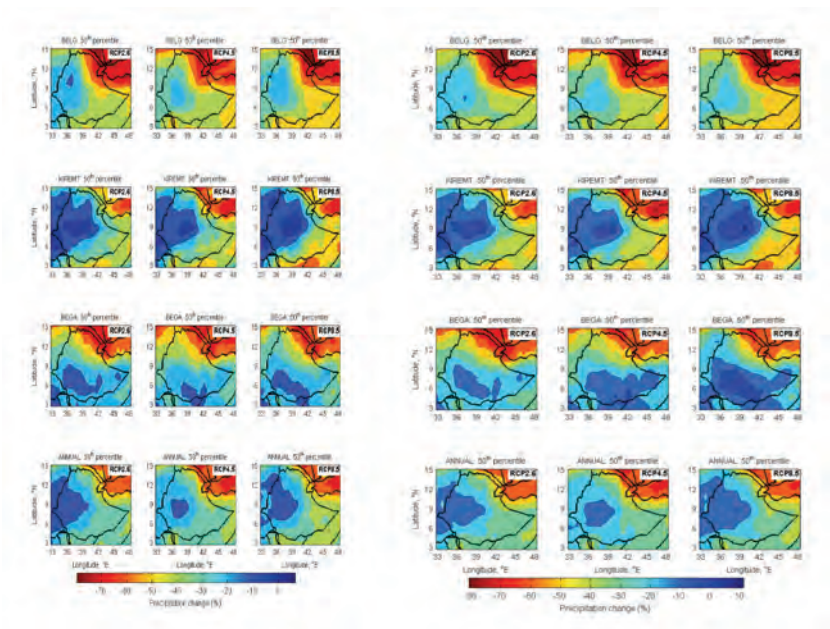


Figure 21 Baro River Basin time series of observed and projected rainfall

Source: Jury and Funk (2013)



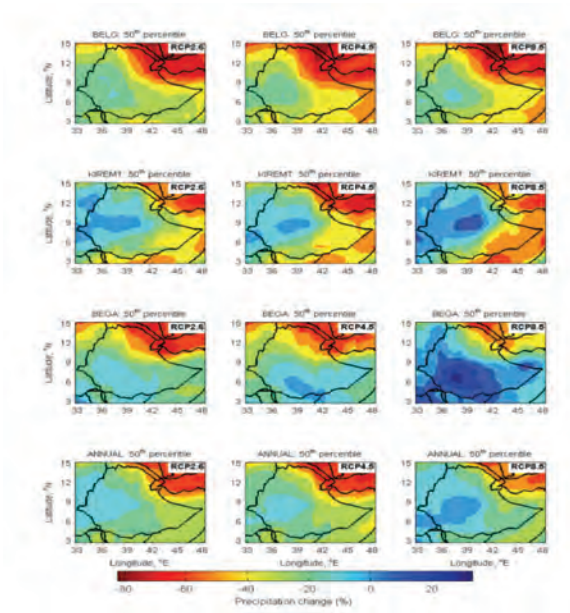


Figure 22 Predicted changes of rainfall over Ethiopia:

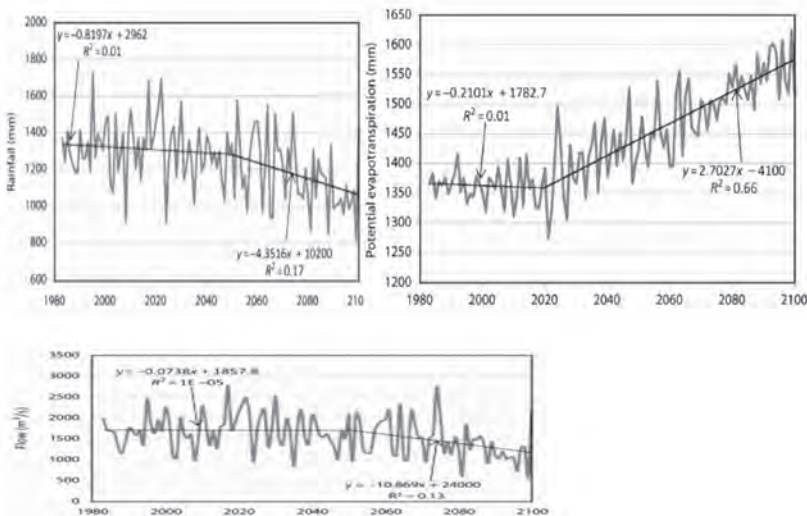


Figure 23 Predicted trend of rainfall, evapotranspiration and annual flow amount in the Blue Nile river at Ethio-Sudan border

Source: McCartney and Girma (2012)



3.4.2. Water availability and streamflow

According to UNECA (2011), Ethiopia's water availability per capita changes from ca 2200 m³ in 1990 to ca 1000 m³ in 2025 because of climate change and other drivers. However, soil moisture is expected to increase in many parts of the highlands. This is also shown by Elshamy et al. (2009) that runoff coefficient decreases by about 3.5% to the end of 21st C in reference to the end of the 20th C.

Future changes of stream flow in Ethiopian rivers shows reduction of water yield in most predictions. Kim et al. (2008) estimated that 14% reduction of runoff will be expected with 3% increase in rainfall and 1.7°C rise in temperature; and 11% runoff reduction is expected with 6% increase in rainfall and 2.6°C increase in temperature. A study on the Blue Nile river flow using 17 GCMs of IPCC 4th Assessment found that 11 of the models showed a reduction of flow all along to the end of the century (Elshamy et al., 2009) (Figure 23). However, there are local differences in the trend of stream flow (Figure 24). Local differences could be attributed to differences in climatic and physiognomic features of the country. In the coming mid of the century, annual flow of Blue Nile river at Lake Tana is expected to decrease; whereas downstream along the river course is expected to increase (McCartney and Girma, 2012). Moreover, the pattern of changes differs between seasonal flows. For instance, the flow of Didesa river, one of the tributaries of Blue Nile River, shows increment of flows in autumn before decreased flow in summer (Gebre et al., 2015). This is also supported by Mellander et al. (2013) that Didesa river (Southern part of the Blue Nile) will be more seasonal than the northern part of the Blue Nile basin. The general reduction of flow in parts of the Blue Nile is more attributed to the increase in evapotranspiration (Conway and Hulme, 1993).

Future annual flow change varies between -4 and 18% among the GCMs in the watersheds of the Rift Valley as compared to the existing flows (Wagesho et al., 2013). However, higher magnitude and frequency of extreme events are common in most of the model predictions those applied in this part of the country.

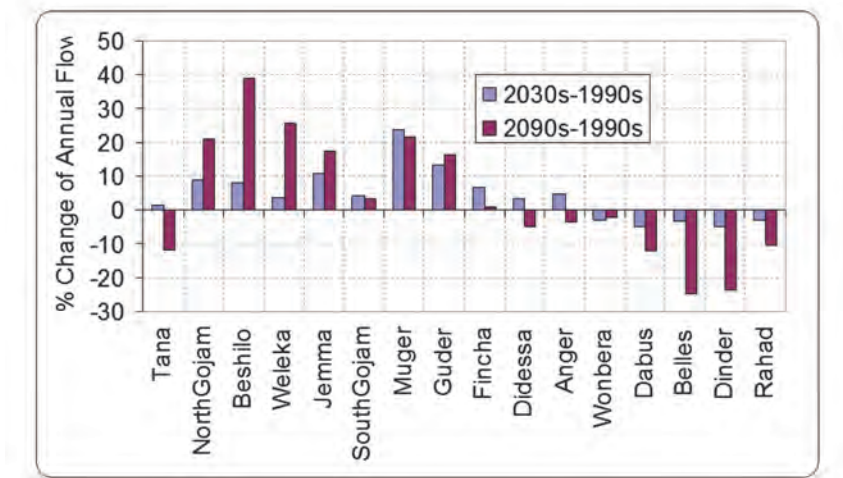


Figure 24 Predicted trend of annual flow amount in the different watersheds of the Blue Nile River.

In general, Ethiopia will face two broad challenges with regard to water availability. Climate change accompanied with rapid population growth affects lowland pastoral areas with dramatic warming; while highlands could face high and intense rainfall which in turn increases the available water (USGS, 2012). Meanwhile the expected intense rainfall in the highlands is also expected to exacerbate soil erosion and land degradation. Because of the increased runoff in the headwaters, it will be less likely that transboundary rivers suffer reduction of flow; even with increased water demands and population growth (Kim et al., 2008).

Impacts of climate change on water resources are concerns for crop yield failure and food insecurity in sub-Saharan Africa (Moreland and Smith, 2012). Because of the increasing evapotranspiration and water use the groundwater reserve in many parts of the rift valley system will be jeopardized both in amount and quality (START, 2011). This is because that as evapotranspiration increases the concentration of saline and other chemicals increases.



3.4.3. Water use and demands

Ethiopia is set out to reach middle income status by 2025 with the trend of existing economic growth. However, trade logistics and energy supply will be potential bottlenecks for future development endeavors. Water is and will be the backbone for energy supply in the growing economy.


More than $165 \times 10^9 \text{ m}^3$ water is expected to be stored in the reservoirs for hydropower and irrigation in the near future (McCartney et al., 2012). Reservoirs for hydropower generation are expected to increase by 14 times and irrigation needs will increase by 23 times in comparison to the existing extent in the Blue Nile basin of Ethiopia (McCartney and Girma, 2012). Such investments are highly exposed for increased evaporation due to the increment of temperature. Amount of water from the reservoirs will reduce by $0.8 \times 10^9 \text{ m}^3 \text{ yr}^{-1}$ in the end of the century due to increased evaporation loss (McCartney et al., 2012).

3.4.4. Extreme events

As the climate continues to change, floods and droughts are most likely to become more severe in many parts of Ethiopia (Urama and Ozor, 2010). Future SPI (Standardized Precipitation Index) analysis for different time scales showed that frequency, duration and severity of drought will increase in drier areas; whereas reduced droughts will be expected in the wet areas of the Blue Nile Basin (Kim et al., 2008). More floods are expected both from climate change and urbanization in Africa (Douglas et al., 2008). Urban poor and adjacent downstream communities will face severe impacts from flooding.

3.4.5. Water-energy-food nexus

Water, energy and food are indispensable for human well-being, poverty eradication and sustainable development (FAO, 2014). Ethiopia has set ambitious goals and targets in several sectors of the economy including agriculture and energy to reach middle-income status by 2025. The country has registered a double digit agricultural growth over the last decade. This growth is driven by the implementation of a series of development strategies and plans in the various sectors of the economy. With increasing population



growth demand for food and energy also increases. As agriculture is the primary source of national food supply increasing agricultural production is required to be able to feed the growing population. This may be possible through expansion of cultivated area and enhanced agricultural productivity. In line with this, the country aims to increase cultivable land by 13%, crop productivity by 30% and irrigation development by 400% (MoFED, 2010).

Productivity improvement requires integrated soil fertility management through natural resources conservation and appropriate fertilizer use. On the other hand, natural resources such as forests and soils are increasingly being degraded. At the same time, the energy use which currently consists of more than 90% biomass (firewood, charcoal, crop residue etc.) use is shifting towards increasing use of electricity predominantly from large-scale hydropower plants, with the aim to improve access to modern energy sources (Karlberg et al., 2015). The traditional energy supply using biomass has the implication of degradation of natural resources which in turn negatively affects food production. The need for natural resources conservation and increasing forest cover of the country is addressed in the Climate Resilient Green Economy Strategy (CRGE) of the country.

The country is also heavily investing on the development of water resources infrastructure such as dams and reservoirs which could be used for irrigation (food production) and hydropower generation (energy). However, consumptive use of water for irrigation represents opportunity cost for energy generation and supply. Hydropower development is considered as one of the priority issues of the country as stipulated in the CRGE strategy. Energy is needed in all sectors including agriculture for irrigation water pumping, mechanization, fertilizer production and application.

The facts outlined above show that there is a close link between water-energy and food which is being widely recognized globally since recently. This suggests that there is a need for integrated management of the resources to sustainably meet the needs in the different sectors. In Ethiopia, however, water, food and energy are predominantly managed as independent sectors, with little consideration of their interdependence or their cumulative impact on ecosystems (Stein et al., 2014). The water-energy-food nexus perspective highlights the interdependence of water, food and energy systems and the

natural resources that underpin those systems (Figure 25). The approach aims at reducing trade-offs and generating cobenefits for sustainable development. Increasingly, it is recognized that unless their interdependencies are taken into account these different sectors cannot be developed and managed in a sustainable and effective way (FAO, 2014; Stein et al., 2014).

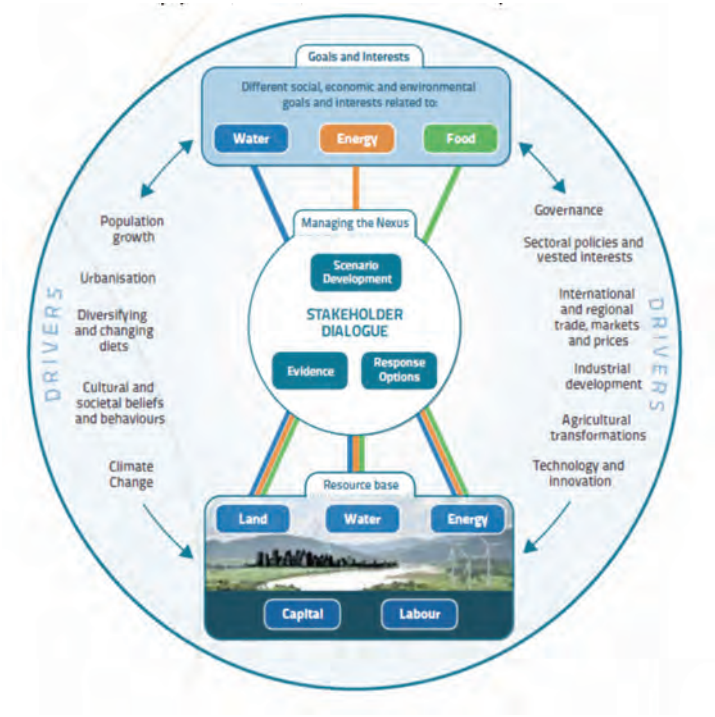


Figure 25 FAO approach to water – energy – food nexus

Source: FAO (2014)

Figure 25 demonstrates the water-energy-food nexus approach of FAO which is a holistic vision of sustainability that recognizes and tries to strike balances between the different goals, interests and needs of people and the environment. Human beings exploit the natural resources to satisfy development needs and nature responds in a complex manner to such exploitation and interventions. This necessitates holistic management.




4. Adaptation and managing risks in the water sector

4.1. Introduction

There is a high level of scientific confidence that climate change is likely to seriously affect the freshwater water resources of the earth, which will subsequently lead to damages on human life, socioeconomic infrastructure and environmental resources (IPCC, 2007). Semi-arid and arid areas are particularly vulnerable to the impacts of climate change, where water is a limiting factor for socioeconomic activities and environmental functions. Areas that have low water infrastructure, particularly developing countries are also vulnerable to the impacts of climate change. Climate change and variability also affect water management practices by affecting the function and operation of existing water infrastructure. Evidence from scientific studies indicate that the negative impacts of climate change on freshwater currently outweigh its potential positive impacts (ECE, 2009). Thus there should be a change to meet the altered conditions and new ways of managing water and designing to adjust with climate change and other human induced environmental changes (IPCC, 2007).

Traditionally, hydrological design rules have been based on the assumption of stationary hydrology, tantamount to the principle that the past is the key to the future. This assumption is no longer valid due to the impacts of climate change. The current procedures for designing water-related infrastructure therefore have to be revised. Otherwise, systems would be over- or under-designed, resulting in either excessive costs or poor performance (Kundzewicz et al., 2007).

The development and implementation of adaptation strategies and risk management in the water sector consists of a broad plan of actions and could follow various approaches such as achieving the minimum level of water security to provide sufficient quantity and quality of water for human livelihoods, so as reducing vulnerability to climate risk (Sadoff and Muller, 2009). Thus, mainstreaming or development-first approach is proposed as an appropriate adaptation for underdeveloped countries' water sector (Oates et al., 2011). Development and implementation of any adaptation policy and strategy in the water resources sector should consider climate change




in the context of the many other increasing pressures on water resources such as population growth, globalization, changing consumption patterns and industrial development (ECE, 2009).

The development and implementation of adaptation strategies and measures should be also based on the results of vulnerability assessments (ECE, 2009). Adaptation procedures and risk management practices for the water sector are being developed in some countries and regions (e.g. Caribbean, Canada, Australia, Netherlands, UK, USA and Germany) that have recognized projected hydrological changes with related uncertainties. In the UK, for example, design flood magnitudes are being increased by 20% to reflect the possible effects of climate change measures to cope with the increase of the design discharge. For the Rhine in the Netherlands the current design flood magnitudes (15,000 to 16,000 m³/s) are planned to increase the design discharge to 18,000 m³/s in the longer term, due to climate change (Kundzewicz et al., 2007).

There are also non climate-drivers that could affect both the quantity and quality of fresh water resources and should be considered in adaptation and risk management planning in the water sector. Some of the non-climate drivers include: land use and land cover changes, urbanization, population growth, economic development, industrialization, pollution, institutional capacity and policy issues (Kundzewicz et al., 2007; Mukheibir, 2008).

Adaptation strategies in the water resources sector at the country level should also include measures covering all the steps of the adaptation chain: prevention, improving resilience, preparation, reaction/ response, and recovery. Measures for prevention and improving resilience are related both to the gradual effects of climate change and to extreme events. Preparation, response, and recovery measures are chiefly relevant for extreme events such as floods and droughts (ECE, 2009). Adaptation should also include disaster risk reduction strategies that must be grounded in local knowledge and communicated broadly so that every citizen is aware about possible adaptation measures (IPCC, 2007).


It is also important to note that water is a vital natural resource that is used by or affects almost all socioeconomic sectors and environmental functions, thus, a very broad range of responses will be needed to the impacts of climate change. Thus, to design and implement effective adaptation strategies in the



water sector, Mukheibir (2008) recommended a cross-sectoral approach and a mix of structural and non-structural, regulatory and economic instruments, and education and awareness-raising strategies should be developed to tackle short-, medium- and long-term impacts of climate change. Thus, adaptation policies and strategies should be developed within the context of Integrated Water Resources Management (IWRM) (ECE, 2009). To address the issues of uncertainty associated with climate change, win-win, no regret and low regret measures should be chosen as priority adaptation strategies (IPCC, 2007).

In developing countries where agriculture is the main economic activity the impact of climate change on water resources is directly related to food security, thus, special emphasis should also be given for agricultural water management (ACPC, 2011). Agricultural water management embraces a whole range of wider practices including *in situ* moisture conservation (e.g. mulching) and *ex situ* water management (e.g. rainwater harvesting, supplementary irrigation, irrigation and various techniques of wetland development) (Amede and Haileslassie, 2010). Irrigated agriculture is becoming an increasingly important intervention towards managing climate variability and change, meeting the demands of food security, employment and poverty reduction (Awlachew and Merry, 2005). Water governance that refers to the wide range of social, economic, political, institutional, administrative systems and decision-making processes and efficiencies play important roles to regulate development and management of water resources and provision of water services (IPCC, 2007) in the face of climate change and variability.

In Ethiopia water resources management and climate change adaptation planning and intervention should give much emphasis to hydrological variability (droughts and floods) (World Bank, 2006; Oates et al., 2011). Recognizing this, the government of Ethiopia has made some important attempts to enhance the level of water security both through public water supply both in the rural and urban areas, development of water management systems: policies, regulations and programs, and development of water infrastructure along the major river basins that could regulate extreme hydrological events and to get economic benefit from hydropower and irrigation developments (FDRE, 2011).



Some water resource developments can be considered as adaptation measures to climate variability whilst others are principally adaptation to increasing demand for water for economic development purposes. Some progress has been made to address the water-related challenges by building multipurpose water reservoirs along major rivers, rainwater harvesting, underground water extraction, irrigation investment and public water and soil conservation practices (FDRE, 2014). Although it is at its early stage, the Ministry of Water, Irrigation and Energy (MoWIE) has developed water sector strategies and programs to enhance the country's water security, reduce water related risks (droughts and floods) and climate change adaptation. Alongside adaptation, the country has committed itself to work on mitigation of climate change (reducing greenhouse gas emissions) as stated in its Climate Resilient Green Economy (CRGE) strategy (FDRE, 2011). During the last 10 years Ethiopia has constructed three big dams (Gilgel-Ghibe I, Tekeze and Tana Beles) to produce hydroelectricity and other three dams (The Grand Ethiopian Renaissance Dam, Gibe III and dams in Genale-Dawa basin are under construction. The government has planned to increase the hydroelectric power generating capacity from 2000 MW in 2009/10 to 8000 MW in 2014/15 (FDRE, 2011). The government of Ethiopia is also working on soil and water conservations, afforestation, and rehabilitation of degraded lands to reduce soil erosion and rate of sedimentation into water reservoirs and lakes and increase groundwater levels.

However, all the water developments, water management and climate change adaptation response efforts are challenged by many environmental and socioeconomic factors. The first major challenge to water resources development and management in Ethiopia is the extreme hydrological variability and seasonality and the international nature of its most significant surface water resources (World Bank, 2006). Ethiopia has very difficult hydrology that varies over time and space with endemic drought and flood events. These extreme hydrological events have induced economy-wide impacts (FDRE, 2007) and they are the focal points for water resources management and climate change adaptation response efforts. The low level of institutional, economic and expertise capacities are also other important challenges for water management and climate change adaptation works (World Bank, 2006; Conway and Schipper, 2011).




4.2. Indigenous water management practices for adaptation to climate variability

Over time, households and communities have developed a range of natural resource and water management strategies in response to extreme climate events in Ethiopia. The type of water management and coping strategies are different from place to place based on the type of agro-ecology, type of water problems (such as drought, floods, soil erosion, water logging, etc.), resources available and other environmental and socio-cultural factors (Holmann et al., 2005). Indigenous adaptation measures vary from collecting wild fruits, switching to non-farming activities, migration and selling assets to collection of fuel-wood and charcoal for sale to provide households with basic needs during difficult times. The sale of household goods and animals and land renting are also among the coping strategies. Most of these coping strategies are used to overcome drought induced water and food shortages in drought-prone areas of the country (FDRE, 2007) and do not provide long-term solutions, rather they are short-term remedies to water and climate related problems (Homann et al., 2005).

To mention examples of indigenous water management practices, in the central highland areas farmers use various water management strategies to mitigate soil erosion, drain waterlogged lands, protect farm lands and settlements from flash floods, conserving soil moisture and cope with drought events. Some of the known agronomic practices are: drainage ditches, crop rotation, contour plowing, mulching, strip cropping, and agro-forestry practices (Ali and Surur, 2012; Mekonnen and Gebremichael, 2014). For example, farmers in Northern Shewa use stone terraces, soil bunds, water ways, drainage ditches and contour plowing to protect against flash floods and soil erosion (Amsalu, 2006; Adimassu et al., 2013). In southern Ethiopia, agro-forestry system and Konso's indigenous terrace building are the well-known indigenous water and soil conservation practices. In some areas such as Wolayta farmers use multiple or inter-cropping systems in croplands as a coping mechanism against effects of crop diseases, insect pests or droughts (Shiferaw et al., 2011).

In the lowland parts of Ethiopia seasonal mobility is a typical strategy of pastoralists used to overcome shortages of water and pasture during the dry



season. Mobility enables them to use the spatially variable water resources and rangelands. The time, direction, duration, and frequency of visit vary from one pastoral territory to another but all have the essential feature that they avoid heavy grazing pressure induced by repeated and longer period of grazing and water shortage (Tesfay and Tafere, 2004). A major ecological advantage of mobility is thus there is little chance for pastoral stock to inflict long-term damage on the rangeland and enabled pastoralists to sustain their rangelands for centuries (Tesfay and Tafere, 2004). Pastoralists also construct ponds to collect rainwater and dig deeper holes to obtain groundwater. For example, the Afar pastoralists harvest rainwater in shallow ponds (*Horoyo*) and access is carefully regulated by user groups. Such regulation includes time of accessing it, number and age of livestock species allowed to use it, and means of improving the structure (Tesfay and Tafere, 2004). The Borana pastoralists also use water from deep sources (Homann et al., 2005). These kinds of water sources are constructed close to settlements and homesteads and reserved for calves, milking cows and weak livestock (Amsalu and Adem, 2009).

Pastoralists also use indigenous early warning systems based on strong and careful observation of the behavior of wild animals, stars and birds that helps local people to predict the coming of rains and intensity. For example, the Dasenech people in South Omo Valley make seasonal flood prediction by observing stars, wind and cloud patterns and behavior of specific animals to make some adjustments against floods (Gebresenbet and Kefale, 2012). There are also traditional administration, negotiation and social institutions that play important roles in the management of water and rangeland resources (Tesfay and Tafere, 2004; Homann et al., 2005; Gebresenbet and Kefale, 2012). However, in the recent times the capacity of these social institutions and indigenous adaptation strategies are challenged by increased intensity and frequency of extreme climate events, rangeland degradation, bush encroachment, population growth, private and public investments affecting the rangelands (Tesfay and Tafere, 2004; Homann et al., 2005; Amsalu and Adem, 2009; Gebresenbet and Kefale, 2012). Yet it is often noted that integrating indigenous water management practices with modern methods is useful to effectively tackle the challenge of hydrological variability in the country, particularly in the drought-prone areas.



4.3. Institutional arrangements for water resource governance and climate change adaptation in the water sector

Effective water management planning requires adequate institutional structures and capacity to provide: 1) appropriate legislation and policy, particularly at the national/sub-national levels, 2) sufficient infrastructure for water storage, drought and flood reduction, 3) appropriate technical and managerial capacity, and 4) to effectively respond to the impacts of climate change on the water sector (ECE, 2009). Institutions play key roles to regulate the development and management of water resources and provision of adequate and safe water supply services to different use sectors.

The current institutional arrangement, proclamations, policies, strategies and programs as well as the national institutional arrangement at the national and regional level in Ethiopia are described in detail in part one. Some studies like Conway and Schipper (2011) and Oates et al. (2011) described that although not sufficient the existing institutional structures, policies and strategies in Ethiopia are useful for water sector development, water management and mainstreaming climate change adaptation in the water sector. Currently, it is the Ministry of Water, Irrigation and Energy - is responsible for water development, water management and water related climate change adaptation planning and implementation. It has the mandate of formulating national water policy, strategy, legal framework, plans, and establishing national standards pertaining to water resources, establishing relevant institutions, commission studies, plan and develop water supply and sanitation schemes, irrigation, hydropower and other energy forms, and water resources administration, protection, monitoring and allocation (MoWIE, 2014).


4.3.1. Water resource considerations in the NAPA of Ethiopia

Ethiopia's National Adaptation Program of Action (NAPA) developed in 2007 under the request of the United Nations Convention on Climate Change (UNFCCC) had a significant coverage of water issues. Although not put into implementation water and water related problems (drought, floods and erosion) were well identified and given priorities for adaptation in the NAPA document. Five out of 11 major strategic priorities for climate change

adaptation were related to water directly or indirectly (NMA, 2007). Summary of NAPA's water related adaptation strategies is presented in Table 9.

Table 9 Summary of water related adaptation strategies and measures identified in the NAPA document

Priority rank	Water related adaptation strategy/program	Adaptation options/measures to be taken	Required cost estimate (in \$)
1	Strengthening/enhancing drought and flood early warning systems in Ethiopia	Improvements of monitoring, prediction facilities and information flows, development of skilled human resource Improvement of observational network	Full project implementation: 10 million Project design: 100,000
2	Development of small scale irrigation and water harvesting schemes in arid, semi-arid, and dry sub-humid areas of Ethiopia	Study design and implementation, identification of suitable sites for water harvesting, small scale irrigation dams and boreholes and prepare land for irrigation, construction/development of dams, boreholes and ponds and provide training for the communities and professionals in water management	Full project implementation: 30 million Project design: 500,000
3	Community based sustainable utilization and management of wetlands in selected parts of Ethiopia	Undertake assessment and consultation with stakeholders, create awareness and training of personnel	Full project implementation: 2 million Project design: 50,000



4	Realizing food security through multi-purpose large scale water development project in Genale–Dawa Basin	Assessment and review of existing master plans and works on Genale–Dawa river basin then make feasibility studies, construction of dams and capacity building	Full project implementation: 700 million Project design: 2 million
5	Promotion of on farm and homestead forestry and agro-forestry practices in arid, semi-arid and dry-sub humid parts of Ethiopia	Identification of potential and target areas, establishment of tree nurseries, training of farmers and agricultural extension workers	Full project implementation: 5 million Project design: 100,000

Source: NMA (2007)

4.3. Key policy and strategic issues for water resource development and climate change adaptation

This section presents a review of water management and climate change adaptation strategies identified and suggested for the Ethiopia's water sector. There are many research outputs and policy documents that have presented different water management and climate change adaptation strategies for the water sector (MoWR, 2001a; World Bank, 2006; FDRE, 2007; Ndaruzaniye, 2011; Oates et al., 2011; MoWIE, 2014). These studies presented different short-term and long-term options. The following sections provide detail descriptions on the existing and planned water management and climate change adaptation programs for the sector.

Ethiopia has a Water Sector Policy issued in 2001, which has the following strategic objectives:

1. Development of the water resources of the country for economic and social benefits of the people, on equitable and sustainable basis.
2. Allocation and apportionment of water based on comprehensive and integrated plans and optimum allocation principles that incor-



porate efficiency of use, equity of access, and sustainability of the resource.

3. Managing and combating drought as well as other associated slow on-set disasters through, inter-alia, efficient allocation, redistribution, transfer, storage and efficient use of water resources.
4. Combating and regulating floods through sustainable mitigation, prevention, rehabilitation and other practical measures.
5. Conserving, protecting and enhancing water resources and the overall aquatic environment on sustainable basis.


The national water sector strategy was subsequently issued, also in 2001, to translate the national water management policy into action. The sector strategy document covers areas of improving water security, water management, hydro power and irrigation development, institution and capacity building aspects, water related risk (drought and flood) management, on the development and management of trans-boundary water issues, research, and health issues. The details of the strategy in each category are presented in Table 10.

Table 10 Summary of water development and management strategies

Sub-sector	Strategy
Water resource development	Undertake assessment and development of the country's surface water resources
	Develop ground water resources and ensure its optimal utilisation
	Make effective and optimum use of available water resources by giving priority to multipurpose water resources development projects
	Strengthen and expand hydrological and hydro-meteorological data records
	Strengthen rainwater harvesting through the construction of small check dams
	Undertake proper assessment, preservation and enrichment of aquatic resources

Water Resources Management	Ensure that water allocation is based on efficient use of water resources
	Promote appropriate watershed management practices
	Protect the national water resources from pollution
Institution and capacity building	Establish effective institutional basis for sustainable development and management of water resources
	Develop and implement capacity building programs at all levels (Federal, Regional, Zonal, Woreda and grassroot level) on water resources management
	Formulate appropriate water legislation for effective water management
Trans-boundary waters issues	Develop projects on trans-boundary waters that are in the best national interest of Ethiopia, and are consistent with the international covenant adapted by the Nile Basin member states
	Assess and update every 3 years the state of water affairs of trans-boundary rivers
	Assess and update every 5 years the demand for water of development projects in each of the trans-boundary rivers with particular emphasis on high priority projects
	Develop and enhance capacity in trans-boundary negotiations and conflict resolution
Research and Development	Evaluate the existing state of research and development activities in the water sector to identify pressing and critical problems in water resources
	Develop institutional framework and conducive environment to promote and carrying out research and development activities
Disasters and Public Safety	Develop and implement comprehensive plan of action to address flood disasters
	Combat the droughts that claim the appalling loss of human life and livestock
Environment and Health Standards	Incorporate environmental studies as a component of the studies to be carried out for water resources development projects

Hydropower development	Prepare inventories of the complete hydropower potential of the country, and identify site specific conditions to put into place to exploit this potential
	Improve electricity use efficiency
	Carry out one feasibility study per year for medium scale hydropower plants to ensure that an adequate number of HPD candidate sites
	Streamline co-operation among the institutional stakeholders and redistributing the institutional responsibilities
	Strengthen technical capacities of the national staff in the study, design, construction, and operation and management of hydro-power schemes
Irrigation Development	Rehabilitate the existing schemes suffering from deferred operation and maintenance, and complete those schemes which were started
	Adopt improved and affordable systems and tools for water irrigation
	Develop standards, guidelines, manuals and procedures for the sustainable operation and maintenance of irrigated schemes
	Prioritize the implementation of various types of irrigation schemes based on a well articulated evaluation based on physical resources and socioeconomic parameters
	Give emphasis to water harvesting methods for small scale irrigation development
	Extend credit facilities and bank loans for the implementation of small scale irrigation schemes to be executed by local community groups
	Reinforce the role of the federal government and regional states in the development of small, medium and large scale irrigation schemes
	Develop a program to strengthen the technical capacities of National/Regional/ Zonal/ Woreda level offices
	Assign priority to those irrigation projects which are of multi-purpose in nature and would contribute towards ensuring food security and risk reduction



Water Supply and Sanitation	Identify the most appropriate, efficient, effective, reliable and affordable water supply and sanitation technologies
	Develop national standards for the design, installation, implementation, operation, maintenance and inspection of the water supply and sanitation systems
	Conduct studies and research on traditional water supply and sanitation technologies
	Develop and enforce standards and guidelines for maintaining water quality
	Promote and encourage water conservation through regulatory and demand management measures

Source: MoWR (2001b)

The World Bank conducted a detailed and comprehensive assessment on Ethiopia’s current water problems and the associated impacts on agriculture and hydropower production and socio-economic development (World Bank, 2006). This study has identified extreme hydrological variability and seasonality as the primary water resource management challenges for Ethiopia. The poor water infrastructure, inadequate research, information flow and institutional capacities are also considered as water related problems and central points for the development of water management strategies. By understanding these problems, the World Bank suggested short-term and long-term water management strategies to enhance the level of the country’s water security and combat the negative impacts induced by hydrological variability. Some of the priority responses identified by the World Bank to address the challenges in Ethiopia’s water sector, which have implications for adaptation to climate change, are presented as follows.


Short-term water management strategic priorities for Ethiopia (World Bank, 2006):

1. Strengthening institutions and capacity

Investment in research and education in particular will be crucial to develop the capacity needed to design effective and appropriate water resource management interventions, watershed management, irrigation development, and water and sanitation services.

2. Increased water storage

To mitigate the economic impacts of water related shocks in Ethiopia,



increasing water storage capacity, both natural and manmade, large scale and small scale is needed. Given both seasonal and inter-annual variability, significant over-year storage will be particularly important. Thus World Bank recommended development of multi-purposes large scale and small scale water storage facilities to control flooding and drought problems, slow sedimentation rates and provide water for irrigation, domestic consumption and hydropower generation and to create opportunity for fisheries and tourism. Storage design must also take explicit account of the country's extreme hydrologic variability and high sedimentation rates. Empirical studies such as Awulachew et al. (2007) reported that the adoption of small scale water storage has created better opportunity for production, better income, reduction of risks and hence generated benefits for poor rural communities. This study has also identified some failures that need attention that includes: limited capacity, institutional instability, flawed project design and lack of adequate community consultation during project planning.

3. Watershed management


Improvements in watershed management will be a crucial element in managing water resources, and restoration of degraded watersheds. The adoption of community based watershed management will have multiple benefits: it can slow down soil erosion, moderate hydrological variability, regulate runoff and groundwater flow, improve infiltration capacity (hence water retention and base flows), and reduce potential flood damage.

4. Irrigation development

Ethiopia's agricultural system does not yet fully benefit from the technologies of irrigation. Therefore, properly designed irrigation investments can provide a secure supply of agricultural water to protect the subsector from the greater part of hydrological variability. It can enhance food security and the reliable delivery of marketable and exportable agricultural products.

5. Develop/enhance the use of groundwater potential for irrigation

Ethiopia's groundwater resource potential is not well known. One distinct advantage of groundwater is its relative reliability because groundwater availability estimations indicate that a significant proportion of this resource could be economically used for irrigation and that ground water based irrigation is likely to be a cost-effective option. Groundwater pumped wells for irrigation can supplement surface water canal irrigation as well as irrigate areas that do not have canal irrigation facilities. For smallholders, the capital requirements to develop shallow groundwater irrigation are



generally low and its productivity is higher compared to surface irrigation.

6. Drainage improvement to protect soil productivity

Rain or irrigation water may accumulate in agricultural fields and cause water logging, which can lead to soil degradation. Management practices should be developed to minimize water accumulation on the soil surface, particularly in vertisol areas to minimize salinization and sodium hazards.

7. Early warning and preparedness systems

Effective early warning systems are a critical component of drought and flood preparedness program, with major benefits for agricultural and hydropower production. However, there is currently a deficiency of reliable meteorological data and observation networks, as well as an inadequate information dissemination system. The country must further develop data collection, early warning systems, market information systems, and permanent diagnosis and research centers (agriculture, hydrogeology, hydrology, meteorology).

8. Responses for livestock survival

To improve drought preparedness in the livestock sector, investments are needed in small feeder roads, improved water management, fodder banks, and range improvement. Funds should also be set aside to provide rapid responses such as destocking, water tankering, and the control of human and animal disease outbreaks.

Long-term water management strategic priorities for Ethiopia (World Bank, 2006):

1. Encourage alternative livelihoods

Most Ethiopians depend directly on rainfall for subsistence agriculture, hence vulnerable to rainfall variability and change. Thus, investments and policies must be considered to create opportunities for less water-dependent, more resilient livelihoods that have less impact on environmental resources. .

2. Seek price and income stabilization

Better road and market infrastructure for agricultural production could enhance domestic market and help to smooth food supplies and prices. Expanded opportunities for off-farm employment would also help lessen the economic shocks arising from hydrological variability driven fluctuations in the agriculture sector by providing supplemental income to the greater majority of the population.



3. Enable private investment in irrigation and non-agricultural activities

Investment policy in irrigated agriculture and energy sectors need to be further liberalized to attract both domestic and foreign private investors. The investment climate and property rights regimes should ensure long-term security and adequate return on investments.

4. Invest in all-weather roads and market infrastructure to shift expectations and incentives

Improving the coverage and quality of Ethiopia's road network will ensure that producers can move their product to markets easily, and would diminish current disincentives to investment in all sectors that arise from the high costs and uncertainty of transport services.

5. Ensure that other infrastructure investments are designed to withstand erosion and flooding

Where high rates of sedimentation are seen or predicted, hydraulic infrastructure such as reservoirs and canal systems should be designed properly to overcome impacts induced by flood and erosion risks.

6. Expand hydropower generation capacity and promote regional power trade


Ethiopia's vast hydropower potential offers opportunities for mutually beneficial power trade in the region. By developing a network of linked energy producing facilities, Ethiopia can increase economic resilience to water shocks. For example, two or more interconnected hydropower-based systems may prove complementary in reducing the effects of variability in seasonal river flows, including droughts and floods. Ethiopia could potentially transmit power through Egypt's grid to the Middle East and even to Europe.

7. Promote financial risk mitigation and credit

Current credit and banking systems do not provide robust risk mitigation products. By considering the high level of Ethiopia's hydrologic variability that it will likely always pose significant risks for agricultural and non-agricultural investors, it is important to explore opportunities to provide insurance, credit, or banking vehicles to help producers manage this risk.

4.4.1. Water in the CRGE vision of Ethiopia

Ethiopia is currently implementing the Climate Resilient Green Economy (CRGE) initiative with the objective to protect the country from the adverse effects of climate change and to build a green economy (FDRE, 2011). CRGE



has three objectives: fostering economic development and growth, ensuring abatement and avoidance of future greenhouse gas emissions, i.e., transition to a green economy, and improving resilience to climate change.

Although most of the identified CRGE strategies (such as hydropower generation, irrigation and improving the rain-fed agriculture) to achieve these objectives are water related and are highly sensitive to water variability and change, the water sector has given very little emphasis and is not a focal point in the CRGE document (FDRE, 2011). However, there are empirical evidences that the current rainfall variability is challenging the Ethiopia's water security, water management and other water related developments by affecting sectors such as energy and health (World Bank, 2006; Conway and Schipper, 2011; Oates et al., 2011). Climate change is also likely to exacerbate the existing water related problems (drought, flood, erosion and water quality, which have strong implications that development projects and other green growth strategies need to consider water related climate risks in their planning. It is because effective water management has been argued that is fundamental to mitigate the impacts of climate change, as water is the primary medium through which these changes will be experienced (Oates et al., 2011).

4.4.2. The climate resilience strategy for the water sector

Since the climate resilience strategies should be developed at sectoral level by concerned federal ministries, the Ministry of Water, Irrigation and Energy (MoWIE) was responsible to develop Climate Resilience Strategies for the water and energy sectors. Thus, MoWIE has identified ten climate resilient strategic priorities in four priority sub-sectors (power generation, energy access, irrigation and access to water, sanitation and hygiene). The details of these strategies, rationales and the required cost estimate are presented in Table 11.

Table 11 Climate resilient strategic priorities in the water and energy sector

Sub-sector priority	Climate resilient strategy	Rational/measures to be taken	Required cost
Power generation	Diverse energy mix	The rational is to obtain energy from different sources (20% wind and solar, 10% geothermal and 70% hydropower) to reduce the impact from extreme rainfall	\$304 million
	Improve energy efficiency	Increasing energy efficiency to reduce the demand for electricity.	
Energy access	Improve efficiency of biomass use	Reducing the demand for biomass by increasing fuel efficiency.	\$246 million
	Accelerate non-grid energy access	Pilot micro-generation projects need to be funded to develop non-grid energy access for rural electrification	
Irrigation	Accelerate irrigation plans	Feasibility and design work needs to be completed to fully understand the irrigation potential and to develop a long-term action plan	\$71 million
	Support the resilience of rain-fed agriculture	Provide support to the Ministry of Agriculture by improving data provided by the National Meteorological Agency	
	Balance water demands	Growing water demands need to be managed and allocated according to the water that is available	

Access to Water, Sanitary and Hygiene (WASH)	Accelerate universal access to Water Sanitation and Hygiene (WASH)	Prioritize meeting the funding gap in the One WASH National Program by focusing on the most vulnerable area and communities	\$220 million
	Enhance the climate resilience of self-supply	Additional approaches such as improving local water storage facilities or participatory water resource management should be implemented	
Cross-cutting issues	Data systems for decision support	Strengthening data systems so that they provide timely, reliable and usable data	\$54 million
	Accelerate delivery of existing plans	A common theme across the CR Strategy is that most of our existing plans already support CRGE, but need to accelerate delivery and implementation	


Source: MoWIE (2014)

4.5. Limits, barriers and costs of adaptation and risk management

4.5.1. Limits and barriers

There are many physical and socio-economic factors that could limit or complicate adaptation response as well as climate risk management activities in the water sector (Kundzewicz et al., 2007; ECE, 2009). Kundzewicz et al. (2007) identified four different types of limits on adaptation to changes in fresh water resources, these are: physical factors, economic or financial factors, political or social factors and institutional factors.


There are many physical and ecological factors that could limit and affect water management and adaptation in the water sector. The first major challenge for water management and climate change adaptation in Ethiopia is the extreme



hydrological variability and seasonality and the international nature of its most significant surface water resources (World Bank, 2006). Ethiopia has very difficult hydrology that varies over time and space with endemic drought and flood events. Drought would be a limiting factor to implement some of the proposed water management and adaptation strategies in the country, particularly in the arid and semi-arid regions, where there is chronic water shortage. Irrigation, water security and hydropower production would be limited due to water shortage during drought times (Conway and Schipper, 2011; Oates et al., 2011).

Flooding is also another growing problem that results from increasing rainfall variability in Ethiopia (World Bank, 2006). Ethiopia experiences both flash and riverine floods that have significant impacts on farmlands, water reservoirs and other socioeconomic infrastructure. Riverine flood is a problem mainly along the lower parts of major river basins and flood plains along some river basins such as, the Awash, Abbay, Baro-Akobo and Wabe-Shebele basins. Although there is no clear evidence about future flood conditions in the country, the tendency is towards increasing changes that could result from increasing rainfall variability (Conway et al., 2007; FDRE, 2007); thus flooding is one of the extreme hydrological events that could largely complicate and or sometimes limit the development of water infrastructures and water management activities in the country.

Flood in Ethiopia carries a lot of sediment load and causes damage on water infrastructures by inundating and water-logging productive lands. High sediment loads due to flooding into rivers and water reservoirs reduces the potential of water reservoirs to hold water. When sediments settle into water reservoirs, the capacity for power generation is reduced in proportion to the sediment entrance into the reservoir. In addition, concentration of sediment at the power inlets hampers operation of dam bottom outlets as well as power intakes. During the last few decades, flooding has caused damage to hydropower generation equipment at the Melka Wakana and Tis-Abbay power plants (World Bank, 2006). This problem is expected to continue due to the increasing inter-annual rainfall variability, high rate of deforestation and agricultural expansion over the highland areas (FDRE, 2007). Thus, sedimentation is one of the growing problems that is now challenging and will continue to challenge the existing and planned water infrastructures




mainly of water reservoirs and the management of drought and flood risks through water regulation.

The complex mountainous and rugged topography of the country is also a major source of limit and barrier for the development and management of Ethiopia's water resources. The central part of Ethiopia that covers almost half of the country is the source for most of the rivers in the country. This part of the country is covered by high mountains, rugged plateaus cut by deep gorges and wide valleys in the highland and plains in the lowlands. The transition from highland to lowlands is very abrupt with sharp falls and cataracts. The steep-slope highlands over the central parts of Ethiopia are experiencing rapid deforestation and expansion for agricultural land and could generate and aggravate flood hazards, soil erosion and sedimentation into water reservoirs, lowland settlements and irrigated farmlands. The lowlands are flat and largely affected by frequent flooding and sediment deposition by ravines, gullies and rivers. These complex and difficult topography are the major limiting factors to access water from deep river valleys and development of water infrastructures (MoWR, 2001a).

Although adaptation need not be limited by uncertain knowledge (Adger et al., 2009) there is high level of uncertainty in the future behavior of rainfall that could cause a significant challenge to understand and acting upon the risks posed by climate change. However, Adger et al. (2009) noted that '... adaptation need not be limited by uncertain knowledge on future climate change'. Instead of viewing this uncertainty as a limit to adaptation, Adger et al. (2007) suggest developing robust and flexible adaptation strategies based on existing information as a direction by which maladaptation can be avoided, and as time progresses and the understanding of climate change increases, adaptation strategies will be adaptable to different decision paths that suit socio-political developments.

Most of the limit and barriers for climate change adaptation in the third world countries would arise from the economic or financial limits (Oates et al., 2011). Every form of adaptation that could be implemented by individuals, communities or government entails some direct or indirect financial costs. Ethiopia is one of the least developed countries in the world which has very difficult hydrology and rapidly growing population (hence increasing the




demand for water) and with very poor water infrastructure development. According to World Bank (2006), Ethiopia would need to invest five times its annual GDP (US\$35 billion according to 2006 estimation) just to achieve a similar water infrastructure by taking the storage in South Africa as a crude benchmark of water security. This amount will be very huge for Ethiopia to use for water development and water management activities. In addition to this, technological limitations in the water sector commonly tie closely with economic limitations, if the technology required for a specific approach is not available or too expensive. The efficiency of implementing institutions and capacity building programs are also significantly influenced by availability of finance (MoWIE, 2014).

Strengthening the country's early warning system is one of the important water management and climate change adaptation strategies that is strongly recommended for Ethiopia (World Bank, 2006; NMA, 2007; Oates et al., 2011). NMA and MoWIE are responsible to collect and disseminate climate and water related early warning information. Currently these institutions have low capacity to generate reliable hydro-meteorological data, observation networks and inadequate information delivery system (Conway and Schipper, 2011). There are many factors that affect the performance of these institutions to produce and disseminate early warning information to the users, which include poor infrastructure, technology, inadequate climate and hydrology monitoring network densities, shortage of trained professionals and so on (World Bank, 2006).

There is also very little knowledge about the nature of current hydroclimate variability and trends for the country (Conway et al., 2007). This would create information gaps to develop spatially relevant water management and adaptation strategies at watershed and smaller scales across the country. It is well known that rainfall and stream flow as well as other climatic elements that affect the water resources base of the country vary from watershed to watershed and even within a given watershed (Gebrehiwot, 2012).

Although there are initial signs of progress in addressing climate risks and adapting to climate change in the water sector in Ethiopia, the historic climatic trends inform Ethiopia's water sector strategies and programs to some extent, future climate projections and socio-economic scenarios are




rarely incorporated into these designs. Climate risk considerations are not being factored into water sector planning and implementation in a systematic way and that institutional structures are currently inadequate (Conway and Schipper, 2011; Oates, 2011).

Although the traditional methods of resource allocation and water management strategies are appreciated for their advantages to tackle some important water related risks, these strategies are currently challenged by many factors. Some of the major constraints are rapid population growth, recurrent drought that overweight the traditional coping strategies, greater socio-economic inequality between households and divergent trends between communities that hinder cooperation in natural resource management (Tesfay and Tafere, 2004; Homann et al., 2005). Consideration of heterogeneous household characteristics, asset ownership, technology specific traits vis a vis farming systems, culture of people, local ecology and institutional arrangements are some of the observed barriers for adopting and applying some soil and water conservation techniques during the past efforts (Tesfay and Tafere, 2004; Homann et al., 2005; Mekonnen and Gebre Michael, 2014).

Although adaptation strategies in the water sector at the country level should also include measures covering all the steps of the adaptation chain: prevention, improving resilience, preparation, reaction/response, and recovery (ECE, 2009), these are not well articulated both in the NAPA document and CRGE development programs (FDRE, 2007, 2011; MoWIE, 2014). Only few adaptation measures such as increase the level of water security both in the rural and urban areas, increase the application of irrigation, increase water storage and watershed management strategies are identified as a preventive or climate resilient strategies by MoWIE for the water sector (MoWIE, 2014). No strategy was set for preparation, reaction/response, and recovery for drought and flood hazards in the CREG document prepared for the water sector.


A serious challenge for Ethiopia is the fact that it shares so many international rivers. Many of the country's river water resources are shared with numerous riparian states: Egypt, Eritrea, Somalia, Kenya and Sudan. Obviously, there are tensions, to a greater or lesser extent, between riparian nations on all



international rivers (ACPC, 2011). The complexity of riparian relations is an obstacle to the development of the full potential that international rivers embody for growth and poverty alleviation. In extreme cases, tensions over international rivers can effectively halt their effective management and development. Tensions over shared rivers encourage the adoption of less economically efficient policies that focus on self-sufficiency (for example, in agriculture and power) rather than on integration. There is a real risk that these tensions could result in the diversion of strategic human resources and policy focus from economic development to security concerns related to water and even a diversion of financial resources to military preparedness (World Bank, 2006). Although some attempt has been made through the development of trans-national initiatives for transboundary rivers such as the Nile Basin Initiative (NBI), in many ways it is inadequate to provide full fledged water related policies and strategies. In particular, the initiative has little or no practical link with local governments and communities and is unable to cause sufficient influence on transboundary water governors (ACPC, 2011).

4.4.2. Costs of adaptation

The costs of climate change adaptation in the Ethiopian water sector depends on the type and magnitude of future climate changes, drought and flood risk occurrences, the level of initial water infrastructure in the country, economic growth and the government's development plans and priorities. So far, very few of these costs have been estimated in monetary terms across the world (Kundzewicz et al., 2007). Efforts to quantify economic impacts of climate-related changes in water resources are hampered by a lack of data particularly in underdeveloped regions like Ethiopia and by the fact that the estimates are highly sensitive to different estimation methods and to different assumptions regarding how changes in water availability will be allocated across various types of water uses, e.g., between agricultural, urban, or in-stream uses. In addition to these, the cost estimate for adaptation also varies with different scenarios. According to Robinson et al. (2013), adaptation in the dry scenarios involves expensive increased investment in dams, irrigation, and hydropower, while adaptation in the wet scenarios involves relatively major investments in improved floodwater management. According to this study adaptation



costs in Ethiopia may range between USD 158 million to over USD 258 million per year.

On the other hand, hydrological changes may have impacts that are positive in some aspects and negative in others. For example, increased annual runoff may produce benefits for a variety of in-stream and out-of-stream water users by increasing renewable water resources, but may simultaneously generate harm by increasing flood risks and groundwater recharge that can be used during the dry season. Increased runoff could also damage areas with shallow water table. In such areas, a water table rise will disturb agricultural use and damage buildings in urban areas. In addition, an increase in annual runoff may not lead to a beneficial increase in readily available water resources if the additional runoff is concentrated during the high-flow season (Kundzewicz et al., 2007).

The social costs or benefits of any change in water availability would depend on how the change affects each of these potentially competing human water demands. Changes in water availability will depend on changes in the volume, variability, and seasonality of runoff, as modified by the operation of existing water control infrastructure and investments in new infrastructure. In addition, quantity of water is not the only important variable. Changes in water quality and temperature can also have substantial impacts on urban, industrial, and agricultural use values, as well as on aquatic ecosystems. For urban water uses, degraded water quality can add substantially to water treatment costs. Increased precipitation intensity may periodically result in increased turbidity and increased nutrient and pathogen content of surface water sources (Kundzewicz et al., 2007).


The cost estimate of adaptation in the water sector can be also affected by and should consider the expected change in sectoral water demands over time in response to changes in population, settlement patterns, wealth, industrial activity, and technology. For example, in Ethiopia the rapid urbanization created substantial growth in localized water demand (FDRE, 2011, 2014), often making it difficult to meet goals for the provision of a safe and affordable, domestic water supply. In addition, climate change will probably alter the desired uses of water (demands) as well as actual uses (demands in each sector that are actually met).

In Ethiopia, the cost required for water management and water sector adaptation to climate change is very high due to the very difficult hydrology of the country that is characterized by extreme events and high inter-annual and seasonal variability (World Bank, 2006) and very poor water infrastructural development (MoWR, 2002a; Oates et al., 2011). The Ministry of Water Resources (MoWR, 2002a) has set out the cost estimate required for the implementation of different development programs in the water sector for short-term, medium-term and long-term time scales (Table 12).

Table 12 Summary of cost estimate required for overall water sector development program (US\$ million)

Sub-sector	Short-term	Medium-term	long-term	Total
Water Supply & Sewerage Program	876.2	1,057.9	1,001.7	2,935.8
Federal				
Regional	876.2	1,057.9	1,001.7	2,935.8
Irrigation Program	307.9	456.9	918.3	1,683.1
Federal	114.7	268.1	700.9	1,083.7
Regional	193.2	188.8	217.4	599.4
Hydropower Program	649.1	525.9	776.7	1,951.7
Federal	647.4	516.2	764.5	1,928.1
Regional	1.7	9.7	12.2	23.6
General Water Resources Program	183.9	231.9	240.5	656.3
Federal	133.7	160.1	153.7	447.5
Regional	50.2	71.8	86.8	208.8
Institution/Capacity Building Program	92.9	63.3	61.7	217.9
Federal	13.2	5.3	5.0	23.5
Regional	79.7	58.0	56.7	194.4
Total	2,110.0	2,335.9	2,998.9	7,444.8
Federal	909.0	949.7	1,624.1	3,482.8
Regional	1,201.0	1,386.2	1,374.8	3,962.0

Source: MoWR (2002a)



The adaptation cost estimated for the Ethiopian water sector in the NAPA document (NMA, 2007) and in the CRGE program (MoWIE, 2014) are indicated in the Tables 9 and Tables 11 above, respectively.


4.6. Opportunities for adaptation and risk management

Ethiopia is endowed with rich water resources; the country has adequate annual rainfall, several major rivers and lakes, and a significant groundwater resource. This resource base is underutilized for socioeconomic development and the country has not yet attained the minimum level of water security and only less than 2% of the resource is diverted for use. Thus, this water resource availability is an important opportunity for the country to provide adequate water service and to adapt to climate change.

The underdeveloped water infrastructure in Ethiopia is one of the opportunities that could be used to reduce vulnerability simply by investing in the development of infrastructure and institutions for water management and climate change adaptation (World Bank, 2006; Oates et al., 2011). Investments in water for food, energy, industry, and navigation, and in associated institutions will create opportunity for the country to achieve resilient economic growth in the face of climate change and could enhance the country's climate change adaptive capacities (Ndaruzaniye, 2011).

In Ethiopia there are initial signs of progress to enhance the level of water security, water management and to address the impacts of climate change on the water sector. There are now many water related proclamations, regulations, strategies, programs and River Basin Master Plan studies that could be very useful to achieve water security, implement climate-smart water management practices, reduce water related risks and climate change adaptation works (Oates et al., 2011).

Moreover, the presence of agricultural and health extension service systems and programs are very important to facilitate water and soil management works and the implementation of water supply, sanitation and health programs in rural areas of the country (FDRE, 2011). If the capacity of natural resource management experts at the grassroots level could be enhanced through appropriate off- and in-service training, they could play important roles to increase the capacity and awareness of the rural communities about



the impacts of climate change and adaptation options, technology transfer and effective watershed management practices (Desta, 2011).

On the other hand, if properly managed, assisted and integrated with modern methods, there are many indigenous water related risk management strategies, soil and water conservation methods and even institutions that are used by the local people over centuries (Tesfay and Tafere, 2004; Homann et al., 2005; Edossa et al., 2007; Gebresenbet and Kefale, 2012).


The Nile Basin Initiative (NBI) offers considerable potential for major cooperative development of the Nile River, including large-scale hydropower in Ethiopia. In addition, opportunities for regional cooperation and integration in a range of activities beyond the river have arisen as a consequence of strengthened relations built on the NBI. Recognizing this, the government of Ethiopia is engaged in a serious effort to promote cooperative development and management of the largest of its shared rivers, the Nile, through the Nile Basin Initiative (NBI). This riparian cooperation could bring huge opportunities and even the potential for transformational change in Ethiopia (FDRE, 2014).

5. Climate change mitigation opportunities in the water sector

In many developing countries the issue of climate change is overshadowed by a number of immediate development priorities such as poverty eradication, food security, health, natural resources management, energy access, transport needs and others (Kalsnaes and Verhage, 2007). However, the effectiveness of development plans and strategies may be reduced and sectoral vulnerability enhanced if climate change adaptation and mitigation are not considered. Natural resources that have been supporting the livelihoods of the majority of the Ethiopia population over centuries are now increasingly degraded. Expansion of cultivation to marginal areas, overgrazing pressure, increasing deforestation, mismanagement of land and water in commercial farm areas, drainage and cultivation of wetlands and climate variability, are altogether contributing to degradation of land and water. These represent areas of concern that are exerting challenges on the development needs and efforts of Ethiopia.

Responses to climate change take two linked tracks - mitigation and adaptation. Mitigation seeks to minimize the human footprint through efforts to control, reduce or even eliminate greenhouse gas (GHG) emissions. This is generally referred to as a transition to low or constrained carbon growth. Examples include the introduction of low-carbon technologies for electricity generation and transport, reforestation, and capturing and sequestering emissions (World Bank, 2009).

Greenhouse gases that are responsible for global temperature rise include carbondioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), carbonmonoxide (CO), nitrogen oxides (NOx), and chlorofluorocarbons (CFCs). Of these, carbon dioxide and methane contribute the most to global warming (Sathaye and Ravindranath, 1998; Wreford et al., 2010). The primary sources of CO_2 are burning of fossil fuels and biomass. Additional CO_2 is released through industrial processes, such as the production of cement. The primary sources of methane are paddy fields, excreta of cattle and other animals, landfills, and waste streams. A major source of N_2O is from the use of fertilizers for crop production. CFCs are released during the manufacturing of Freon substitutes and insulation. NOx comes primarily from fuel combustion, during which nitrogen and oxygen combine at high temperatures.




The sources of GHG emissions may be categorized broadly into energy and non-energy sectors. The energy sector comprises the energy end uses in industry, transportation, households, commercial establishments, agriculture, and the supply and transformation of energy. The non-energy sector includes forestry, agriculture, and waste management (Sathaye and Ravindranath, 1998). Globally, agriculture accounts for about one-fifth of the projected anthropogenic greenhouse effect. It produces about 50 and 70% respectively of the overall anthropogenic CH₄ and N₂O emissions (IPCC, 1996).

In this section of the report, reduction options of GHG emission through water management practices are dealt with. Among the different water use sectors, agriculture is the dominant sector where wider options for climate change mitigation could be found. There are lists of several technical options proposed for mitigation of emissions from agriculture (IPCC, 1996; Sathaye and Ravindranath, 1998; Smith et al., 2008; Wreford et al., 2010; Delgado et al., 2011). These measures may be categorized as: reducing emissions through improved farming efficiency, including genetic improvement; displacing fossil fuel emissions by alternative energy sources; and enhancing the removal of atmospheric CO₂ through sequestration into soil and vegetation sinks. Many agricultural practices can potentially mitigate greenhouse gas emissions, the most prominent of which are improved cropland and grazing land management and restoration of degraded lands and cultivated organic soils (Smith et al., 2008).

It is estimated that about 18% of the world's croplands receive supplementary irrigation (Fischer et al., 2007). Expanding this area or using more irrigation technologies can enhance carbon storage in soils through enhanced yields and residue returns. However, these gains may be offset by CO₂ from energy used to deliver and distribute water to irrigate the fields or from N₂O emissions from higher moisture and nitrogen fertilizer inputs (cf. Smith et al., 2008). Improvement of irrigation management is vital to reduce GHG emissions from agriculture. Efficient use of irrigation water will reduce nitrogen losses, including nitrous oxide emissions, and minimize CO₂ emissions from energy used for pumping while maintaining high yields and crop-residue production (Pasustian et al., 2006).

Ethiopia is taking significant measures to contribute to climate change




mitigation. The government commitment to consider climate change adaptation and mitigation in its development plans and strategies is clearly stipulated in climate resilient green economy strategy and growth and transformation plans. As part of the implementation of these plans and strategies, widespread efforts are underway that include: reforestation of deforested areas, integrated watershed management, development of renewable energy potentials like hydropower, wind, and geo-thermal.

Measures of climate change mitigation through agricultural water management are mainly focusing on improving productivity to enhance more efficient use of resources and hence reduce losses (nutrient, water, energy, etc) as well as increase biomass to enhance carbon sinks. Some of these measures include:

- Improving agricultural water management both in irrigated and rain-fed agriculture
- Proper planning of timing and amount of fertilizer and water application
- Minimizing unproductive water use in agriculture
- Use of more efficient and renewable energy sources in water management
- Drainage and rehabilitation of waterlogged and saline irrigated areas to enhance productivity
- Adapt where possible energy and water efficient irrigation methods
- Use of renewable energy for water lifting and distribution
- Rehabilitation of existing irrigation infrastructure and improved management practices to enhance efficiency so as to conserve water and water quality
- Integrated soil fertility and crops management to enhance yield and water use efficiency
- Enhancing the capacities of irrigators through provision of services like: extension, research, credit, market information and the like.

In conclusion, Ethiopia as a least developed country has insignificant contribution to global climate change (greenhouse gas emission). Nevertheless, it remains one of the highly vulnerable regions to the effects of



climate change. The country has been taking significant steps to contribute to climate change mitigation. Carbon sequestration through watershed reforestation and conservation are widely promoted and implemented. Climate resilient green economy (CRGE) policy of the country signifies the country's commitment to climate change mitigation. Development of emission free alternative energy sources are given due emphasis in the energy sector. Strengthening of research is vital to understand the contribution of solid and liquid wastes from growing urbanization, agricultural inputs like fertilizers and herbicides etc, and the livestock sub-sector.

6. Knowledge gaps and research needs: concluding remarks

Ethiopia has made some progress to prepare for and implement some water development programs, water management activities and adaptation to climate change, which could enhance the level of water security. However, there are many knowledge gaps that need detail study and research that has to be addressed to enhance the level of water security, water management and the planning for climate change adaptation practices in the country.

There are major uncertainties in quantitative projections of changes in the hydrological characteristics of the different basins in the country (Oates et al., 2011). Precipitation, a principal input to water systems, is not reliably simulated in present climate models. There is no good agreement between models to project the future rainfall changes over Ethiopia, although some research outputs have indicated a tendency towards slightly increasing changes (Block, 2008; Conway and Schipper, 2011; Oates et al., 2011). As a result the way and extent of how climate change will affect the Ethiopian water sector is not yet well understood. This is a real challenge for policy makers, planners and the community at large to develop long-term water management and climate change adaptation strategies in the water and other water-sensitive socio-economic sectors. Thus, research into the water–climate interface is required: to improve understanding and estimation, in quantitative terms, of climate change impacts on freshwater resources and their management in the country and to fulfill the pragmatic information needs of water managers who are responsible for adaptation (Conway and Schipper, 2011). Among the research issues related to the climate–water interface and development are:

- Detection and attribution of observed changes in freshwater resources, with particular reference to characteristics of extremes, is a challenging research priority, and methods for attribution of causes of changes in water systems need refinement to develop appropriate water management and climate change adaptation strategies,
- There is a need to improve understanding of sources of uncertainty in order to improve the credibility of climate change projections for impact assessments,



- Impacts of climate change on aquatic ecosystems (not only temperatures, but also altered flow regimes and water levels) are not adequately understood,
- Relatively few results are available on the economic aspects of climate change impacts and adaptation options related to water resources, which are of great practical importance for the country,
- There is a strong need for enhancing research on climate change impacts on water quality and extreme events,
- Very little is known about the country's groundwater resource base and the degree of exploitation and utilization for socio-economic activities in the country; in this regard a lot has to be done to map and quantify the groundwater resource, and
- Efforts to quantify the economic impacts of climate-related changes and adaptation costs in water resources are hampered by a lack of data and by the fact that the estimates are highly sensitive to different estimation methods and to different assumptions regarding how changes in water availability will be allocated across various types of water uses.

In addition to these important questions for research, there are also a number of developmental issues that require policy attention as the country steps up investments on water infrastructure development. These include;

- Capacity development through short, medium and long-term training at all levels of water governance;
- Development and implementation of training programs in the areas of climate change and its impact on water resources (extreme events, vulnerability and risk, mitigation and adaptation, hydrological modeling, climate change projections, etc);
- Water resources development planning, design and operation activities are affected by lack of data. Many watersheds and rivers are not gauged and monitored. For this purpose, the river basins of the country need to be equipped with standard hydrometeorological monitoring equipment and stations; and
- Management of water without managing land is seldom possible.



Unwise land use and hence land degradation as well as improper water use in irrigated and rainfed agriculture is increasingly affecting the surface and groundwater bodies. Integrated watershed management practices need to be strengthened, and water management in both rainfed and irrigated agriculture requires attention.



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WATER AND ENERGY SUB-WORKING GROUP

ENERGY SECTOR

Executive Summary

Energy is crucial to economic and human development. Access to modern, reliable and affordable energy services is a pre-requisite to poverty alleviation, economic growth, and social transformation. However, at the global level, the energy system – supply, transformation, delivery and use – is the dominant contributor to climate change, representing around 60 percent of total current greenhouse gas (GHG) emissions. Energy development is not only the contributor of GHG but it is also critically influenced by climate change emanating from anthropogenic emissions.

This assessment report on energy sector and climate change is the first assessment report by EPCC which reviewed published scientific papers and governmental reports, research results and other relevant reports on energy and climate change from the Ethiopian context..

In this assessment report, energy resource potential and development, climate change and current policy measures, vulnerability of energy sectors to climate change, mitigation and adaptation measures of energy sector and conclusion, recommendations and some information gaps were discussed.

Ethiopia is endowed with a variety of renewable energy such as hydroelectric power potential (more than 45,000MW), solar irradiation (avg. 5.5 kWh/m²/day), geothermal resources, (at least 5000MW), wind power (1,350 GW), abundant biomass potential (1,120 Mt sustainably exploitable) and agricultural waste (15-20Mt/year) and some proven potential of fossil fuel (natural gas 113B m³, coal 300 Mt and oil shale 253Mt) while petroleum is still at the exploration stage.

Energy development of Ethiopia is mostly based on exploitation of renewable energy resources. Energy generated from hydropower is highly vulnerable to fluctuations in rainfall, temperature and evaporation. For example, reduced power production during drought years takes a significant toll on the economy. In 2002/3 power supply was cut one day a week over four months because of drought. This caused a sustained reduction in GDP generation. Loss of electricity also impacts basic services, especially in schools and hospitals.

Ethiopia has taken different policy measures to mitigate and adapt climate changes. These measures are basically based on implementation of CRGE strategy. The most important part of this strategy in energy sector is

facilitated by improving energy efficiency in energy production (switching from traditional fuel to other renewable energy, consumption, dissemination of efficient technologies e.g. improved cook stoves). Policy measures were investigated considering green development path while climate change mitigation and adaptation were assessed based on guiding principles of sustainable development, reliable, secure and affordable energy services, impact on reducing GHG emissions and vulnerability to climate change and possible synergies between various measures that may serve both adaptation and mitigation actions.

The report concludes and recommends that it is very important to develop energy resource that are insignificantly influenced by climate change caused by induced factors such as temperature increase, variable rainfall, and extended droughts and wide effort should be practised to diversify energy production (energy mix), improve energy efficiency, accelerate non-grid energy access and utilizing varieties of indigenous energy resources, localization and dissemination of efficient energy technologies, mobilize local financial resources from both public and private sources and build the capacity of both local communities and developers on renewable technologies and climate matters.

This assessment report also identified the gaps of lack of freely accessible digital databases on historic climatological and hydrological conditions. Moreover, there are not sufficient research results as well as research institutions provide data on relationships between climate change and the energy supply and demand situations.

7.Introduction


Energy is at the heart of most critical economic, environmental and developmental issues facing the world today. Clean, efficient, affordable and reliable energy services are indispensable for global prosperity. Developing countries in particular need to expand access to reliable and modern energy services if they are to reduce poverty and improve the health of their citizens, while at the same time increase productivity, enhancing competitiveness and promoting economic growth. On the other hand, at the global level, the energy system – supply, transformation, delivery and use – is the dominant contributor to climate change, representing around 60 per cent of total current greenhouse gas (GHG) emissions (AGECC 2010) ¹.

Access to modern energy services is crucial to continued economic growth and development in Ethiopia. The current level of energy consumption dominated by traditional biomass is not adequate enough to meet the energy needs of a growing population as well as maintaining the impressive economic growth experienced in Ethiopia over the last two decades. The over-reliance on biomass resources and the use of inefficient technologies is not only hindering development in the energy sector but it also accompanied by environmental and social consequences including land degradation, deterioration of biodiversity and scarcity of fuel wood and water resources, has worsened the quality of life of the people, especially rural communities who depend mainly on this resource.

The Ethiopian Government, in its National Energy Policy, has given emphasis in developing its huge energy resources, especially renewable energy and diversify its energy mix to enhance supply side that can support economic growth adequately. The commitment of the government has remarkably conducted rapid expansion of the power infrastructure, increased use and diversity of energy in industry, rapid rise and diversity of energy demand for transport, increased use of off-grid electricity in rural areas and increased use of improved cooking devices in both rural and urban areas (MoWIE 2014)².

¹ THE SECRETARY-GENERAL'S ADVISORY GROUP ON ENERGY AND CLIMATE CHANGE (AGECC), SUMMARY REPORT AND RECOMMENDATIONS 28 April 2010 New York

² Ministry of Water, irrigation and Energy: Identification and Prioritization of Renewable Energy Technologies for Development and Preparation of Project Implementation Documents: Small Wind Generators for Rural Electrification Menz Gera Midir, North Show Zone, Amhara Regional State




There is also a commitment to ensure that appropriate actions are taken to reduce future GHG emissions that will arise due to rapid expansion of the energy sector. Measures that are put in place include developing the huge renewable energy resources in Ethiopia as well as deploying more efficient technologies, both at the production and end-use levels.

As indicated in the Climate Resilient Green Economy strategy (CRGE 2011) of the government, Ethiopia aims to achieve middle-income country status by 2025 by switching its development path from a conventional development to a green economy trajectory. The government aims to avoid the unsustainable use of natural resources, while also promoting the complete switch to the use of renewable energy resources in order to minimize the current and future GHG emissions resulting from fossil fuels utilization and unsustainable exploitation of natural resources. According to the CRGE strategy, GHG emissions would be more than double from 150 Mt CO₂e in 2010 to 400 Mt CO₂e by 2030 following conventional patterns of development. The CRGE strategy aims to reduce GHG emissions by 250 Mt CO₂e by following a green development pathway. In line with the energy policy and CRGE Strategy, Ethiopia is actively investing in renewable energy development, especially hydropower and wind, while it is also planning to develop its geothermal energy resources. In addition, considerable measures have been taken to manage the demand side by improving and disseminating efficient energy technologies including stoves, lighting devices and equipment and utensils.

This report reviews the energy sector in Ethiopia in detail in terms of energy resources and development, climate change, mitigation and adaptation measures and policy measures, and concludes with a set of recommendations.

Considering energy resource potential, Ethiopia is a land of opportunities since it is well endowed with abundant renewable energy sources. It has huge hydroelectric power potential (more than 45,000MW), solar irradiation (avg. 5.5 kWh/m²/day), geothermal resources, (at least 5000MW), wind power (1,350 GW), abundant biomass potential (1,120 Mt sustainably exploitable) and agricultural waste (15-20Mt/year). The country also has proven potential of fossil fuel (natural gas 113B m³, coal 300 Mt and oil shale 253Mt) while petroleum is still at the exploration stage.

Despite the abundance of renewable energy resource potential, energy




sector development of Ethiopia is still largely dominated by traditional production and consumption of biomass resources. The use of modern liquid and gaseous fuels and electricity plays a marginal part. According to the Ministry of Water and Energy (2011)³ traditional usage of biomass accounted for 92% of energy consumption, hydrocarbon based fuels mostly used for transport covered 7% of demand and electricity was used to meet only 1% of the energy requirements of the country. In terms of sectoral demand, household consumption accounted for 93% of energy consumption, the transport sector was responsible for 5% of the demand and the commercial and industrial sectors registered a share of only 2%. Other sectors like agriculture had negligible demand as they are still dependent on human and animal power. The energy resource potential of the country and the current energy development are examined in detail in Chapter Two of this report.

Ethiopia designed and implemented a development strategy to enhance accelerated economic development to reach the status of middle-income countries by 2025. But traditional energy production and consumption and global climate change are challenging the task of this development. To meet the challenges, the government has taken various policy measures which will enable the country to overcome the consequences of global climate change. These include investigation of current situation of climate changes and its consequences for instance emission trend, policy analyses and measures, sectoral reduction mechanisms, etc. Climate change and existing policy measures are discussed in detail in Chapter Three. This Chapter discusses also the vulnerability of energy sector to climate change (recent trends and future projections, its implication for the energy sector) in terms of increasing temperature, water variability, increasing flood and other relevant issues.

In Chapter Four, adaptation and mitigation in the energy sector is reviewed based on basic guiding principles selected by the team, which are: Sustainable development as top priority; Providing reliable, secure and affordable energy services for all sectors; Appropriate attention to measures that impact on reducing GHG emissions and vulnerability to climate change; and the possibility of synergies between various measures that may serve both adaptation and mitigation actions, allowing the country to use its limited resources efficiently to achieve the required goals. Even though

³ MoWE, Energy Balance and Statistics for 2005/6 – 2010/11, May 2012.



Ethiopia's contribution to global GHG emissions is negligible, the country has taken considerable mitigation and adaptation measures by developing and switching to other renewable energy (solar energy, wind energy, geothermal energy and modern biomass energy like briquette from bio-wastes, biogas, biodiesel and ethanol), dissemination of efficient, reliable and affordable end-use energy technologies and improving the efficiency of energy production and distribution, which are considered as main mitigation and adaptation options for the country. This is extensively considered in this Chapter.

Going forward, this report's conclusions and recommendations are elaborated in Chapter Five while Chapter Six highlights the role of sufficient knowledge and consistent data that are the basic inputs both for energy development and environmental wellbeing. Thus, important data and knowledge gaps must be filled by gathering relevant climatic and energy resource and utilization data, and their better assessment to document the interactions between climate change and the Ethiopian energy sector with the aim of better informing relevant decision making.

In general, this preliminary review report on energy sector was conducted by assessing and reviewing all possible documents (government strategies, policies and reports and other available studies) and other globally published literature and scientific papers to indicate current situation and future trend of climate change and its influence on local and global development, and to create awareness among responsible bodies for the implementation of effective planning and response for climate change and adaptation.

8.Current Energy Situation of Ethiopia

Energy resources potential of Ethiopia

Ethiopia has abundant renewable energy resources potential including hydro, solar, wind, geothermal and biomass. Table 2.1 highlights the major energy resources in the country. Despite the huge potential, only a very small portion has been developed due to the lack of or low levels of financial, technical, and market capacity, etc.

The energy policy of Ethiopia places high emphasis on renewable energy development and encourages diversification of the energy mix.

Table 2.1: Energy resources⁴

Resources	Exploitable Reserves	Utilization (%)
Hydropower [MW]	45,000	<5%
Solar/day [kWh/m ²]	Avg.5.5	<1
Wind power [GW]	1,350	<1
Wind Speed [m/s]	> 6.5	
Geothermal [MW]	5000	<1
Wood [Million tons]	1,120	50
Agricultural waste [Million tons]	15-20	30
Natural gas [Billion m ³]	113	0
Coal [Million tons]	300	Negligible
Oil shale [Million tons]	253	0

Sources: GTZ and EREDPC, EEPCC; MME, and EIGS, SWERA, Wind & Solar Master Plan

The following sub-sections describe the various energy resources in Ethiopia.

⁴ Overview of the Energy Sector in Ethiopia, Federal Democratic Republic of Ethiopia, Ministry of Water, Irrigation and Energy, June 2014



Biomass

The major biomass resources in Ethiopia include wood, agricultural residues, animal waste and human wastes are considered as major biomass resources of Ethiopia. The estimated potentials for these biomass resources include 1,120 million tons of wood, 15-20 million tons of agricultural wastes, 27.8 million tons of dung from current livestock and poultry population annually and about 7 million tons human waste annually. The total energy that can be derived annually from these resources is estimated to be about 101,656.77 TCal. Woody biomass accounts for about 79% of this potential, with contributions of 11%, 8% and 2% from animal waste, crop residue and human waste, respectively (MoWE, 2011)⁵.

Fuel wood and tree residues are the major sources of energy for cooking and lighting to the vast majority of the rural population, who reside mostly in remote areas. The contribution of dung and crop residues for the total energy consumption of rural households is around 18% of the total.

Table 2.2: Biomass resources—2000 [million tons]⁶

Region	Woody Biomass		Crop Resi- due	Dung
	Stock	Annual yield		
Amhara	111	5.84	5.56	3.45
Oromiya	346	17.94	8.31	10.67
Southern Nations and Nationalities	241	9.90	5.26	4.07
Gambela	69	3.32	0.017	0.035
Dire Dawa	0.56	0.034	0.058	0.035
Harari	0.086	0.0057	0.047	0.019
Total*	767.63	37.04	19.26	18.28
*Total excludes Tigray, Afar, Somali, Benshangul, AddisAbaba				

Source: WBISPP, Reports for the regions,1997,2000, and 2001

5 Ministry of Water and Energy : Draft Climate Change Adaptation Action Plan of Water and Energy Sector February 2011 Addis Ababa Ethiopia

6 Overview of the Energy Sector in Ethiopia, Federal Democratic Republic of Ethiopia, Ministry of Water, Irrigation and Energy, June 2014

Table 2.3: Biomass resource availability by region in '000 Tons (2000)⁷

Region	Woody Biomass		Woredas Exceed- ing Wood Yield	Crop Residues	Animal Dung
	Stock	Yield			
Tigray	30,990	810	72%	863	2,094
Afar	21,645	1,443	10%	122	2,644
Amhara	138,887	5,842	90%	6,235	7,431
Oromiya	373,345	19,905	66%	10,957	10,618
SNNP	227,949	10,098	65%	5,669	4,013
Somali	NA	NA	NA	NA	NA
Benishan- gul-Gu- muz	76,614	3,530	15%	211	175
Gambela	69,155	3,320	0%	80	120
AddisA- baba	N	N	100%	N	N
Dire Dawa	568	35	71%	42	36
Harari	86	6	100%	48	17
Total	939,238	44,986	66%	24,227	27,148

NA =Not Available, N=Negligible

Source: WBISPP, 2000.

Ethiopia has a favorable weather condition to grow various biomass resources on about 25 million hectares of land to produce biofuels from seeds of various oil seed plants and sugar cane, (MoME 2007)⁸. Oil seed plants are normally grown by the private sector, local communities, NGOs and the government while ethanol is being produced by governmental sugar factories.

Hydropower Potential

Ethiopia is often described as the water tower of north-eastern Africa, because most of its major rivers flow to neighboring countries in almost all

⁷ Ibid

⁸ Ministry of Mines and Energy: The Biofuel Development and Utilization Strategy of Ethiopia, August 2007, Addis Ababa, Ethiopia



directions as shown in Figure 2.1.

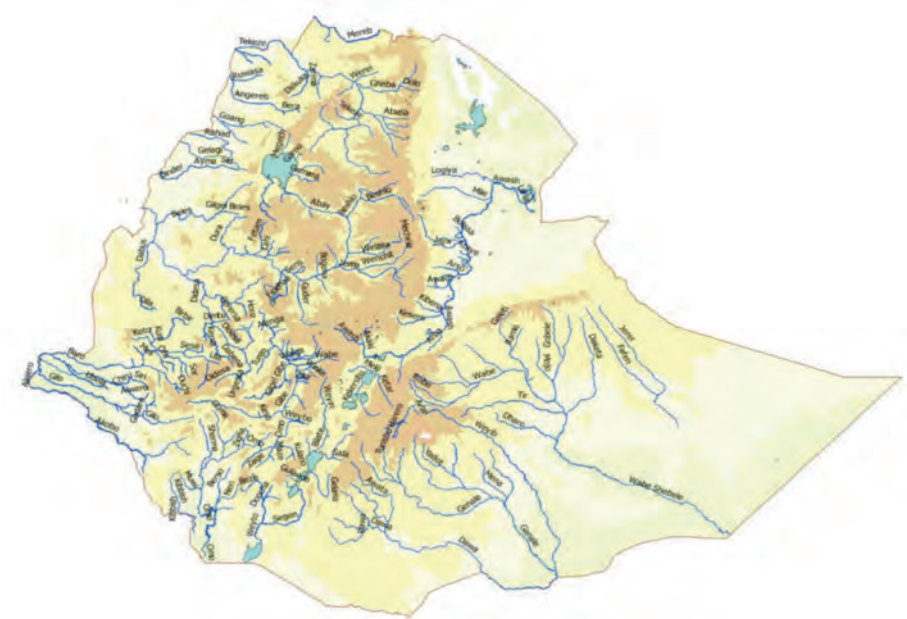


Figure 2.1: Rivers of Ethiopia

The technically exploitable hydropower potential in Ethiopia is estimated at over 45,000 MW. This resource presents ample opportunities for the Ethiopian government in terms of meeting growing domestic electricity demand and economic opportunities in exporting electricity to neighboring countries. For these reasons, the development of hydropower resources is given high priority in the Ethiopian energy sector policies and strategies.

Ethiopia can be divided into eight large basins as depicted in Figure 2.2, seven of which are named after the main rivers that cross the basin. The basins are: Abbay river (Blue Nile), Awash river, Genale river, Wabi Shebele river, Baro Akobo river, Tekeze river, Omo Gibe river and Rift Valley⁹.

⁹ Ibid

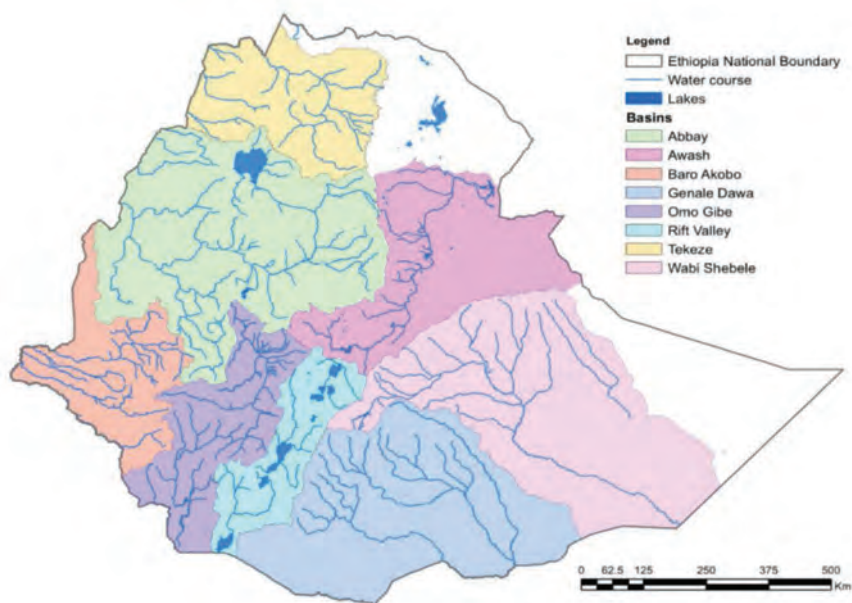




Figure 2.2: River basins in Ethiopia

Power Plant	Installed Capacity	Average Energy	Project Cost	IDC Cost	Total Cost	Cost/kW Inst.	Annualized Cost	Average Levelized Cost	Rank
	(MW)	(GWh/year)	(million \$)	(million\$)		(\$/kW)	(million\$)	(\$/kWh)	
BekoAbo	935	6632.2	1260.8	441.3	1,702	1,820.50	170.348	0.0257	1
Genji	214	910.2	197.6	69.1	267	1,246.30	26.692	0.0293	2
Upper Mendaya	1700	8582.3	2436.4	852.7	3,289	1,934.80	329.173	0.0384	3
Karadobi	1600	7857.2	2576	901.6	3,478	2,173.50	348.027	0.0443	4
Geba 1 + Geba2	372	1709.4	572	200.2	772	2,078.40	77.275	0.0452	5
Genale6	246	1532.4	587.9	205.8	794	3,226.30	79.428	0.0518	6
Sor2	5	38.5	18.6	3.7	22	4,461.60	2.233	0.058	7
Upper Dabus	326	1460.3	628.2	219.9	848	2,601.60	84.88	0.0581	8
Gibe IV+V	2132	8051.3	3625.2	1088	4,713	2,210.50	471.651	0.0586	9
BirbirR	467	2724.1	1231.1	369.3	1,600	3,427.10	160.17	0.0588	10
Werabesa +Halele	436	1972.8	886	310.1	1,196	2,743.40	119.708	0.0607	11



Yeda 1 + Yeda2	280		1089.4	540.2	189.1	729	2,604.50	72.982	0.067	12
Genale5	100		574.6	297.7	89.3	387	3,870.60	38.737	0.0674	13
Tams	1700		5760	3241.5	972.3	4214	2,478.70	421.715	0.0732	15
Baro 1 + Baro2	645		2614.3	1595.9	558.6	2,154	3,340.20	215.614	0.0825	16
Lower Didessa	550		975.6	619.2	185.8	805	1,463.50	80.557	0.0826	17
Tekezell	450		2720.7	1690.4	591.6	2,282	5,071.20	228.382	0.0839	18
Gojeb	150		561.7	526.8	184.4	711	4,741.40	71.177	0.1267	19
Aleltu East	189		804.1	760.6	266.2	1,027	5,433.20	102.768	0.1278	20
Abu Samuel	6		15.7	18.5	2.8	21	3,536.80	2.124	0.1351	21
Aleltu West	265		1067.3	1180.5	413.2	1,594	6,022.70	159.487	0.1494	22
Wabi Shebele	88		691	887.8	221.9	1,110	12,637.60	111.058	0.1607	23
Lower Dabus	250		637	866.3	259.9	1,126	4,504.70	112.707	0.1769	24

Table 2.4: Plan of future hydropower generation¹⁰

10 Ibid



Wind Energy

Ethiopia has a gross wind energy resource of 3,030 GW, whereby the potential technically exploitable wind power capacity is 1,599 GW, and the potential economically exploitable capacity is 1,350GW (MoWE 2012)¹¹. For technical and economic reasons, appropriate wind regions for grid-based electricity generation are those with wind density of 300 W/m² (wind speed 6.5 m/s) and above. Such wind regions primarily occur on high terrains such as ridges and mountain tops which are mainly located at the edge of the highlands that form the great east African rift valley and Somali regional state of Ethiopia. Besides grid-based electrification, there is available wind potential to generate electricity for small towns, villages, farms and other scattered remote areas.

Seasonal and daily variation in wind velocity is considerable; wind velocity is higher between early morning and mid-day and in terms of seasonal variation. In the highland plateau zone there are two peak seasons – March to May and September to November; and in the eastern lowlands, wind velocity reaches its maximum between May and August. In most of these places, maximum wind velocities are 3 to 4 times greater than the minimum. Medium to high wind speed of 3.5 to 6 m/s exists in most eastern parts and central Rift Valley areas of the country. Perhaps due to their mountainous terrain and land use/land-cover type, most western and north-western parts of the country have generally low wind velocity¹², Figure 2.3.

11 Master Plan Report of Wind and Solar Energy in the Federal Democratic Republic of Ethiopia (Final Version) by Hydrochina Corporation, July 2012

12 GTZ (2007): Eastern Africa Resource Base: GTZ Online Regional Energy Resource Base: Regional and Country Specific Energy Resource Database: II - Energy Resource.

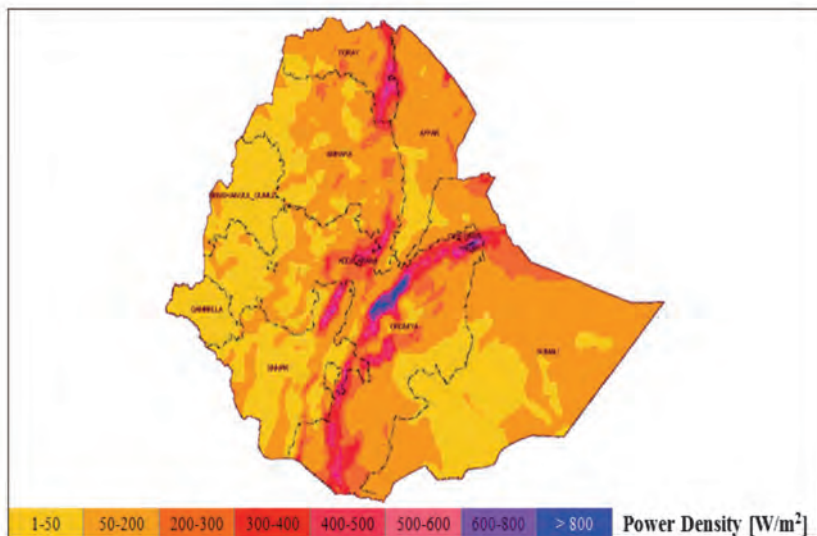


Figure 2.3: Annual mean wind speed

The first wind installation in the country was the 51 MW Adama I Wind Farm, built in 2011. The 120 MW Ashegoda Wind Farm started operation in October 2013 and is one of the largest wind farms in Africa¹³. A third Wind Farm, Adama II Wind Farm, which has an installed capacity of 153 MW, is under construction and is expected to be completed by early 2015.

¹³ Renewable Energy in Ethiopia -Wikipedia, the free encyclopedia; http://en.wikipedia.org/wiki/Renewable_energy_in_Ethiopia



Figure 2.4: Adama I 51 MW Wind Farm (34 WTGs each generating 1.5MW)

Solar Energy

Studies indicate that for Ethiopia as a whole, the yearly average daily radiation reaching the ground is 5.26 kWh/m^2 . This varies significantly over the year, ranging from a minimum of 4.55 kWh/m^2 in July to a maximum of 6.25 kWh/m^2 in February and March. On a regional basis, the yearly average radiation ranges from values as low as 4.25 kWh/m^2 in the areas of Itang in the Gambella Regional State (western Ethiopia), to values as high as 6.25 kWh/m^2 around Adigrat in the Tigray Regional State (northern Ethiopia).

According to the data from Solar and Wind Energy Resource Assessment (SWERA) and Solar and Wind Master Plan studies, the national technically exploitable potential of grid-based and building integrated distributed PV system is about 1.1 TWh per year, whereas the national technically exploitable potentials for off-grid distributed applications for households, rural health centers and rural schools is about 4 TWh per year, 6.24 GWh per year and 15.6 GWh per year, respectively. The national technically exploitable potential of independent PV systems mainly for water lifting operations for some households and farms is about 36 GWh per year.

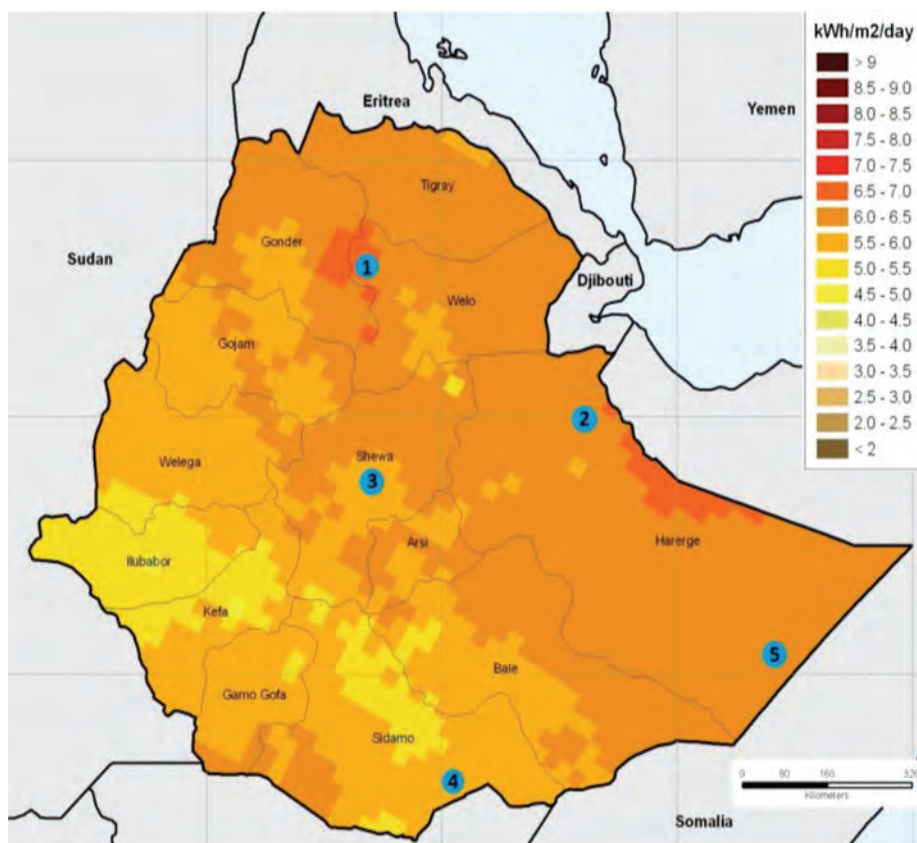


Figure 2.5: Annual mean global solar radiation, kWh/m²/year

Due to its mountainous and rugged topography, a significant number of people who reside in remote areas and villages in Ethiopia have no access to modern utilities, primarily due to technical challenges in expanding modern energy to those areas, thus affecting sustainable development. In such areas, energy from solar radiation is considered as one of the best options for a variety of applications including use for water pumping systems and lighting systems of households, heat water for cooking, agricultural drying, and telecommunication systems as well as for refrigerating and preserving medicines in health centers.

Geothermal Energy

Ethiopia is among the few countries in Africa with a significant amount of geothermal resources. These resources are found scattered throughout the Ethiopian Rift valley and in the Afar Depression, which are both part of the Great East African Rift System. The Ethiopian rift extends from the Ethiopia-Kenya border to the Red Sea in a NNE direction for over 1,000 km within Ethiopia, and covers an area of 150,000 km². Based on investigation results, it was found that Ethiopia could possibly generate more than 5,000 MW of electricity from geothermal resources.

The identified areas with geothermal prospects are widespread throughout the whole Ethiopian rift valley. Prominent among the geothermal prospect areas are shown in Figure 2.6.

- **Lakes District**
Aluto-Langano, Corbetti, and Abaya;
- **Southern Afar**
Tulu-Moye, Gedemsa, Dofan, Fantale, Meteka, Teo, Danab;
- **Northern Afar**
Tendaho and Dallol (Danakil Depression)

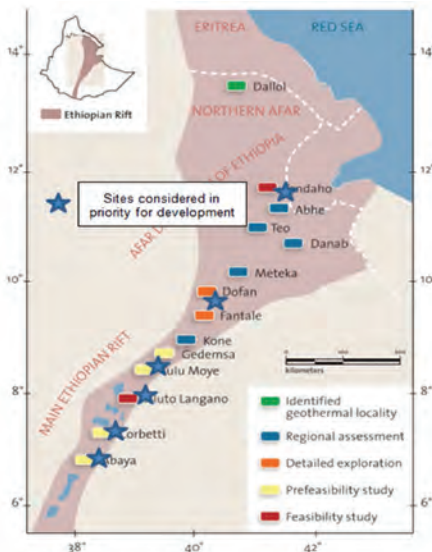



Figure 2.6: Prospect areas of Geothermal power generation



Considering the shortage of modern energy supplies in the country and the climate change issue due to greenhouse gas emissions, there is a need to develop geothermal energy in Ethiopia to serve as a source of reliable base-load power generation to increase its hydropower generation, which relies on highly seasonal fluctuations. The diversification of energy sources is essential in order to ensure a sustainable energy supply. The development of geothermal power would help substitute imported fossil fuel; provide a major backup to an uncertain hydropower supply; serve the arid and semi-arid areas of the country where hydropower is unavailable; and , contribute to the UNFCC effort to reduce global warming.


Others

Coal

Exploration for coal started in the 1930's during the Italian occupation. Some areas had been in use for brick factories since then. According to the exploration results, coal resource estimate is 320 million tons distributed in 9 sites mainly located in the northern, central and south-western part of the country (Delbi - 20 Million tons and Moye 50 Million tons). Other places of occurrences are the central region (Mush Valley 0.3 Million tons) and north-western part of the country (Chilga 19.7 Million tons, in Geba basin 250 Million tons and Wuchale 3.3 Million tons), all of which are under study (EIGS, 2008). Resource quality ranges from medium to low grade (sub-bituminous to lignite). Some of better quality coal deposits are located in the high forest areas in the south-western part of the country where development of sites will potentially have serious environmental consequences.

Natural Gas

Basically in Ethiopia, proven petroleum reserve is not ascertained to-date. However, some indications (ecological and geomorphologic) have been recorded in the Ogaden, Gambella, the Blue Nile Gorge and Makele areas while the potential of natural gas is promising. The first discovery of natural gas was in 1973. This is one of the discoveries made within the east African continental margin, which includes a wide on-shore belt that extends from Ethiopia to South Africa through Somalia, Kenya, Tanzania and Mozambique. In a place called 'Calub', located in the south-eastern part of the country,



1200 km from Addis Ababa, about 76 billion m³ of gas was discovered (MME, 2006). In the previous years, six wells were constructed to enable extraction of the gas at Calub field. Another promising gas field is the Hillala area, discovered in 1974. The Hillala gas condensate pool is located 75 km west of Calub gas field. According to a study made by the Soviet Petroleum Exploration Expedition in 1993, the estimated initial gas in place was about 40 billion m³, (MME, 2006).

Oil Shale


The Inter-Trapean oil shale bearing sediments are widely distributed on the south-western Plateau of Ethiopia in the Delbi-Moye, Lalo-Sopa, Sola, Gojeb-Chida and Yayu Basins. The oil shale-bearing sediments are deposited in fluvial and lacustrine environments. Oil shale deposits in Ethiopia can be used for production of oil and gas.

Energy development in Ethiopia

Ethiopia's energy sector is dominated by the consumption of traditional biomass resources, while the use of modern fuels and electricity play a marginal part. The latest data show that in 2011, traditional biomass accounted for 92% of energy consumption. Hydrocarbon-based fuels mostly used for transport accounted for 7% of consumption while electricity accounted for only 1% of the energy consumption in the country¹⁴. In terms of sectoral demand, the household sector accounted for 93% of energy consumption. The transport sector accounted for about 5% of the consumption, with the commercial and industrial sectors accounting for only 2%. Other important sectors such as agriculture had negligible consumption as they are still dependent on human and animal power.

Biomass resources are exploited for the most part for self consumption by the rural communities. Commercial exploitation of the resource, in the form of fuel wood and charcoal, cover only around 20% of the biomass consumption. This signifies that local availability of biomass resources plays a major role in the supply of these fuels, with long distance trade limited mostly to charcoal. All these have led to unsustainable exploitation of biomass resources in most parts of the country, posing acute challenges for the future.

14 MoWE, Energy Balance and Statistics for 2005/6 – 2010/11, May 2012.



Petroleum-based fuels are mainly consumed by modern transport in urban areas and for intercity transport. Individual vehicle ownership level remains very low (less than 1% of population), though most urban dwellers and a growing number of rural people use public transport with some regularity. All of the fuels being used are imported into the country at a huge cost to the economy and with significant impacts on its balance of payment.

The government of Ethiopia has already developed a biofuels strategy. The main objective of the Ethiopian bio-fuels strategy program is to enhance energy security and access to transport fuels. The strategy is focused on allocating marginal land for bio-fuel plants cultivation, accelerating bio-ethanol and bio-diesel development and technology transfer, increasing domestic use and export earnings from bio-fuels and, enhancing domestic coordination and international cooperation for the development of biofuel resources. The bio-fuel development program is also expected to establish and promote an agriculture-based industry for increased agricultural and industrial outputs, employment and exports.

There is an increase inflow of private investment in biofuels production in Ethiopia. The government, as part of the biofuels strategy, is allocating marginal land to investors to grow biomass resources for the production of biofuels; more than half a million hectares of land has already been allocated to licensed developers. Out-growers in large numbers are also increasingly involved in this new business in large numbers.

Since fuel blending with ethanol began in October 2008, local production of ethanol is increasing rapidly and is expected to increase even more, as stipulated in the biofuels strategy due to the new blending market and additional sugar factories under construction that will be producing ethanol in large quantities. The bio-ethanol activities in Ethiopia include:

- In October 2008, distribution of E-5 blended fuels started in Addis Ababa.
- As of March 2011, distribution of E-10 blended fuels started in Addis Ababa.

- Currently, two oil distribution companies, Nile petroleum and Oil Libya, carry out the blending processes.
- The Ethiopian Government is committed to the increment of production of ethanol that the country will be producing over 194.9 million liters at the end of 2015 (GTP) through coordinating the governmental and private sugar industries on the wider use of technologies including ethanol stoves. One strategy for local market development for ethanol stoves in Ethiopia is the development and promotion of appropriate use of proven and tested ethanol stove technologies.

Similar to other renewable energy resources, biofuel will also play significant roles in the Ethiopian energy sector and for climate change adaptation programs.

Historically, the use of other hydrocarbons such as coal and gas has been non-existent, but usage of imported as well as locally mined coal in the cement industries has started to pick up lately, though still statistically insignificant.

Hydropower is the major source of the electricity in Ethiopia, accounting for about 92% (1,940 MW) of the total supply. This amount is, however, less than 5% of the economically exploitable potential of the hydropower resource. Presently, only about 48% of the population live in areas with geographic access to electricity; many towns and villages in rural areas still lack any access to electricity. The current annual *per capita* electricity consumption is less than 100 kWh, which is one of the lowest levels of consumption, even among the least developed countries. For example, the *per capita* consumption in Ethiopia is too low compared to the average Sub-Saharan Africa *per capita* consumption of 500 kWh/year. Recently, due to expanding economic activities in the country, the electricity demand is increasing at an accelerated rate. Recently Ethiopia has interconnected with two of its neighboring countries – Djibouti and the Sudan. Thus, the existing situation and future growth in power demand calls for development of the hydropower resource with a sense of urgency¹⁵. The percentage contribution of each hydropower plant to the total capacity is represented in Figure 2.7.

¹⁵ Ibid

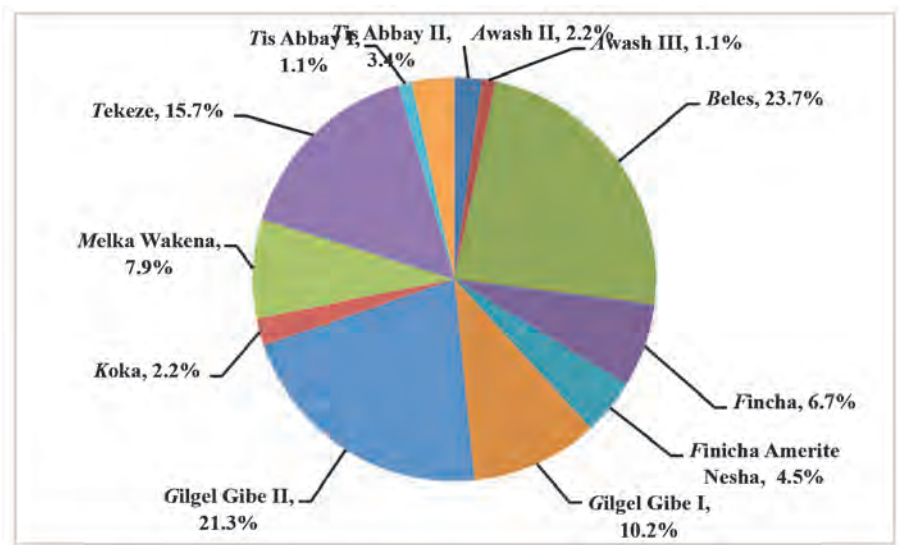


Figure 2.7: Percentage contribution of various hydropower plants to the total installed capacity

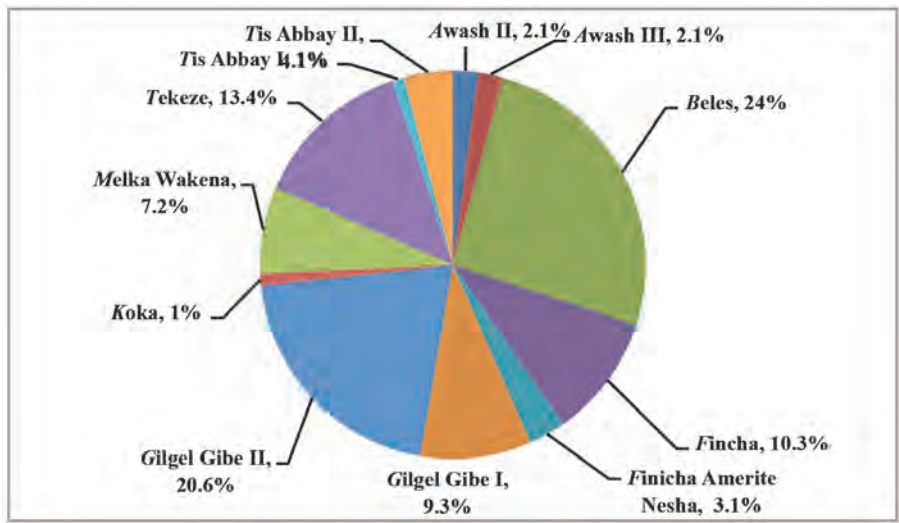


Figure 2.8: Percentage contribution of various hydropower plants to the average energy generation for the year 2010/2011

In terms of access to electricity, about 23% of households are directly connected to the national electricity grid, though it is mainly used for lighting¹⁶. To further expand electricity access to household and to meet the demand of electricity by the commercial and industrial sectors, indigenous renewable resources have been developed. Currently, the electricity generation capacity of Ethiopia has reached around 2,200 MW. The electricity network also consists of 12,000 km of high voltage transmission lines and 140,000 km of medium and low voltage distribution lines bringing power to end-users. The country has recently begun exporting electricity to Djibouti and the Sudan, with plans to expand power export in the future.

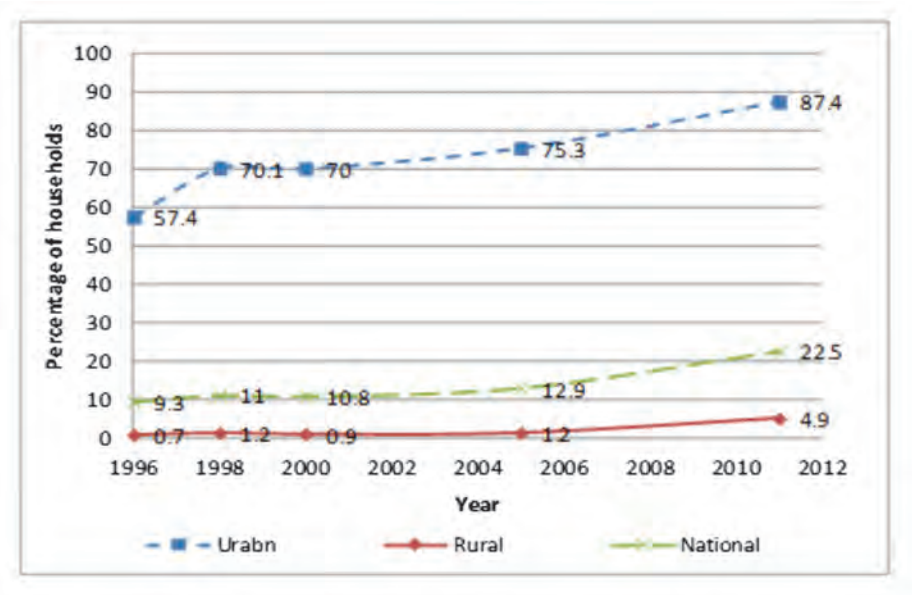


Figure 2.9: Percentage distribution of households connected to grid electricity by place of residence

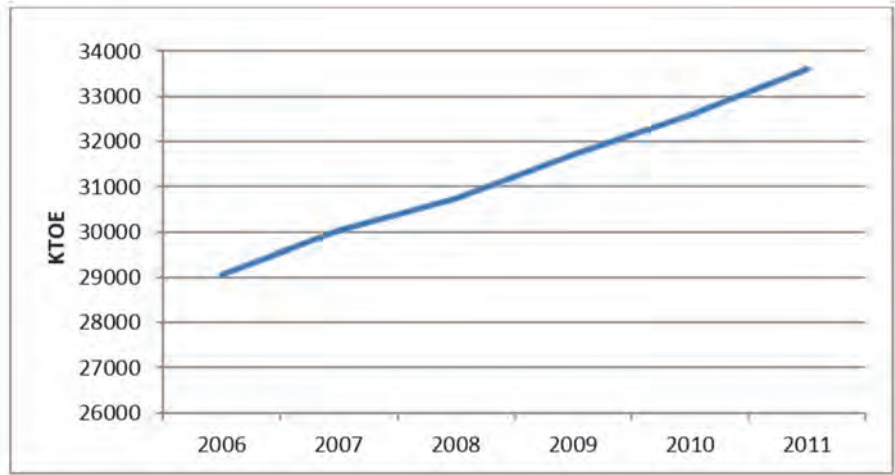
Source: Updated Rapid Assessment and Gap Analysis on Sustainable Energy for All: Ethiopia

Detailed projections of future energy demand are so far available only for the electricity sector¹⁷. The sector has recently experienced a sharp increase

16 CSA, Ethiopian Welfare Monitoring Survey 2011, April 2012.
 17 Ethiopian Electric Power Corporation, Ethiopian Power System Expansion Master Plan Study, February, 2014.

in power demand with more than 20% annual growth in demand for many years now. The rapid increases in electricity demand has started to pose a serious challenge for the sector, necessitating hitherto unseen levels of public investment in power generation and network expansion activities and efforts to bring the service to new areas of the country. Accordingly, the demand is expected to continue to rise at a significant rate for the next decade as the country strives to attain its target of achieving a middle-income country status by 2025. Thus, local electricity consumption is expected to rise from the level of 6,443 GWh in 2012 to 111,000 GWh by 2037, and together with regional power export possibilities could rise to as much as 147,000 GWh. This indicates around a 20-fold increase in electricity demand over the time period, highlighting that significant efforts are required to meet this challenge. The plan in general is to develop the country’s abundant renewable energy resources to meet this demand. These constitute hydropower, geothermal, wind, solar and biomass resources, thus contributing to the overall green growth strategy adapted by the country.

Concerning biomass, business-as-usual scenarios predict that, even though the share of biomass energy will fall from around 92% today to about 70%, the actual consumption will rise by 50% by 2030¹⁸, mainly due to population increase, thereby continuing the challenge of meeting this demand sustainably, as well as fastening fuel shift to other forms of energy, primarily electricity.



18 MoWE & EUEI-PDF, Biomass Energy Strategy Formulation for Ethiopia, July 2013.



Figure 2.10: Total primary energy supply of Ethiopia

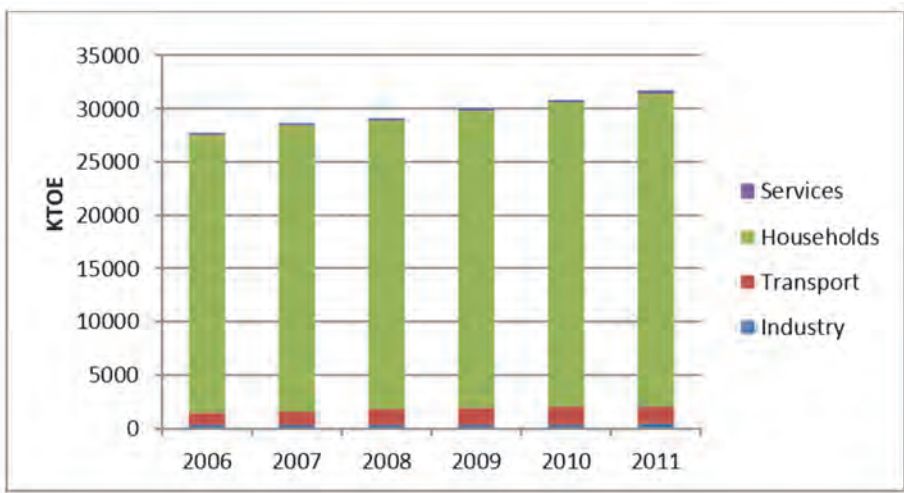


Figure 2.11: Energy consumption by sector

9.Climate Change Vulnerability of the Energy Sector and Current Policy Measures


Climate change impact assessment and implications for development in Ethiopia

Climate change poses significant threats to Ethiopia's development, but at the same time presents opportunities. Climate change is not just a future possibility for Ethiopia, it is a present reality. That is why Ethiopia should start now to protect its people and the environment, while, at the same time, building a green economy that will help to realize the ambitions set out in the Growth and Transformation Plan (CRGE 2010). Ethiopia has, therefore, embarked with a strong commitment to propel its growth and transformation towards reaching a middle income status by the year 2025. This national vision is anchored on environmental responsive investments and green growth. The GTP recognizes the principles of sustainable growth as embodied in the 1997 National Environmental Policy.

In 2011, the Climate Resilient Green Economy (CRGE) strategy was adopted as a national strategy framework to embody both sustainable green development goals and climate change mitigation and adaptation. The Climate-Resilient Green Economy (CRGE) initiative follows a sectoral approach and has so far identified and prioritized more than 60 initiatives, which could help the country achieve its development goals while limiting projected 2030 GHG emissions to about today's 150 Mt CO₂e – about 250 Mt CO₂e less than estimated under a conventional development path. The green economy plan is based on four pillars:

1. Improving crop and livestock production practices for higher food security and farmer income while reducing emissions;
2. Protecting and re-establishing forests for their economic and ecosystem services, including as carbon stocks;
3. Expanding electricity generation from renewable sources of energy for domestic and regional markets; and
4. Leapfrogging to modern and energy-efficient technologies in transport, industrial and buildings sectors.

The Ministry of Water, Irrigation and Energy (MoWIE) has led the development



of the Climate Resilience Strategy for the water and energy sectors. The main development agenda of the Ethiopian government is poverty eradication through broad-based, accelerated and sustained economic growth. Ethiopia's economic growth and social development plans are set out in the Growth and Transformation Plan (GTP1), which spans the 2010-2015 period. Through 'Agricultural Development-Led Industrialization', Ethiopia aims to build an economy which has a modern and productive agricultural sector and a strong industrial sector, ultimately increasing per capita income of the citizens so as to reach the level of those in middle-income countries by 2025 and to achieve the Millennium Development Goals by 2015. The sector strategy has made in-depth analyses taking into account climate challenges such as current climate-temperature and historical rainfall patterns and their impacts and risks will bring negative effects on future water and energy resource development.

The current energy situation greatly increases the country's vulnerability to climate change. For example, Ethiopia's reliance on fuel wood and charcoal brings widespread land degradation, exposing bare soil to erosive rainfall and gully erosion. As climate impacts increase, there is likely to be a higher reliance on forest products for livelihoods.

Energy generated by hydropower is also vulnerable to fluctuations in rainfall, temperature and evaporation. For example, reduced power production during drought years already takes a significant toll on the economy. In 2002/3 power supply was cut one day a week over four months because of drought. This caused a sustained reduction in GDP generation. Loss of electricity also impacts basic services especially in schools and hospitals.

Ethiopia's energy sector development is still very low and the majority of the people are dependent on naturally existing biomass energy. Modern energy services rely on electricity generated from hydropower and imported fossil fuels. As indicated by various investigations, biomass and hydropower energy resources are highly vulnerable to climate changes. Consequently, the energy production of Ethiopia is severely affected by these changes. This situation leads to extreme demand and supply gaps which need urgent intervention in all directions.




Climate change risks, impacts and assumptions in the energy sector

Like other development sectors, climate change has significant impacts on the production, transmission and consumption of energy (Climate Change Adaptation Program in Water & Energy Sector, 2011) (IPCC, 2014). The energy sector in Ethiopia is among the five sectors most vulnerable to climate change and weather variability (World Bank 2008). And this requires serious attention to be given to the impacts of climate change on energy sector.

The impacts of climate change on energy supply and demand will not only depend on climatic factors but also on patterns of economic growth, land use, population growth, distribution, technological change and social and cultural trends that shape individual and institutional actions. For example, on the one hand changes in temperature due to climate change could affect demand for energy in that the rising ambient air temperatures will most likely lead to substantial increase in energy demand for air conditioning. On the other hand, there has been little research carried out to date on how climate change may affect energy supply. In the Ethiopian context, not enough is said about vulnerability of climate change on the energy sector. Even though, Ethiopia is endowed with renewable energy resources, these are not sufficiently exploited and developed. The high demand and use of fuel wood, which decreases the vegetation cover, exacerbates land degradation aggravating vulnerability to climate change as shown in Table 3.1.

Table 3.1: Climate Change Impacts and Vulnerability

Climate change impacts	Induced impacts	Vulnerability to climate change
Temperature and Rainfall <ul style="list-style-type: none"> • Increased temperature followed by drought. • The average annual minimum temperature over the country has been increasing by 0.25°C every ten years while average annual maximum temperature has been increasing by 0.1°C every decade (NMSA-2001) • Averaged rainfall over the whole country shows decreasing trend over the northern and south-west of the country while increasing trend in central part of the country (NMSA-2001) 	Extended Periods of Drought <ul style="list-style-type: none"> • Shortage of water (in some localities streams have dried • Evaporation has increased • The growth of trees, bushes and other plants that susceptible to increased temperature has limited • Ecosystems have been disturbed(animal population and crop shave affected) • Increased temperature could result wild fire 	Biomass Energy Resources Deterioration <ul style="list-style-type: none"> • Fuel wood scarcity aggravated and worsen the life of community • Utilization of animal dung and other bio residues as sources of energy is increased as result energy and food insecurity is increased • Both large and small hydropower production challenged • Loss of biomass energy and biodiversity



Extreme events	Extended drought <ul style="list-style-type: none"> • Extended heavy rainfall followed by flood • Increased and extended clouds 	Crippling hydro-power dependent power sectors <ul style="list-style-type: none"> • Increased siltation of hydropower dams and damage hydro turbines by increased incidences of floods • Infrastructure for energy production, transmission and distribution could be affected by extreme events • Solar radiation could be reduced thus affecting the effectiveness of solar electric systems • Wind production would be drastically disturbed if wind speeds increase above or fall below the acceptable operating range of the technology.
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Resource poor rural farmers are the most vulnerable segment of society due to their dependency on climate sensitive agriculture sectors for living. The recent drought in 2003, 2009 and 2011 clearly showed the vulnerability of farming communities to climatic impacts (CRGE, 2011).

According to the World Bank (2010), major floods also occurred in different parts of the country in 1988, 1993, 1994, 1995, 1996 and 2006. Increased intensity and frequency of severe weather events impact design and safety requirements of future energy infrastructure and other capital investments.


This calls for changes in design standards in order to improve climate resilience of energy infrastructure.

Since the early 1980s, the country has suffered seven major droughts, five of which led to localized famines, in addition to dozens of local droughts (World Bank, 2010; Diao and Pratt 2007, as cited in: Robinson et al., 2013). Chronological occurrences of droughts and famine in Ethiopia are given in Table 3.2 below.

Table 3.2: Chronology of El Niño and Drought history in Ethiopia

El Niño Years	Drought/Famine	Regions
1539-41	1543-1562	Hararghe
1618-19	1618	Northern Ethiopia
1828	1828-29	Shewa
1864	1864-66	Tigray and Gondar
1874	1876-78	Tigray and Afar
1880	1880	Tigray and Gondar
1887-89	1888-1892	Most of Ethiopia
1899-1900	1899-1900	Most of Ethiopia
1911-1912	1913-1914	Northern Ethiopia
1918-19	1920-1922	Most of Ethiopia
1930-32	1932-1934	Most of Ethiopia
1953	1953	Tigray and Wollo
1957-1958	1957-1958	Tigray and Wollo
1965	1964-1966	Tigray and Wollo
1972-1973	1973-1974	Tigray and Wollo (About 200,000 people dead)
1982-1983	1983-1984	Most of Ethiopia
1986-87	1987-1988	Most of Ethiopia
1991-92	1990-1992	Most of Ethiopia
1993	1993-94	Tigray, Wollo and Addis
	2002/2003	Most of Ethiopia (15 million people in need of food assistance)

Sources: Quinn and Neal (1987); Degefu (1987); Nicholls (1993); Webb and Braun (1994) cited in (ICPAC, 2007).



Increasing temperature and incidence of droughts affects availability of water, biomass, crop residues, animal dung, etc, which are known to be used both as modern and traditional energy sources. Water availability affects the energy production from hydropower. For instance, Ethiopia faced a big power shortage due to failed small (autumn) rains and increasing temperature in 2009, increased demand and the delay of the ongoing construction of hydropower plants partly. This power cut cost the Ethiopian economy 1% in GDP growth (Hilawi Lakew, 2009).

Future temperature: Modeling the future climate envelope, there is a relatively high degree of certainty about temperature changes due to climate change. The climate models all agree on an overall increase in temperatures across the country and at regional scale, with a decrease in variability of temperatures. The models suggest that Ethiopia will see further warming in all seasons between 0.7°C and 2.3°C by the 2020's and of between 1.4°C and 2.9°C by the 2050s. Therefore, in general, the models indicate warmer and more consistent temperatures across the country.

Future Rainfall: Seasonal rainfall patterns may change significantly in some regions. Rainfall is much more complicated to predict and there is less certainty of overall trends. The climate models indicate that under some scenarios, there may be significant changes in seasonal rainfall patterns in some regions (see Figure 3.1).

- There will be broadly similar seasonal (i.e. month-to-month) rainfall patterns in the western part of the country in the future, with any changes in annual rainfall being spread across the year;
- However, the central and eastern regions may see some shifts in monthly rainfall patterns. The wettest scenarios indicate an increase in rainfall outside of the main Kiremt rains. However, the driest scenarios indicate that there could be a shorter Kiremt period with less rain in general and more significantly that the shorter Belg rains may be reduced or even lost altogether.
- The models show a diverse range of outcomes for the south and south-eastern region. The wettest scenarios indicate that the main gu rains could come earlier and that deyr rains could be longer. The driest scenarios indicate a drastic fall in the main gu rains, which could have

major consequences for food security in the Somali, Amhara and SNNP regions.

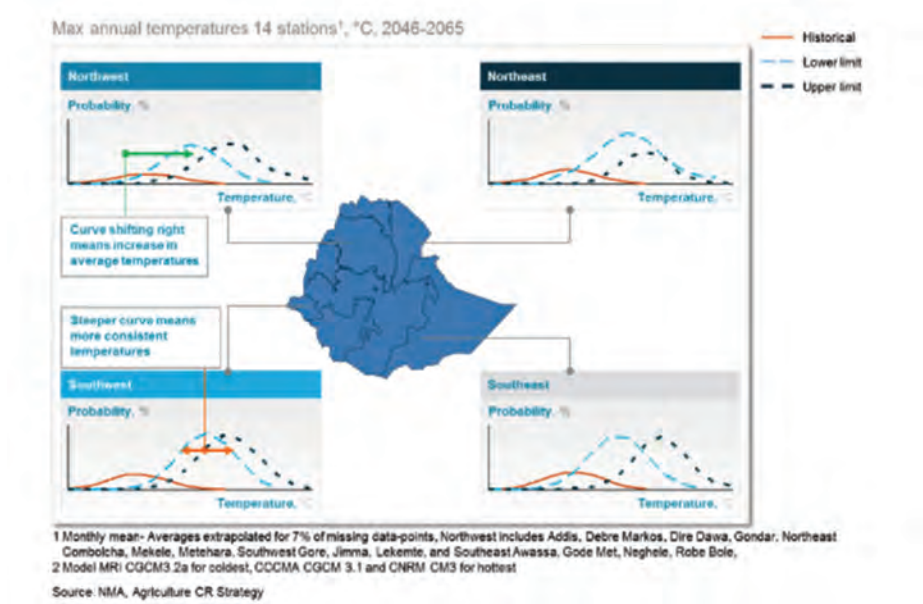


Figure 3.1: Future temperature envelope under climate change (Draft CR, 2014)

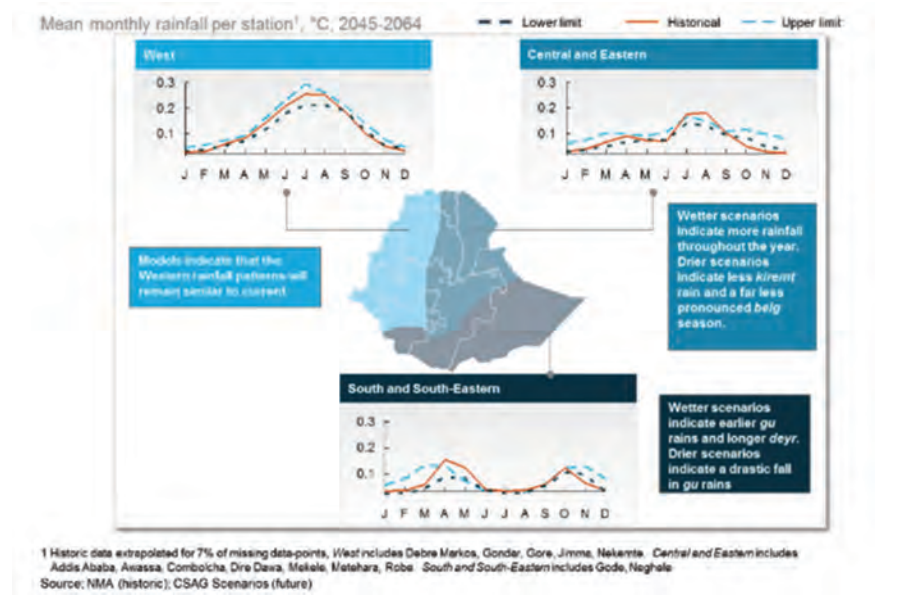


Figure 3.2: Future month-to-month rainfall envelope under climate change (Draft

CR, 2014)

The belg and gu rains are critical factors for food security and livelihoods and their failure has serious impacts on communities in the south and east of the country (mainly in Somali region and in the south of Oromia and SNNPR.)

The draft CR strategy proposes the following underlying planning assumptions based on the available analysis.





	Month-to-month variability	Year-to-year variability	Long-term change
<div>Temperatures</div> 	<ul style="list-style-type: none">Limited change to current seasonal patterns	<ul style="list-style-type: none">Marginally less year-to-year variability	<ul style="list-style-type: none">Higher temperatures across all regions (+0.8 to +2.7°C)
<div>Rainfall</div> 	<ul style="list-style-type: none">Potential drying or shifting of <i>belg</i> and <i>gu</i> seasons in CE and SSE regions	<ul style="list-style-type: none">Increased year-to-year variability with an increase in extremes	<ul style="list-style-type: none">Uncertain in West, both drier and wetter outcomes possible

Figure 3.3: Climate planning assumptions (2046-2065) (Draft CR, 2014)

Implications for development in Ethiopia

The above planning assumptions have been mapped to the water and energy sectors, and the subsequent implications for economic growth and poverty reduction are highlighted below. This qualitative illustration of the potential impacts was used to identify key areas for more detailed analysis.

Table 3.3: Key water and energy vulnerabilities to climate change (Draft CR, 2014)

Climate stressor	Impacts related to water and energy on ...	<div>  Negative impact  Positive impact </div>	
		Economic growth	Poverty reduction
<ul style="list-style-type: none"> • Increase in temperature 	<ul style="list-style-type: none"> ▪ Higher evaporation of dams and rivers, potentially reducing supply ▪ Increased demand for power for cooling ▪ Increased human, animal and crop water demand 	<div>↓</div> <div>↓</div> <div></div>	<div></div> <div></div> <div>↓</div>
<ul style="list-style-type: none"> • Increased rainfall variability 	<ul style="list-style-type: none"> ▪ Less certainty of the productivity of hydropower assets ▪ Less certainty of the productivity of thermal generation assets ▪ Less certainty of irrigation volumes available for use ▪ Less certainty for rural livelihoods and income 	<div>↓</div> <div>↓</div> <div>↓</div> <div></div>	<div></div> <div></div> <div>↓</div> <div>↓</div>
<ul style="list-style-type: none"> • Increase in rainfall extremes (floods and droughts) 	<ul style="list-style-type: none"> ▪ Floods can damage water and energy assets and increase soil erosion ▪ Droughts impede the productivity of energy assets ▪ Droughts reduce irrigation volumes ▪ Droughts increase water stress for people and their livestock 	<div>↓</div> <div>↓</div> <div>↓</div> <div>↓</div>	<div></div> <div></div> <div>↓</div> <div>↓</div>
<ul style="list-style-type: none"> • Increase in rainfall in West 	<ul style="list-style-type: none"> ▪ Allows increased production from hydropower ▪ Depending on rainfall pattern, can lead to increased agricultural productivity and more secure livelihoods 	<div>✓</div> <div>✓</div>	<div>✓</div> <div>↓</div>
<ul style="list-style-type: none"> • Decrease in rainfall in highland 	<ul style="list-style-type: none"> ▪ Reduced productivity of hydropower energy assets ▪ Significantly reduced harvest and food security ▪ Increased water stress for people and their livestock 	<div>↓</div> <div></div> <div></div>	<div></div> <div>↓</div> <div>↓</div>

Other studies have also identified significant impacts of climate change on Ethiopia's economic and poverty reduction objectives. The Climate Resilience Strategy for Agriculture estimated that the worst case scenario could negatively impact GDP by 10% or more by 2050. The recent Economics of Adaptation to Climate Change (EACC) study concluded that impacts were felt through three main channels: agriculture, roads and dams. Although the four scenarios used in the EACC study are different from the ones used in the draft CR Strategy for Water and Energy, the identified losses are significant, ranging from around 1% reduction in GDP to over 10%.

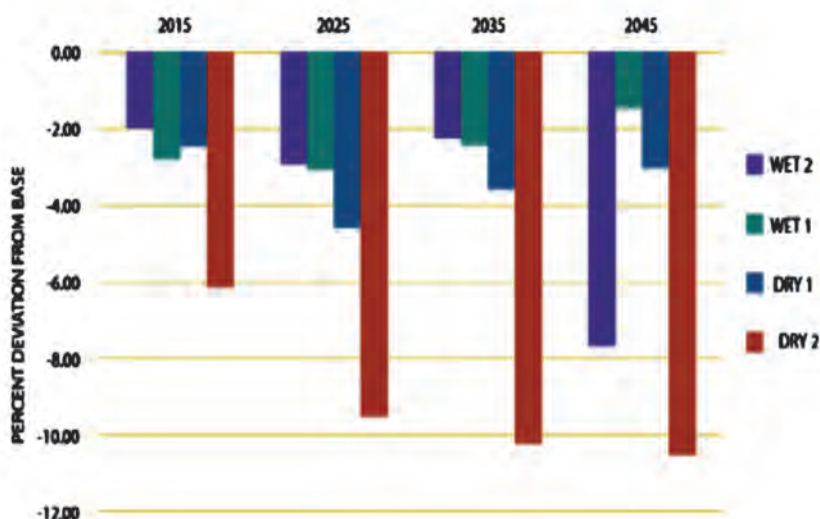


Figure 3.4: Potential impacts of climate change on GDP in Ethiopia (World Bank)

To summarize, the main climate change impacts that challenge the Ethiopian energy sector are water shortages, variable rains, temperature increase, floods and drought. The main possible implications of the above mentioned impacts are:

- Extended periods of drought will lead to reduced water availability resulting in deteriorated fuel wood availability that worsens the lives of rural communities, specifically women and children;
- Extended periods of drought will affect animal population and crops causing reduced biomass residues that are used for cooking and lighting;
- Extended periods of drought will lead to reduced water availability for hydropower generation. The shortage of water is manifested by dried streams/springs and some tributaries of main rivers in the country;
- The variability of rainfall such as extended and heavy rainfall will cause flood/overflow, increasing sedimentation/siltation, which affects hydropower dams and other water development infrastructures; and
- Changes in cloud cover, temperature and pressure patterns will directly affect wind and solar resources.

Emission trends

Ethiopia's contribution to global GHG emissions is very low. However, the projected environmental impacts of conventional economic development in Ethiopia risks following the pattern observed around the globe. If current practices prevailed, GHG emissions in Ethiopia would more than double from 150 Mt CO₂e to 400 Mt CO₂e in 2030. On a per capita basis, GHG emissions are set to increase by more than 50% to 3.0 tons CO₂e and would thus exceed the global target to keep per capita emissions between 1 ton and 2 ton per capita in order to limit the negative effects on climate change.

In general, Ethiopia's contribution to the global increase in GHG emissions since the industrial revolution has been practically negligible. Even after years of rapid economic expansion, the 2010 *per capita* emissions of less than 2 tons CO₂e are modest compared with the more than 10 tons per capita on average in the EU and more than 20 tons per capita in the US and Australia. Overall, Ethiopia's total emissions in 2010 were around 150 Mt CO₂e. Of the 150 Mt CO₂e in 2010, more than 85% of GHG emissions came from the agricultural and forestry sectors. They were followed by power, transport, industry and buildings, which contributed 3% each, Figure 3.5.

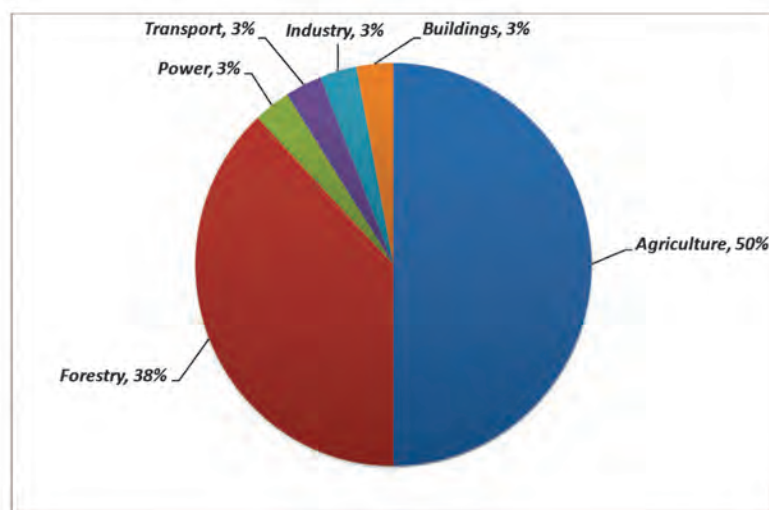


Figure 3.5: Share of GHG emission in 2010 (Total GHG emissions 150 Mt CO₂e)



Current policy measures and analysis

Ethiopia is experiencing the effects of climate change, with an increase in average temperature and changes in rainfall patterns. Climate change presents the necessity and opportunity to switch to a new development pathway, which promoted economic growth as well as ensure sustainable development. The government of Ethiopia has, therefore, initiated the Climate-Resilient Green Economy (CRGE) strategy, to protect the country from the adverse effects of climate change and to build a green economy that will help realize its ambition of reaching middle-income status before 2025. The first step in implementing the CRGE vision was to develop, a Green Economy (GE) strategy and the next stage of implementing the CRGE vision was to develop Climate Resilience Strategy for key sectors of the economy.

The first Climate Resilience strategy focused on the agriculture and forestry sectors (completed in 2014). The Climate Resilience strategy for water and energy under development continues this analysis and, integrates with the Green Economy strategy, sets the overall priorities for implementing the CRGE. Each of the strategy and priority directions and actions are presented below.

The Green Economy (GE) Strategy

The GE strategy identified and prioritized more than 60 initiatives, which will enable Ethiopia to achieve its development goals while limiting greenhouse gas emissions in 2030 to today's levels (150 MtCO₂e). These initiatives would help to avoid 250 MtCO₂e of GHG emissions in 2030 with 'no and low regrets' (the abatement cost of most of the options was less than \$15/tCO₂e). 42% of these savings (104.1 MtCO₂e in 2030) come from initiatives related to energy and water.

Table 3.4: GHG abatement potential of major initiatives

SECTOR	INITIATIVE
Electricity	Exports: Exporting excess renewable energy has an abatement potential of up to 19 MtCO ₂ e in 2030 by reducing emissions in the neighbouring countries.
Green cities and buildings	Efficient lighting: This initiative has an abatement potential of approximately 5.1 MtCO ₂ e, and is the largest abatement lever in the Green Cities and Buildings sector.
	Waste gas management (biogas): Emissions from landfill and liquid waste can be reduced by 1.8 MtCO ₂ e in 2030 through the capture of gas.
Forestry/Soil	Reduced forest degradation: Reducing the demand for fuel wood through dissemination of efficient cooking and baking technologies has a total abatement potential of around 50 MtCO ₂ e.
Industry	Energy efficiency in the cement industry: The introduction of energy efficient technologies in the cement industry could reduce emissions by more than 5 MtCO ₂ e in 2030.
	Alternate fuels in the cement industry: An increase in the use of biomass for cement manufacture can displace fossil fuels and reduce emissions by up to 4.2 MtCO ₂ e in 2030.

Transport	Alternates transport fuels: Changing the transport fuel mix using a combination of adding biodiesel to the diesel mixture, increasing the amount of ethanol in the gasoline mixture and promoting the adoption of hybrid and plug-in electric vehicles has a combined abatement potential of nearly 1.0 MtCO ₂ e.
	Electric rail development: Shifting freight transport from road to an electric rail network would eliminate emissions from the largest source of transport emissions, avoiding 8.9 MtCO ₂ e. A further 0.1 MtCO ₂ e will be avoided by the Addis Ababa light rail.

Under the GE, providing a focus for action, the CRGE has already four fast tracked initiatives, which are important enablers for the country's economic development, and their implementation is feasible and considered as a priority by the government for implementation as shown in Table 3.5 below.

Table 3.5: Four fast-tracked initiatives

Rationale for importance of green economy initiative	
Power infrastructure financing	<ul style="list-style-type: none"> Electric power generation is a critical component to realize growth and economic development and a condition for green growth in other sectors <ul style="list-style-type: none"> Fundamental to meet growing domestic demand Offers significant export potential Securing the financing enables scale-up of clean/renewable power generation capacity
Rural energy-efficient stoves	<ul style="list-style-type: none"> Fuelwood usage is the largest source of rural energy supply and one of the largest contributors to GHG emissions Efficient stoves can have massive benefits by increasing rural household income, health, women's empowerment, and education while decreasing emissions by around 50 Mt CO₂e in 2030
Efficient livestock sector	<ul style="list-style-type: none"> Livestock accounts for around 11% of the formal GDP and is also the largest source of GHG emissions in the country Sectoral growth can be achieved while reducing the projected emissions of the sector by up to 45 Mt CO₂e per year in 2030 Ethiopia could possibly monetise these reduced emissions to support GDP growth in Livestock
REDD	<ul style="list-style-type: none"> Forests account for 1/3 of total emissions today and offer huge abatement potential through less deforestation and less forest degradation In addition, already today Ethiopia has the second-largest afforestation and reforestation programme in the world



Sector Reduction Mechanism (SRM)

The Sectoral Reduction Mechanism (SRM), as part of the CRGE, is a comprehensive system for reducing vulnerability and emissions. The SRM is a mechanism for mobilizing action on climate change on the ground. The purpose of the SRM is to reduce emissions and vulnerability to build a climate resilient green economy with zero-net carbon emission by 2025 through providing upfront support and ex-post payment for the preparation and implementation of reduction interventions. The SRM has three main aims, which together will help achieve its purpose. First, the SRM will help to mainstream green growth and resilience into Ethiopia's broader development activities. Second, the SRM will ensure that Ethiopia's efforts to acquire low carbon and climate resilient technologies to build a green and resilient economy are aligned and coordinated. Finally, the SRM will leverage climate related investment.

The objective of the Sector Reduction Mechanism (SRM) is to elaborate the policy, technical, institutional and financial requirements and the modes of operation to:

1. Enable the implementation of Ethiopia's Climate Resilient Green Economy vision and strategy through attracting, accessing, blending and leveraging domestic and international public and private investment by engaging with bilateral and multilateral grant providers, lenders, investors and carbon traders in order to unlock the potential of the engines of a climate resilient green growth that will move Ethiopia towards becoming a climate resilient middle income country with zero increment of emission from the 2010 level;
2. Provide the support required for the preparation and implementation of sectoral reduction policy measures, sectoral reduction actions and concrete sector-wide investment proposals for the penetration of both low carbon and resilient green technologies now, up to and beyond 2025.
3. Stimulate market demand for and increased availability of green goods and services both for consumption and productive use; and
4. Track the progress towards enabling Ethiopia to achieve a climate resilient middle income status with zero net carbon emission through the monitoring, reporting and verification (MRV) of reduction actions and results.



Types of Actions

5. Actions that reduce the cost of vulnerability and the quantity of emissions spans from unsupported, supported, rewarded to credited actions.
6. Unsupported actions will be encouraged, but will not be obligated to fulfill strict measurement, reporting and verification requirements. However, they may be recorded and recognized as Ethiopia's contribution to the global good.
7. Supported and rewarded actions should comply with strict measurement, reporting and verification requirements.
8. Credited actions should comply with international requirements issued pertaining to reduction, avoidance and/or removal of greenhouse gas emissions and issuance of carbon credits.


Currently, the sector reduction strategy for the Ministry of Agriculture has been finalized, while the strategy for the Ministry of Water, Irrigation and Energy is under consultation. Analyses on the impacts and risks on the water and energy sector are highlighted below:

The Climate Resilience Strategy: Water and Energy Sector

The Climate Resilience strategy, in its draft stage, sets out the implementation priorities for the Ministry of Water, Irrigation and Energy, building on the Green Economy strategy. As has been stated before, Ethiopia's highly variable climate has always been a major challenge and has a significant impact on the country's development objectives. Climate change further increases this uncertainty in three main ways:

1. Continued temperature increase of 0.8 to 2.7°C;
2. Continued rainfall variability with more frequent extremes; and
3. Parts of the country could see changes in key seasonal rainfall.

Since most of Ethiopia's existing plans for water and energy are core parts of delivering the CRGE vision, accelerating delivery of the existing plans of the MoWIE has paramount importance. Based on the above climate planning assumptions, 11 strategic priorities listed in Table 4.2 below, have, therefore,



been identified, which will be elaborated after more detailed analysis of implementation options.

Objectives of the Strategy

In light of this and given the key role of water and energy in the GTP, the Climate Resilience Strategy for Water and Energy describes:

- **The Challenge:** Identification of the economic and social impacts of current climate variability and future climate change on water and energy in Ethiopia.
- **The Response:** Identification of the priorities that the water and energy sectors can build climate resilience and reduce the impact of climate variability and climate change.
- **Implementation:** Mapping the necessary steps to finance and implement measures in the water and energy sectors to build climate resilience in Ethiopia and deliver an integrated Climate Resilient Green Economy.

In the energy sector, four strategic priorities have been identified as response measures.


Power Generation

Strategic Priority 1.1: Diversify energy mix – hydropower production is hugely dependent on rainfall. Therefore, the energy mix has to be diversified to minimize the uncertainty of hydropower generation in times of prolonged droughts. This requires some key strategic decisions to ensure that a diverse and stable energy mix can be delivered. The recent planned sector reforms need to be fully implemented.

Strategic Priority 1.2: Improve energy efficiency – increasing energy efficiency can contribute towards reduction in the demand for electricity.

Energy Access

Strategic Priority 2.1: Improve efficiency of biomass use –the demand for biomass can be reduced by increasing fuel efficiency. The National Improved Cook Stoves Program can contribute significantly to reducing demand.



Strategic Priority 2.2: Accelerate non-grid energy access—the Rural Electrification Fund needs to be revised to deliver at scale. Pilot micro-generation projects need to be funded to demonstrate the potential for mini- and micro-grid and off-grid solutions.

Nationally Appropriate Mitigation Action (NAMA)

In line with commitments within the Copenhagen Accord, Ethiopia compiled and submitted the country's voluntary Nationally Appropriate Mitigation Actions (NAMAs) from various sectors, to the Executive Secretary of the UNFCCC in January 2010. The NAMAs contain aspirational targets for actions across the sectors to mitigate climate change which, under commitments made within the Copenhagen Accord, should be afforded financial and technological assistance from industrialized nations.

A summary of NAMAs specific objectives for the energy sector is provided below.

- **Electricity generation from renewable energy for the grid system**
 - **Hydropower:** Ten hydropower generation facilities to be completed with 5,632 MW power generation capacities by 2015
 - **Hydropower projects under study:** Hydroelectric power generation studies to be completed with potential of 8,915 MW capacities
 - **Wind power projects:** Seven wind power projects, with a total of 762 MW electric power generation capacities to be completed by 2013
 - **Geothermal power projects:** Six geothermal power projects with a total of 450 MW electric power generation capacities to be completed in 2018
- **Bio-fuel development for road transport and for household use (to produce ethanol & biodiesel)**
- **Electricity generation from renewable energy for off-grid use and direct use of renewable energy**
 - Solar home systems, small hydroelectric power generation facilities, wind pumps, solar pumps, institutional photovoltaic systems, solar lanterns, solar water heaters, solar cookers, improved biomass household stoves, biodiesel stoves, household biogas, institutional biogas plants.

10.Adaptation and Mitigation Measures in the Energy Sector

Identification of Response Measures

For the purpose of identifying Ethiopia’s energy sector responses to the unfolding reality of climate change, there is a need to identify a set of priorities that need to be addressed if the country is to contribute reasonably to the global mitigation effort and at the same time be well prepared to meet the consequences of the evolving climate situation. In order to strike the right balance between climate change adaptation and mitigation measures, and also benefit from maximum possible synergies, there is a necessity to examine the issue at hand from multiple perspectives, including realistic expectations of how much the country might contribute to the reduction of GHG emissions, the degree of vulnerability it faces, the need to achieve rapid social and economic development, the interactions with other sectors and the likes.

The water and energy sectors have identified and prioritized the most appropriate response measures for climate change adaptation program (2011), categorized into two broad categories. These categories are (1) macro level/governmental long-term development programs and (2) local micro level/grass root level interventions, as shown Table 4.2 below. Some of these proposed measures are under implementation.

The water and energy sectors have identified and prioritized the most appropriate response measures for climate change adaptation program (2011), categorized into two broad categories. These categories are (1) macro level/governmental long-term development programs and (2) local micro level/grass root level interventions, as shown Table 6.2 below. Some of these proposed measures are under implementation.

Table 4.1: List of projects for climate change adaptation in water and energy sector


No	Project Title
1	Development of multipurpose dams
2	Promotion of water harvesting technologies
3	Development of flood control and early warning system
4	Watershed management to rehabilitate the degraded land
5	Promotion of universal access plan
6	Implementation of demand management program
7	Development of standards and design criteria for installation water schemes
8	Development of water supply and sanitation mapping
9	Development of small-scale wind and solar pumps
10	Institutional and small-scale industries biomass energy conversion technologies
11	Dissemination of solar home system and institutional photovoltaic (PV) system
12	Dissemination of efficient biomass stoves
13	Dissemination of biogas digester
14	Development and promotion of small scale bio-fuel technologies

The most important priorities that will serve as principles guiding the determination of appropriate response measures are described in the following subsection. The process then will progress to the next step of listing the various measures proposed and evaluating their worth against the guiding principles.

Guiding principles

One of the most important challenges facing Ethiopia today is achieving rapid and sustainable economic development. The rate of poverty has continued to diminish, and the incidence of poverty declined markedly between 2004/05¹⁹ and 2010/11. The headcount poverty rate fell from 38.7 % in 2004/05 to 29.6 % in 2010/11. Even incorporating population growth, this implies that there were fewer people living in poverty in total than there were in 2004/05. All this implies that Ethiopia is on the right track to achieving the Millennium Development Goals target of reducing poverty by half by 2015 (Development

¹⁹ Ethiopian fiscal year runs between July 7 and July 6 of consecutive years.




and Poverty in Ethiopia 1995/96-2010/11, MoFED, June 2013). The challenge to continue to eradicate poverty altogether still remains. Moreover there is a national endeavor to reach a middle income country status by 2025. To achieve this vision, the country has been registering for many years now one of the fastest economic growth rates in Africa averaging 11.4% between 2003/4 and 2010/11 Ethiopian fiscal years (MOFED, National Accounts Statistics (GDP) Estimates for 2003 EFY, 2011). On the other hand, at 2.5% per annum, the population growth rate is also very significant. These two factors have together brought about significant pressure on the country's natural resources, and also huge requirements in terms of financial, institutional and human resources. Thus the need for **sustainable development** is one of the topmost national priorities.

The provision of modern energy plays a critical driving role in achieving development targets. Emphasis here is on the need to have a sustainable provision of reliable, secure and affordable energy to meet the needs of the economy and society at large. Ethiopia's *per capita* energy consumption in 2010 was only 960 kg/year of bio-energy, 25 kg/year of petroleum-based fuels and less than 100 kWh/year of electricity, which is one of the lowest in the world²⁰. Evidently development and building a modern economy will entail the production and consumption of much larger amounts of energy than today. As the country moves from an agrarian economy that relied very little on modern energy, into one in which the manufacturing and service sectors play a growing role, demand for energy will keep rising in parallel.

Concerning electricity alone, in the GTP period (since 2011) an average of 21% sales growth has been registered (EEPCO, 2013). It must be noted that there is a large amount of suppressed demand in the sector and the actual demand is much higher. Future projections also show that this fast demand growth trend will continue. By 2037 electricity demand will be 10 times the current levels. Ethiopia also plans to export electricity to the east African region and even beyond, which not only helps the country earn foreign currency income, but also contributes to the reduction of GHG emissions from the region as it often displaces fossil-fuel based generation. All these facts highlight the unavoidable need for large increases in electricity generation and related

20 Updated Rapid Assessment and Gap Analysis on Sustainable Energy for All (SE4All): The UN Secretary General Initiative, Ethiopia, December 2013



facilities. Consumption of other fuels in the domestic, transport, industry and service sectors will also grow rapidly in line with the rising levels of living standards and higher levels of economic activity. Therefore, the country requires the development of an energy sector that provides **reliable, secure and affordable energy services** for all sectors.

Historically, global climate change has been more pronounced since industrial revolution, because of its abundant extraction and utilization of world energy resources specifically fossil fuels by developed nations. Like other developing countries, Ethiopia has insignificant contribution to this historical emission of anthropogenic greenhouse gases from fossil fuel. This is because most of its energy production and consumption is based on renewable energy (biomass and hydropower).


Ethiopia's current contribution to the global increase in GHG emissions since the Industrial Revolution has been practically negligible. Even after years of rapid economic expansion, today's per capita emissions of less than 2 t CO₂e are modest compared with the more than 10 t per capita on average in the EU and more than 20 t per capita in the US and Australia. Overall, Ethiopia's total emissions of around 150 Mt CO₂e (in the year 2010) represent less than 0.3% of global emissions (CRGE, 2011). On the other hand, Ethiopia is one of the most vulnerable countries to adverse effects of global climate change arising from induced anthropogenic greenhouse gases into the atmosphere.

When the energy sector's GHG emission is examined further:

The contribution of power sector only accounts for very low emissions as it is largely based on hydropower accounting for more than 90% of total power generation capacity, supplemented by the use of off-grid diesel generators.

As more than 80% of the country's population is engaged in the small-scale agricultural sector and live in rural areas, traditional energy sources represent the principal sources of energy in Ethiopia. Thus the main emission contribution in energy sector comes from forest degradation due to fuel wood consumption (25.3 Mt CO₂e) which is 46% of the emission from the forestry sector (55 Mt CO₂e in 2010).

Although Ethiopia is not a producer of fossil fuels, it imports fossil fuels from




abroad, which is used mostly for transport and industry sectors. This is also costing the country to expend significant amount of its foreign currency. Concerning GHG emissions, these imported fossil fuels contribute towards the country's emission.

Ethiopia's energy sector has insignificant contribution to global climate change but it has taken considerable mitigation and adaptation measures by designing and implementing various development policies, strategies and programs. All these development policies, strategies and programs increase the capacity of the country to resist influences from local and global climate changes. Some of these are:

- Development and implementation of energy policy that initiate environmentally friendly development of renewable energy
- Implementation of Plan for Accelerated and Sustained Development to End Poverty (PASDEP, 2006-2010), which realized for the country an average annual growth rate of 11 %.
- Growth and Transformation Plan(GTP, 2010-2015)) that aims at fostering sustainable development to achieve the Millennium Development Goals (MDGs) with targeted investments in selected sectors to enable Ethiopia transition from a Least Developed Country (LDC) to a middle income country by 2025.
- Implementation of CRGE (2011-2030). This sectoral based emission reduction enables the country to attain fast development (reaching the status of middle income countries) without causing negative climate change impacts and it also enhances efforts towards reducing vulnerability and GHG emissions. CRGE provides the country the opportunities to obtain financial support and technology transfer from abroad through ongoing climate change negotiation efforts (using negative impacts of global climate change as opportunity).

In recognition of the above mentioned historical facts, Ethiopia should give appropriate attention to measures **that impact on reducing GHG emissions and vulnerability to climate change.**

Like many developing countries, Ethiopia's financial, technical, human and institutional resources are limited. This requires careful prioritization of initiatives for adaptation and mitigation mechanisms. Where possible,



selecting measures that help to address both adaptation and mitigation significantly is to be given consideration since this brings cost effectiveness. Thus, the **possibility of synergies between various measures that may serve both adaptation and mitigation actions** allows the country to use its limited resources efficiently to achieve the required goals.

Mitigation and adaptation potentials and possibilities

From the Ethiopian context, both mitigation and adaptation measures arise from the implementation of the green economy strategies as discussed in the previous sections, and the specific initiatives, that are in line with the guiding principles stated above, are detailed in this section.

Mitigation Measures


From the Ethiopian context, the major mitigation options in the energy sector are based on, distribution and consumption for both traditionally used biomass and modern energy, efficient energy use in all sectors of Ethiopia, provision of efficient biomass and modern energy technologies, sustainable and controlled harvesting natural resources, specifically biomass resources, fuel switching to other renewable energy resources such as hydro, geothermal, wind and solar, improving data collection on energy production and facilitating the participation of the private sector in energy production by investigating and avoiding all barriers.

These mitigation measures are classified into three main categories which are: (a) dissemination of efficient end-use energy conversion technologies, especially in biomass production, conversion and utilization technologies; (b) switching to other renewable and modern energies in households, industry, services and transport sectors; (c) using renewable energy sources for power generation.

a) Disseminating energy efficient end-use energy conversion technologies

Energy Efficient Biomass Stoves

The limitation of developing other renewable energy resources exert extreme burden on biomass resources of the country which manifested by



forest degradation, because the majority population who have no access to modern energy depend on unsustainably collected and consumed fuel wood. This results in fuel wood scarcity and depletion of water resource²¹ which worsen the life of people specifically those who reside in rural areas. Therefore, both demand and supply side intervention is a very crucial issue to mitigate environmental problems resulting from unsustainable utilization of the biomass resources.

Fuel wood is still the most important energy source in the household and service sectors of Ethiopia and the **major contributor to greenhouse gas emission**. As indicated in CRGE strategy (2011), it contributes 46% of emission from forestry sector (55mt CO₂e). Fuel wood is collected by users in rural areas while it is purchased in urban areas. Basically free access to biomass resources of the country has significant contribution to its depletion and emission. However, dissemination of fuel wood saving technologies has been identified as very important emission reduction measure in the energy sector.

Energy efficient biomass stoves commonly substitute traditional open fire stoves (three stone stoves) used in most of rural households. Ministry of Water, Irrigation and Energy collaborating with regional energy institutions and other stakeholders disseminate efficient biomass stoves such as Mirt stove for baking, Tekikil and Rocket stoves for cooking to improve economical and the health of rural communities and to reduce CO₂ emission from inefficient utilization of biomass resources.

According to World Bank Environmental Department (2011), in developing countries, about 730 million tons of biomass is burned each year, amounting to more than 1 billion tons of carbon dioxide (CO₂) emitted into the atmosphere.

Ethiopian has already taken considerable measures to reduce GHG emission from biomass fuel utilization by improving and disseminating energy efficient biomass stoves. Therefore, at the end of 2006 EFY about 13.59 millions of improved biomass cook stoves were disseminated which were 7.01million up to 2002EC (baseline year of GTP 1) and 6.58 million during GTP 1 (from 2003

21 Current situation indicates that some of streams and rivers became dried while the volume of some rivers shows decreasing pattern from year to year



to 2006 EC) (MoWIE, 2014).

Basically biomass energy is the main source of energy and it will also continue to play dominant role in future Ethiopian energy consumption. As a result it will also remain a significant contributor of CO₂ emission to the atmosphere. Since 2014 about 13.59 million improved biomass cooks were disseminated and it is also designed to disseminate about 34 million improved biomass cook stoves by 2030 (CRGE 2011). The implementation of this measure has contributed not only to the reduction of CO₂ emissions from inefficient utilization of biomass resources but it has led to sustainable biomass harvesting with multi-dimensional outcomes: (1) it reduces deterioration of forest cover (minimize elimination of biodiversity); (2) increase CO₂ sequestration; and (3) improve social and economic situations of rural communality. Particularly it reduces burden on rural women consequently, adaptation to climate change is enhanced.

As also indicated in CRGE (2011) forest degradation leads to CO₂ emissions, and is primarily caused by fuel wood consumption and logging in excess of the natural yield of the forests, with the major driver being population growth, emissions are projected to grow from around 25 Mt CO₂ in 2010 to almost 45 Mt in 2030. On the other hand, the projection by CRGE (2011) indicates that the single most important lever is to reduce demand for fuel wood through fuel wood efficient stoves, offering a potential of almost 35 Mt CO₂ reduction, while other advanced cooking and baking technologies (electric, biogas, and LPG stoves) offer an additional combined potential of more than 15 Mt CO₂. Capturing this abatement potential requires the switch of more than 20 million households to more efficient stoves.

In general, emission reduction activities in energy sector should give special attention to this area (improving and dissemination of energy efficient biomass stoves) specifically in household and service sectors which has multi-dimensional advantages as summarized below:

- It mitigates CO₂ emission;
- It improves life of rural communities specifically women and children by reducing indoor air pollution. Currently, it is estimated that worldwide 2 million lives mostly women and children—are lost annually, resulting



from exposure to indoor biomass cooking smoke (World Bank 2011)²²;

- Energy efficient biomass stoves improve the economic capacity of rural community by reducing time and money spent to collect and buy fuel wood, respectively. Specifically it builds the capacity of rural women to adapt vulnerability from climate change by diverting time for collecting fuel wood to productive activities;
- It is possible that time not spent on household drudgery could be used for income-producing activities, thus reducing poverty in the country and improving overall adaptive capacity;
- It reduces deforestation that would result from unsustainable fuel wood harvesting; consequently emission from burning biomass fuel is reduced and CO₂ sequestration from atmosphere is also facilitated; and
- It reduces the loss of biodiversity.


Other energy efficiency options

Other energy efficiency measures play a minor role in GHG emissions today but will be important in the future as the economy and populations expand - Transport, industrial and buildings (CRGE, 2011)

These sectors and their climate related measures will be elaborated in a separate report. However in order to highlight the linkages between the energy sector supply side and the demand side as represented by these sectors it is important to mention here that demand side energy efficiency measures, selection of appropriate technologies and fuel switch in these sectors is often the most cost effective ways to reduce potential GHG emissions and also help bring greater access to modern energy and higher medium to long term economic, social and environmental gains.

In the transport sector the initiative is to introduce stricter fuel efficiency standards for passenger and cargo transportation and promote the purchase

22 World Bank Environment Department: Household Cook stoves, Environment, Health, and Climate Change: A New Look at an Old Problem, May 2011



of hybrid and electric vehicles to counter the low efficiency of the existing vehicle fleet.

Use of inexpensive electricity generated from renewable energy to help curtail the growth of off-grid fossil-fuel energy use (ex. diesel generators, kerosene lamps), which is the largest source of GHG emissions in the buildings sector in 2010. Green economy initiatives identified to achieve this involve accelerated transition to high efficiency light bulbs for residential, commercial, and institutional buildings.


Among the industrial sub-sectors, cement will be one of the fastest growing, also causing the vast majority of GHG emissions from the industry sector. Output will increase tenfold from 2.7 Mt in 2010 to 27 Mt in 2015. Some cement factories use outdated technology that is not only energy inefficient, but also causes high emissions from the production process. The initiatives identified in terms of energy efficiency include improved energy efficiency of the process by converting the technology used from dry to pre-calciner kilns and from rotary to grate coolers and by introducing computerized energy management and control systems, which can decrease the energy demand and hence the cost of and emissions from cement production.

The cement sub-sector has been highlighted because it represents the most GHG emitting industry and its GHG abatement initiatives have high chances of implementation, action to put the other industrial sub-sectors also on a sustainable economic development path is also required. The textile, leather, steel, chemicals, mining and fertiliser industries are important parts of the envisaged economic development model of the country (CRGE, 2011).

b) Fuel switching

Since the majority of the population of Ethiopia is utilizing biomass energy resources with traditional energy technologies (stoves), diverting this situation to modern energy is one of the modern energy options available (fuel switching) for mitigation. This enhances the accessibility of the community to modern energy technologies.

These include:


- 
- Disseminating biogas stove for cooking/boiling (100% fuel wood saving),
 - Electric stoves for baking, cooking and boiling (electric from hydro-source and 100% fuel wood saving)
 - LPG stove for cooking and boiling (89% GHG abatement potential) are used as mitigation options in Ethiopia
 - Increasing biogas production for cooking and lighting
 - Increasing production of briquette from biomass wastes
 - Increasing bio-fuel production both ethanol and biodiesel for household and institutional consumption

Energy switching is also important mitigation measure in other sectors. For the transport, industrial and building sectors, the following measures are supported to reduce GHG emissions and also introduce significant social, economic and environmental co-benefits (CRGE, 2011):

- Construct an electric rail network – powered by renewable energy – to substitute road freight transport. Shifting transport from road to electrified rail would not only decrease transport costs and improve the trade balance through reduced import of fossil fuels (economic benefits), but would also lower emissions, congestion, air pollution, and traffic accidents (social and environmental benefits).
- Improve urban transport in Addis Ababa by introducing urban electric rail, and enabling fast and efficient bus transit
- Substitute imported fossil fuels with domestically produced biodiesel and bio-ethanol.
- Increase share of biomass (bio-residue) in the mix of energy for production in cement factories, potentially decreasing costs and emissions.

c) **Renewable energy for power generation**

Renewable power production is the third main strategy for mitigation. It is also playing a great role in keeping Ethiopia's GHG emissions low in the future Ethiopian economic development. Nevertheless, its contribution to climate change mitigation is smaller compared to the other measures as long as the



current national commitment to clean and renewable electricity production continues.

Ethiopia is endowed with ample natural resources that can be used for electricity generation. This is achieved primarily by exploiting its vast potential for hydro, geothermal, solar, wind power, biomass, etc – all of which would deliver electricity at virtually zero GHG emissions. The main Ethiopian power system is largely based on hydropower so far, but there is a national policy to increase the energy mix by diversifying to the other renewable sources. For isolated or remote villages electric production is designed to be produced from solar, small wind generators, small hydro etc. to mitigate climate change and its adverse impacts. To facilitate and maximize energy production from renewable resources policy measures have been taken to increase the participation of the private sector in energy production.


If adequately captured, the projected power supply could even exceed the growing domestic demand. Hence, increasing the supply and at the same time maximizing energy efficiency offers the possibility to export clean energy to neighbouring countries. Since environmental problems are global, these electricity exports, in turn, provide the opportunity to replace electric power generated from fossil fuels in these countries, which has significantly higher average costs and significantly higher emissions. Thus via electricity exports, Ethiopia can share its green development to other countries in the region while contributing positively to its trade balance. Moreover, the generation of clean and renewable electric power also allows green development of other sectors of the economy, such as the replacement of trucks by electric rail or diesel pumps by electric pumps for irrigation. (CRGE, 2011).

Adaptation measures

As indicated in previous sections the draft CR strategy is under development, and the following strategic priorities are implemented for building resilience for the energy sector:

Diverse energy mix

Hydropower production is dependent on rainfall, so the aim is to diversify the energy mix to minimize the generation uncertainty. The climate resilience



analysis reinforces the decision to continue to diversify the generation mix. This requires some key strategic decisions to ensure that we can deliver a diverse and stable energy mix.

Improve energy efficiency

Increasing energy efficiency will reduce the demand for electricity creating favorable situation for adaptation, while at the same time leads also to the reduction of GHG emissions.

Managing energy demand will help reduce the climate risk to power supply as well as increasing resource efficiency. The Energy Proclamation (No. 810/2013) sets out how energy efficiency will be managed and promoted by the Ethiopian Energy Authority (EEA), including the establishment of the Energy Efficiency and Conservation Fund. Further regulations and directives are in development to implement the Proclamation. The Ethiopian Energy Authority (EEA) is responsible for developing and implementing energy efficiency strategies and programs. In a hydropower dominated country like Ethiopia, energy saving is more important than reducing maximum demand as the generation system is constrained by energy available rather than capacity. However, it is prudent to target both energy and demand as this would reduce infrastructure costs and losses. The EEA and the Green Economy strategy have identified 4 core energy efficiency policies and programs.

- Continue actions to promote efficient lighting in domestic and industrial sectors.
- National Energy Efficiency Labeling Program
- Energy Audits in industrial, commercial and public sector
- Energy Efficiency awareness to general public

Successful implementation of these programs could significantly reduce energy demand and peak power demand in 2030 if they lead to technology and behavioral change. Two shifts in particular could contribute 97% of potential savings:

- Switching to efficient lighting in residential, industrial and commercial settings

- 
- Upgrading to efficient motors in industrial and irrigation usage.

Energy Access

Improve efficiency of biomass use – reducing the demand for biomass by increasing fuel efficiency. The National Improved Cook-stoves Program can contribute significantly to reducing demand.


To secure sustainable domestic energy needs, biomass needs to be used more efficiently whilst improving living standards. The Biomass Energy Strategy has been developed in partnership between MoWIE, MEF and a National Programme for Improved Household Biomass Cook Stoves Development & Promotion in Ethiopia (known as the National Improved Cook Stoves Programme, NICSP) has been developed with a goal of distributing 30 million cook stoves by 2031. To date the program has distributed 6.8m cook-stoves throughout the country. The NICSP needs ongoing support to establish mechanisms for effective program implementation, market development, quality control and monitoring. However, only 2% of the required funds are in place, which leaves a shortfall of USD 245m. There is a need to explore innovative approaches for securing this funding, including by linking to the second order benefits, such as reductions in emissions, deforestation and dam siltation.

Accelerate non-grid energy access

The Rural Electrification Fund needs to be revised to deliver at scale. Pilot micro-generation projects need to be funded to demonstrate the potential for mini- and micro-grid and off-grid solutions.

Securing sustainable energy for all plays a role in building climate resilience and is an important part of our poverty eradication ambitions. The Universal Electricity Access Plan plays a key role, but given Ethiopia's challenging geography, it is not always economically feasible to extend the grid to remote communities, therefore there is a need to develop more off-grid options alongside developing non-electricity energy access.

The Rural Electrification Fund was established in 2003 (Proclamation No 317/2003) to provide loans and technical assistance for rural electrification. To date, around 20,000 Solar Home Systems have been installed through REF,



with a further 8,000 planned across 4 regions. Design and environmental studies have also been carried out for 5 micro-hydro schemes and for 4 micro-solar schemes.

REF's current structure and delivery model has been effective to date, but needs to be revised to deliver at scale. There is a need to review the current approach and develop more effective delivery models that can deliver off-grid energy access at scale. This will require co-ordination of REF activities with EEP's grid expansion plans to avoid stranded assets and develop an integrated plan for extending electricity access.

In addition to REF, MoWIE has several alternative energy programs for increasing access to modern fuels including the National Biogas Program for Ethiopia (NBPE) and Biofuel Program. The institutes must build on this experience to develop effective delivery models that can accelerate non-grid energy access and strengthen the impact of REF and other programs. MoWIE is finalizing the country's Sustainable Energy for All Action Plan, which aims to accelerate these existing efforts and plans.

Cross-cutting issues

Data systems for decision support – strengthening data systems so that they provide timely, reliable and usable data to decision makers at all level.

High quality data is only valuable if it is used to inform decision-making. In addition to improving the datasets, we need to improve the way that data is used to inform policy and ensure that complex modeling can be translated into relevant policy implications. Therefore one must focus the development of data systems on the information that end-users require to inform their decisions.

Accelerate delivery of existing plans – a common theme across the CR Strategy is that most of our existing plans already support CRGE, but we need to accelerate delivery and implementation. Key bottlenecks are co-ordination and streamlining of plans, performance feedback and monitoring gender.

- **Coordination and streamlining of plans** – there is a significant amount of activity in the energy sector and multiple development partners, which can overlap and conflict. Co-ordination must be improved by




more clearly setting out a common agenda and plan. The energy sector does not currently have a Sector Working Group but must take steps to improve co-ordination of plans, working with development partners.

- **Performance feedback loops** – improve accountability, reporting and learning mechanisms. Currently disparate projects need to group by policy priorities and incorporate into MoWIE strategic oversight.
- **Monitoring gender impacts** – many of the current plans and programs contribute significantly to gender equality and women's development. However, much of this is not adequately captured and reported.

Diversification of power generation, provision of decentralized and non-utility power supplies, supply and demand side efficiency measures and the application of an Integrated Resource Planning as a decision support mechanism for the power sector are also measures proposed for creating long-term reliability and sustainability in electricity provision by the Report on Hydropower Risks (Helawi Lakew, 2009) and thus align very well with the recommendations proposed by the draft CR strategy.

Green development path also facilitates adaptation of the country to global and local climate change, creating interdependence and feedback between adaptation and mitigation measures. The effect of mitigation measures on adaptation can be seen from the fact that mitigation reduces the potential severity of the impacts of climate change, which in turn make adaptation to the new realities easier and less costly. Though Ethiopia's contribution to the global mitigation effort is modest, the measures themselves play no small part in helping the country adapt and have sustainable development. All three groups of mitigation measures, i.e. biomass and other energy efficiency measures, fuel switch and the development of diverse renewable energy based power supply also figure prominently for their climate resilience potential.

Expanding electricity generation from renewable energy for domestic and regional markets builds climate resilience through reduction of risk of exposure to a single source like hydropower, thereby building adaptive capacity. Improving the efficiency of end-use technologies (specifically traditional stoves) not only reduces GHG emissions but also, coupled with reduction in deforestation and forest degradation, results in sufficiency and sustainability




of biomass resources for future energy use. The implementation of mitigation measures in the transport, industrial and buildings sectors –utilization of modern and energy efficient technologies, fuel switch to renewable-based electricity and sustainably exploited bio-energy substitutes, etc – lessen the dependence of these sectors on expensive and imported fuels, improves the countries trade balance. These results in effect contribute to the climate resilience of the national economy as a whole. Therefore implementation of the CRGE strategy as a whole would strength the economic capacity of the country to adapt to the impacts of global and local climate changes (CRGE, 2011) (draft CR Strategy).

Costs of adaptation and mitigation

Historically, Ethiopia's climate has already experienced increases in temperatures of about 1°C in the last 25 years, and as well as high intra and inter annual rainfall variability. All climate models predict further increases in temperatures and continued intra and inter annual rainfall variability, with an increased frequency of extreme hazards. However, there is great uncertainty as to whether the climate will become drier or wetter in Ethiopia. It is critical for the MoWIE to build a risk management approach in its future plans to be able to address this uncertainty.

According to the draft CR strategy for the water and energy, Ethiopia's water and energy sectors face an overall risk of 150 MUSD annually with the current climate and up to 675 MUSD annually in the driest future climate scenario from reduced power generation and irrigation. In addition, up to 70m people could be left vulnerable from lack of water or fuel access if MoWIE's plans are not fully rolled out and funded. Overall investment required in adaptation measures to mitigate climate risk is about 2 billion USD, mainly from existing programs, budgets that need to be brought forward in time and from measures to have a positive pay back over less than five years.

In the energy sector, the climate resilience analysis focused on hydropower generation and woody biomass as they represent the highest future sources of power generation and fuel consumption respectively, while being highly vulnerable to current and future climate. In hydropower, the estimated average value at risk under current climate is 150 MW annually but could go up to 382 MW annually (1% and 4%% of effective hydropower generation



capacity respectively) under the driest climate scenario, due to increased risk of extremely dry years. For example, the driest scenario has a once in every 20 year occurrence of a 2,500MW power generation loss. However, under the wettest scenarios, the MoWIE would also generate a surplus of non-firm power during the rainy season. To address this uncertainty, the MoWIE could in a first phase:

- Focus on energy efficiency policy measures, which would be sufficient to address the average climate risk under the driest outcomes, and
- Consider fast tracking on its planned geothermal investments, which is the second most cost efficient renewable resource after hydropower in Ethiopia and the most climate resilient. Expected investment required to rollout these measures is 810mUSD on levelised cost of energy calculations, but energy efficiency measures all have positive payback. In a second phase, once the direction of rainfall is confirmed, the MoWE can assess whether it is required to mitigate towards wind capacity.

In terms of biomass, up to 12 million people are currently at risk of losing access to woody biomass fuel, 80% of which is used for cooking. The MoWIE has set ambitious plans to rollout 34 million efficient cook stoves throughout the country, which has a number of objectives (e.g., reduce household fire risks) and would allow to reduce all fuel access risks even under high climate change risks. The cook stove plan already focuses on the most cost effective cook stoves, but 245m USD funding is still required to finance the overall plan (including implementation capabilities and contribution from households) and ensure fuel consumption remains sustainable.

Table 4.2: Strategic Priorities of Climate Resilience Strategy for Water and Energy

Power Generation	1.1 Diverse energy mix 1.2 Energy efficiency	\$304m
Access to Energy	2.1 Biomass efficiency 2.2 Off-grid energy	\$246m
Irrigated agriculture	3.1 Accelerate plan 3.2 Strengthen rainfed agri. 3.3 Balance water demands	\$71m
Access to WASH	4.1 Accelerate access 4.2 Enhance self-supply	\$220m
Cross-cutting	5.1 Improve data and systems 5.2 Accelerate delivery	\$54m
Grand total		\$895m

Source: MoWIE, draft document on Climate Resilience Strategy for Water and Energy

The Climate Resilience Strategy for Water and Energy sets out high level Strategic Priorities

- The strategic priorities will initially require at least **\$895m** up to 2030. Further analysis is needed to identify the best way of implementing these priorities and for detailed costing and credible implementation plans.
- The existing activities have already contributed to the Strategic Priorities and require only building on these, integrated with the GTP planning.
- Once developed, implementation plans will be financed through several methods:
 - **CRGE Facility** – fast-track funding (2 years) and longer-term.
 - **Other sources** – domestic treasury, own revenue and external assistance.
- Implementation is not just about money; there are delivery bottlenecks that also need to be addressed.
- MoWIE Ministers will review overall progress quarterly, supported by 4 working groups that will use existing mechanisms as far as possible.

Table 4.3: Investment required to mitigate 2290 MW

Policy Objective	Type of Measure	Measure	Cost \$m	VAR addressed MW	Funding Source
Diversify power portfolio	Preparedness for potential large scale changes	Geothermal	\$630m ¹	1,360MW ²	Private sector, but differential cost with hydro could be sourced from climate funds
Manage domestic demand ³	Low or no regret moves	Industry	Capex \$100m Net: -\$144m	465MW	Private sector
		Residential	Capex \$40m Net: -\$102m	270MW	NGOs / climate funds
		Services	Capex \$40m Net: -\$65m	200MW	Private sector
Total			\$810m	2,290MW	

Should the grid expansions fall behind plan, off-grid solutions should be included in scope of considerations

1 Cost of building additional 1,000MW to 2030
2 Will cause a decrease in revenue for the Ethiopian government
3 Load factor for geothermal included


Source: MoWIE, draft document on Climate Resilience Strategy for Water and Energy

Table 4.4: Additional funding required for the cook stove plan

Policy Objective	Type of Measure	Measure	Cost \$m	VAR addressed Woody biomass averted	Funding Source
Decrease Demand for Woody Biomass	Already doing and do more of	Roll out of Tikkil and Mirt	Capex: \$220m ¹ Net: -\$1.8bn	35 mT ²	Climate Funds Households Manufacturers
	Capabilities and Implementation	Readiness to Pilot phase	Capex: \$30m		Climate Funds Donors
Total			\$250	35 mT	
Current Funding Secured			\$5m		
Further Funding required			\$245m		

1 Members assume roll out of electric stoves to those already connected in 2011
2 2030 projected demand is now cast to be ~150m T, without a come impact factor of 11
3 Full capex cost; total live site estimate for electric stoves is 20% of \$20m

Source: MoWIE, draft document on Climate Resilience Strategy for Water and Energy



Developing the necessary power capacity from renewable energy will be an enormous challenge as the pace of growth required is high. The total investment in expanding electric power generation capacity could be funded via a combination of tariff adjustments and the attraction of private capital, climate finance and sovereign wealth funds (CRGE, 2011).

Barriers and opportunities

Constraints

Ethiopia's vulnerability mainly comes from its low level of socio-economic development, inadequate infrastructure, lack of institutional capacity and a higher dependency on natural resources (NAPA, 2007). These are also manifested in Ethiopia's energy sector development. Some of these barriers to adapt adverse impacts of climate in energy sector are:

1. **Resource constraints/barriers:** These barriers mainly relate to financial, human and institutional capabilities of the country.
2. **Financial barriers:** Capital shortages and high capital costs for environmentally friendly modern renewable energy technology is one of barriers for climate change mitigation and adaptation. Lack of information about the availability of renewable technologies and technology suppliers is frequently observed as barrier in rural Ethiopia. The household income of majority of the rural community is at low level. Thus, the affordability of the too expensive renewable energy technologies is a critical obstacle or barrier of mitigation and adaptation.
3. **Limitation of human capacity as barrier:** Limitation of qualified human resources to avail information or survey results on adverse impacts of climate change on energy resources, energy production and distribution, quality data on impacts of climate change on ecological, social and economic development of the country, limitation of awareness on real consequences of climate changes which hinder energy technology transfer are considered as capacity barriers.
4. **Institutional barriers:** These barriers include lack of strong coordination mechanism both at the federal and regional levels on climate change and its consequences, lack of elaborated links of federal and regional sector offices with defined responsibilities on environment issues, lack of capacity, i.e., absence of well-developed institutions for research and development (R&D) on climate change adaptation



and institutionally organized information exchange or information distribution among different sectors and communities, etc.

5. **Technical barriers:** From a global perspective, the large number of different technologies that are available to mitigate climate change facilitates the achievement of prescribed climate protection goals (IPCC 2013)²³. From Ethiopian perspective, dissemination of modern renewable energy technologies have beneficial role in both mitigation and adaptation of climate changes. But the penetration of such globally available technologies is at an infant stage. Unavailability of these technologies in local market, limitation of developed and adapted technologies that fit with local conditions and lack of technical capacity on these technologies are main technical barriers to implement mitigation and adaptation activities.
6. **Low level of private sector participation in energy as barrier:** The private participation in energy development in Ethiopia is at an infant stage. Lack of power purchase agreement for independent power producers and some regulatory gaps hinder their participation and thus the scale of availability of renewable energy technologies in the local market.

Local and global opportunities

By developing a green economy, one can exchange GHG emissions abatement for climate finance to fund some of the required investment. Implementing the initiatives would also offer important co-benefits. For example, it would improve public health, through better air and water quality and would promote rural economic development by increasing soil fertility and food security. This is even more relevant for Ethiopia because many of the climate initiatives identified have low or even negative costs, leading not only to GHG emission reductions, but also to the realization of new for economic growth opportunities. Although these initiatives come at higher costs than the traditional development pathway, they might offer the possibility to fully fund the incremental costs via a monetisation of the emission reduction through climate – related finance. In a global comparison, many of Ethiopia's initiatives are comparatively inexpensive – which can be crucial in giving the country a competitive advantage in attracting climate finance (CRGE, 2011).

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Ethiopia is also beginning to export electricity generated from renewable energy to countries in the region (up to 28 TWh). This will substitute for their conventional electric power generation and hence decrease GHG emissions by nearly 20 Mt CO₂e (which could come on top of the total 250 Mt CO₂e savings identified in other sectors in Ethiopia), thereby creating opportunities of GHG reductions not only in Ethiopia but also around the region in Africa (CRGE, 2011).

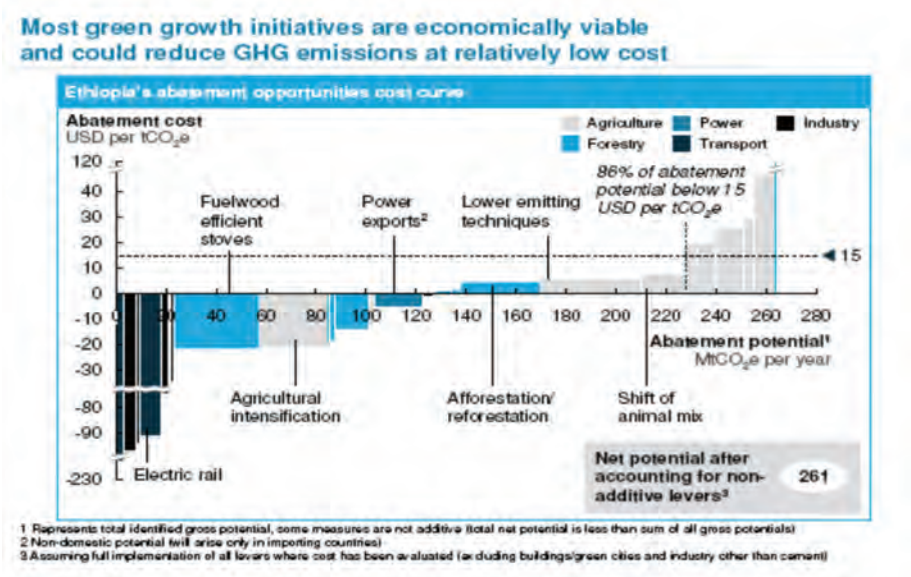


Figure 4.1: Economic potential of GHG abatement initiatives (CRGE, 2011)

The country has already set up a CRGE financing facility and the first group of mitigation and adaptation projects approved for funding. The purpose of this facility is to streamline the evaluation, selection and financing of CRGE compliant programs and projects and also to facilitate for the country to benefit from increasing the number of international climate related funds. The facility will also be an instrument for aligning the national development plans (current and future Growth and Transformation Plans) and budgetary cycle to the requirements of a Climate-Resilient Green Economy. It will also serve as a platform for coordination among various sectors as climate change is an economy-wide phenomenon.

Although there are different barriers (financial, market, technically skilled



human resources etc.) in renewable energy development that are challenging the country, globally renewable energy technologies are technically mature, which creates a good opportunity to deploy them at significant scale avoiding the barriers.


11. Conclusions and Recommendations

Conclusions

Ethiopia has made significant progress in recent years in expanding energy access and developing the country's huge exploitable potential of renewable energy resources mainly hydropower, wind, solar and geothermal. These energy diversifications improve rural development through income generation, job creation, as climate change mitigation and as adaptation priority measures to develop climate resilient communities. To protect the country from the adverse effects of climate change and to build a green economy that will help realize its ambition of reaching middle income status before 2025, the government of Ethiopia has therefore initiated the Climate-Resilient Green Economy (CRGE) initiative, which follows a sectoral approach. The green economy plan is based on four pillars of which energy is one of them.

The CRGE has two components: a Green Economy Strategy and a Climate Resilient Strategy. The latter includes a SRM (Sector Reduction Mechanism) and action plan, which is under the final stage of preparation for the energy and water sectors. In the energy sector, the strategic priorities: i) power generation - diversify the energy mix and improve energy efficiency and ii) Energy Access - improve efficiency of biomass use and accelerate non-grid energy access, have been identified as response measures. While in building the green economy the two priority initiatives, i.e. scaling up of renewable energy generation for domestic and regional markets and rural energy access and improved efficient stoves programs and similar projects (including sustainable energy for all, energy+ partnership initiative that aims to increase rural access and decrease GHG emissions, which is based on payment by results approach) have been under implementation.

From the reviewed documents and analysis made, the energy sector of Ethiopia is highly vulnerable to climate change, because naturally, the main sources of energy (hydropower and biomass) are influenced by climate change induced factors such as temperature increase, variable rainfall, extreme floods and extended droughts. To reduce the vulnerability of the sector to climate change urgent interventions are needed to increase the adaptive capacity of the sector, following three options, namely i) energy




diversification by developing renewable energy ii) dissemination of efficient energy technologies and avoiding obsolete energy technologies; and iii) building the capacity of both community and developers. In general, the identified losses due to climate change are significant, ranging from around 1% reduction in GDP to over 10% by 2030.

Ethiopia faces significant challenges of inadequate technology, finance, human and institutional capacity resources to realize mitigation and adaptation measures that are indicated in its relevant policies and strategies. Nevertheless, Ethiopia can count on significant technical and financial assistance if it undertakes this effort – among others, from funders who are already supporting energy projects in the country. The potential benefits are huge: greatly improved quality of life and new economic opportunities in rural areas, a large infusion of new investment, new sources of revenue, and a chance to not only achieve the Millennium Development Goals and/or GTP but then again become a model for the new “green economy” in Africa. By aspiring to – and achieving – a constructive contribution to the green economy, it is possible to lay the longer-term foundation for reaching middle-income status by or before 2025. Therefore, the planned initiatives and fast-track projects already under implementation need to be strengthened and additional financial sources should be looked for.

Recommendations

Despite progress made in formulating Climate Resilient Green Economy (CRGE), National Adaptation Program of Action (NAPA), Nationally Appropriate Mitigation Actions (NAMA), etc., the magnitude of the potential challenge posed by climate change and extreme weather requires additional efforts. Ethiopia’s energy production and consumption is based on biomass and hydropower which are vulnerable to climate change. To enhance GHG mitigation and adaptive capacity of the sector, thus allowing it to continue to play a significant part in the economic and social development of the country, the following recommendations are given:

1. Implementing currently identified measures, as well as programs and projects considered in the GTP1, that help build mitigation and adaptation potential for the country.

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2. Energy diversification: utilizing varieties of indigenous energy resources to increase the capability to switch from one form of energy to another during severe climate change, thereby building resilience.
 3. Developing renewable energy - give more attention to renewable energy resources that are less vulnerable to climate changes, as well as scaling-up the role out and localization of technologies that play significant roles in helping the country mitigate and adapt to climate change.
 4. Dissemination of efficient energy technologies, that help to reduce energy demand and therefore increase the adaptive capacity of communities by reducing pressure on forest resources,
 5. Improve maintenance of existing assets, many of which were designed and constructed several decades ago. Check that the sizing of existing assets is robust to climate variability and projected changes in average climatic conditions and explore whether water storage could be increased at reasonable cost to help manage seasonal and annual variations.
 6. Ensure new assets are resilient. For new assets at the design stage, review the robustness of design and site locations to climatic variability and projected climate change including design of energy-generation assets as well as associated infrastructure,
 7. Strengthen measures to control illegal forest logging that, among other things, contributes to soil erosion and siltation of reservoirs.
 8. Investigate applicability of weather coverage and insurance instruments for energy sector risk management.
 9. Recognizing the risks associated with climate change is a valuable first step towards better planning of new investments in infrastructure and averting potential damage to existing infrastructures. Integration of climate risk considerations in design, siting, and operation of energy facilities, through measures such as standards and codes, and the review process for replacing or repairing damaged infrastructure are often the cheapest and easiest measures.
 10. Building the capacity to mobilize local financial resources from both



public and private sources, as well as leveraging climate finance and other form of funds available. Exploring new financing options to improve investments in household level renewable energy technologies in addition to existing options that are used by government for mega projects will help solve the financial constraints. Experiences in mobilizing local financing for the conventional energy sector could be used for the household level renewable energy technologies. The mechanisms should take into account the local context with respect to sources and patterns of income, attitudes to borrowing, availability of micro-credit agencies, and ability to repay over long and short term periods.

11. Build the capacity of both local communities and developers on renewable technologies and climate matters.
12. Build strategic partnerships with countries, companies and private sectors in promoting renewable energy technologies particularly in the rural part of the country,
13. Develop inter-sectoral networking: working with other sectors with which energy shares a strong linkage (water, agriculture, etc) to coordinate and optimize response measures.
14. All levels of government, communities, nonprofit organizations and the private sector must prepare for more extreme weather events, droughts, and altered ecological systems. Dedicated body/task force at the national level that quickly responds to disasters associated with the extreme weather needs to be established. The taskforce will respond and take emergency action at the time of high damage on energy infrastructure.
15. Overall strengthening of the national institutional and human capacity at all levels to better identify, implement and follow-up measures for building a climate resilient and green economy.



12. Gaps in Knowledge and Data

This review report relied extensively on a limited number of studies, strategies and other documents. This was primarily due to lack of literature on the impacts of climate change on the energy sector in Ethiopia. On the other hand, vulnerability of the energy infrastructure and energy resources is not the same in all regions of Ethiopia. Dramatic physiographic variability leads to climate variability in the country. Decisions about climate change on the other hand are complex, costly and have long-term implications. It is therefore vital that such decisions are based on the best available evidence. Thus the following is highly recommended:

1. Data gathering on the varied and especially renewable energy resource potential of the country needs to be undertaken to have a more reliable assessment of the various energy resources, which helps reduce the significant variations and uncertainties in existing resource potential estimates. This gives a better foundation to plan and optimize the future energy supply *vis-s-vis* energy demand and climate change.
2. Climate information database helps to bridge information gap. Based on the available information better characterization at the regional and local levels of climate change trends relevant to the energy sector, including water availability, wind resources, solar and cloud cover, and likelihood and magnitude of droughts and floods plays an important role in risk management. Near-term and longer-term projections will help for proper planning. Therefore, digital databases on historic and observed climatological and hydrological conditions need to be compiled and freely accessed. Monitoring sites equipped with automatic devices able to record and transmit in real time the key weather variables (rainfall, runoff, temperature, sunshine hours, wind speed, reservoir head, evaporation, turbidity, etc) is important. Better meteorological data gathering that assists more robust modeling, which in turn gives more reliable predictions on the national and local level climatology and hydrology in the country, is a prerequisite to better assess the impact of climate change and future situation of hydropower potential in the country.



3. Continued and multifaceted research by academic and research institutions into the relationships between climate change and the energy supply and demand situation, further research on climate change impacts using downscaled climate change scenarios, researching the impacts of changes in seasonal conditions and extreme climatic events should be given a high priority as Ethiopia experiences economic and population growth, since it will help to continuously fine tune policies and strategies to better handle any eventualities associated with climate change and its consequent impacts on the energy sector in Ethiopia.



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