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Master thesis in Sustainable Development 2018/30
Examensarbete i Hållbar utveckling

The challenges and Opportunities of the Grand Renaissance Dam for sustainable Energy - Water - Food - Ecosystem services Nexus in Ethiopia.

Bisrat Woldemichael Handiso

DEPARTMENT OF EARTH SCIENCES
INSTITUTIONEN FÖR GEOVETENSKAPER

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Abstract

Ethiopia has been challenged by multidimensional poverty. However, it has the potential to minimize the threat through an integrated multipurpose development process. In this regard, hydropower has a significant role to reduce energy poverty and enhance the multipurpose use of natural resources efficiency. Hydropower is a source of clean, sustainable and renewable energy. It has a contribution to reducing carbon emission and maintaining environmental sustainability. In Ethiopia, it is the major source of electricity. The country is rich in natural resources, including water to produce energy, however, electricity supply is still uncertain. The data shows that the country has the potential to produce 50,000 MW energy from water resources. Yet, it exploited 3,822 MW in 2018, approximately 7.6 % of its potential. Moreover, the country faces issues with energy security. Additionally, water and food supply also face an uncertain future. In this case, the country has planned the growth and transformation plan I and II for 2015 and 2020 to increase the energy production to 10,000 MW and 17,000 MW energy respectively. Consequently, the government launched different multipurpose hydropower plant projects. This project focuses on the multipurpose use of the Grand Ethiopian Renaissance Dam, particularly for the sustainable energy-water-food-ecosystem service nexus at the national level. I applied the combination of methods such as the energy-water-food-ecosystem nexus, the SWOT analysis and the sustainability assessment as they are suitable for the complexity of such a project. Indeed, the GERD has benefits for the country in producing renewable and clean energy, generating income and increasing the water storage capacity at the national level. However, the project neglected the values of ecosystem services integration with the dam and its sectors. As a result, the dam affected the existed terrestrial biodiversity and ecosystem. Therefore, the GERD had not been the well-prepared plan that considers institutional cooperation and sectoral integration to use for multipurpose function and its sustainability. In these regards, unless the dam to take proper management of the project and natural resources, the hydropower plant would not have been generating sustainable energy production.

Key Words: Sustainable development, Hydropower plant, Grand Ethiopian Renaissance Dam, Natural Resource Management, Energy, Water, Food, Ecosystem services, Environment, Climate Change, Ethiopia

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Summary

This thesis aims to contribute to the research about the challenges and opportunities of the hydropower plant for sustainable energy, water, food and ecosystem services integration at the local level. Hydropower plant has a significant role to generate renewable, clean energy, which is reliable for environmental sustainability and climate change mitigation. The multipurpose hydropower plant can be used for energy, water, food security and ecosystem services integration to maximizing the efficiency of the natural resources and to minimizing environmental risks and economic cost. In Ethiopia, hydropower is the major sources of electricity take account 97.2 % in 2018. Yet, the country exploited only 7.6 % of its potential. In addition, the country is affected by multidimensional poverty and climate change impact as well. An integrated hydropower is the cost-effective, flexible and reliable source of energy which can be contributed to reducing poverty. The GERD is the hydropower plant in Ethiopia which has the contribution to sustainable development in environmental, economic and social perspectives. On the other hand, it has the impact on the existed biodiversity, terrestrial ecosystem and the local communities. The project is highly connected to environmental sustainability and climate change resilience. However, producing clean energy is not a guarantee for sustainability. In this regard, the thesis analysed the challenges and opportunities of the Grand Ethiopian Renaissance dam sustainability to maintain its maximum production and ecosystem at the national level.

Key Words: Sustainable development, Hydropower plant, Grand Ethiopian Renaissance Dam, Natural Resource Management, Energy, Water, Food, Ecosystem services, Environment, Climate Change, Ethiopia

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Acronyms

bbl: Barrel
BCM: Billion cubic meter
CH4: Methane
CO2: Carbon dioxide
CSA: Central Statistical Agency of Ethiopia
EEP: Ethiopian Electric Power
IEA: International Energy Agency
IHA: International Hydropower Associations
FDRE: Federal Democratic Republic of Ethiopia
GERD: Grand Ethiopian Renaissance Dam
GoE: Government of Ethiopia
GW: Giga watt
Ha: Hectare
Km: Kilometer
Kwh: Kilo watt hour
m: meter
MA: Millennium Ecosystem Assessment
m/s2 : meter per second square
MoAL: Ministry of Agriculture and Livestock
MoC: Ministry of Construction
MoCT: Ministry of Culture and Tourism
MoFED: Ministry of Finance and Economic Development
MoEFCC: Ministry of Environment, Forest and Climate Change
MoWIE: Ministry of Water, Irrigation and Electricity
MW: Mega watt
NO2: Nitrogen oxide
OECD: Organisation for Economic Co-operation and Development
SDGs: Sustainable development goals
UN: The United Nations
UNECA: The United Nations Economic Commission for Africa
UNECE: The United Nations Economic Commission for Europe
UNFCCC: The United Nations Framework Convention on Climate Change

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Chapter One
1.Introduction

The World has been challenged by poverty, such as lack of to access food, safe water, modern energy, and environmental catastrophes; climate change impact of global warming, natural resources degradation, loss of biodiversity and disruption of ecosystem services. Moreover, the global communities have been faced with challenges in all three dimensions of sustainable development; economic, social and environmental (UN, 2013). On the other hand, the number of population, their demand, and activities are increased, an unsustainable consumption and production patterns have resulted in economic and social costs may affect the human life and the natural resources as well.

The climate change impact affects environment sustainability and ecosystems which maintaining, providing, regulating and supporting services for the human well-being and nature as well. In fact, poverty is multidimensional indicators which including lack of basic needs and modern energy (UNDP, 2006; Reddy, 2000) which are highly connected with the human well-being. In this regard, the RIO+[20] of World Summit of the United Nations taken account to promote sustainable development at the global level which can be minimizing poverty, human impact, and environmental risk, and to enhance the benefits of nature (UN, 2012).

In 2013, the UN adopted the new agenda 2030 of sustainable development that focused on the economy, environment and social equity interaction which has been applying on seventeen goals, including poverty reduction, ensure to access affordable, reliable, sustainable and modern energy for all (UN, 2015). In addition, the UN has taken positive action to combat climate change and its impacts, to access clean water and sanitation, protect life on earth, promoting sustainable cities and communities, and climate change resilience action. However, the UN's Millennium Development Goals aimed to eradicate extreme poverty, improve living conditions and facilitate progress towards sustainable development, but not addressed access to modern energy (González-Eguino, 2015).

Sustainable development is a concept which concerns local, regional as well as global challenges of "common future" that focused on human well-being activities that interact with the nature in a sustainable way. The concept widely accepted and well recognized since 1987 the United Nations Brundtland report, that defined the "ability to make development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (UN, 1987). Moreover, sustainable development has been addressing an integration of economic, social and environmental objectives of society in ways that maximize the human life, without compromising the ability of future generations to meet their needs (OECD, 2001). However, the global environmental sustainability is under threat, with accelerating growth in global greenhouse gas emissions and biodiversity loss (UN,2013).

The approach aimed to maximize economic development efficiency and reduce environmental impact on climate change resilience that concern both the present and the future generation need too. Eventually, in 2015 the concept adopted by the United Nations to improve the lives and future perspectives of individuals, everywhere around the globe to achieve sustainable development goals of 2030 agenda (UN, 2017). In this regard, each of the UN member states, including Ethiopia has been applying the agenda for positive change of the societies life and maintaining natural ecosystem. Moreover, the concept focused on how to minimize poverties and environmental risks through its pillars integration with environment, economy and social equity.

The global level, 18 % people were living in extreme poverty with lack of basic needs, including to access food and safe drinking water (World Bank, 2014), and 31 % people have no access electricity in 2010 (González-Eguino, 2015). In Africa, particularly Sub-Saharan Africa, 53.3 % were living in poverty, including lack of access of food and safe drinking water, and 93.3 % of the people have not access electricity services in 2011 (Alkire and Housseini, 2014). Ethiopia is one of the world countries which has been faced by extreme poverty, such as lack of to access basic needs and modern energy. In

2011, the country 58.1 % of the people are destitute, which are lack of basic needs to access the quality of food, water availability and safe drinking water, and sanitation in 2011(Alkire and Housseini, 2014). In addition, 77 % of the people have not been accessed electricity in 2015 (Bersisa, 2016).

Poverty is a multidimensional socio-economical phenomenon, which defined that the lack of to access basic needs; food, water. Shelter, education, health, social, cultural and political power (Alkire and Housseini, 2014). On the other hand, energy poverty defined by Reddy, "the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe and environmentally benign energy services to support economic and human development" (Reddy, 2000).

The global communities consume electricity from the main sources are fossil fuel, hydropower, nuclear, biomass, wind, geothermal and solar take account 67.5 %, 16%, 13 %, 1.3%, 1.1%, 0.3 % and 0.07 % respectively in 2015 (Berga, 2016). However, the major sources of electricity; fossil fuels take account to release more CO_2 gas, which contributes to increasing greenhouse gases in the atmosphere. As a result, in the form of global warming, the world temperature increases, then it affects not only the life but also the sustainability of natural resources and ecosystems.

In this case, since 1992, the UNFCCC is underway to reach the global agreement on the reduction of GHG emissions that is important to reduce and mitigate climate change impacts at global level. In fact, global climate change is the most serious consequence of global warming, which is one of the most threat to the life of the Earth. The climate of Africa is controlled by complex maritime and terrestrial factors, which include the El Niño-southern oscillation (ENSO) influences mostly Eastern and Southern Africa, including Ethiopia (Desai and Potter, 2014). However, Hydropower as a renewable energy plays a key role in climate change mitigation (Branche, 2015).

Hydropower is an important renewable energy resource that contributes significantly to the avoidance of GHG emissions and the mitigation of global warming (Berga, 2016), because it has been emphasized as a source of sustainable, renewable energy, which is important for the supply of water for various uses and has become a critical issue in most nations owing to water scarcity and increasing conflicts between water resources consumers (Lorenzon, et al., 2017). Hydropower electricity is generated through the transformation of hydraulic energy into mechanical energy to activate a turbine connected to a generator (Branche, 2015). Therefore, the multipurpose hydropower project to take consider the energy, water, food, and ecosystem services nexus to minimizing environmental impacts, to enhance natural resources efficiency; agricultural production and to maintain climate change resilience and ecosystem services (UN, 2013).

On a global level, 25 % of hydropower dams are associated with multipurpose reservoirs (IHA, 2017). Moreover, energy is directly related to the most critical economic and social issues which affect sustainable development such as water supply, sanitation, food production and environmental quality on local, regional and global levels (Behl, et al., 2013). Therefore, hydropower can be a way to increase the share of the water resource for multipurpose reservoir, then it is possible to improve the efficiency of ecosystem services integration with the GERD.

Hydropower and climate change has closed relationship. On the one hand, hydropower is an important renewable energy resource that contributes significantly to the avoidance of GHG emissions and the mitigation of global warming. On the other hand, it is likely that climate change will alter river discharge, resulting in impacts on water availability, water regularity, and hydropower generation (Berga, 2016).

The conceptual relevance and pragmatic potential of hydropower plant nexus have been emphasized by many policymakers during various concepts for multipurpose (Smajgl, et al., 2016), that can be associated with ecosystem services. Multipurpose reservoirs offer storage capacity to manage floods, provide sustainable energy storage during extended droughts, and supply water for irrigation and domestic uses (IHA,2017). Therefore, hydropower plants have potentials to be used as multipurpose and be a solution to competing uses over energy, water, food and ecosystem services (IHA, 2017).

Therefore, hydropower can be a way to increase the share of multipurpose reservoirs and to improve the ecosystem services efficiency.

In the modern world, energy is the determinant factors of economic activities and human quality of life. However, Ethiopia has been faced by energy poverty those who the most energy consumers are dependent on traditional primary sources supply shared; biofuel, 91.6%; oil, 6.1 %; hydropower, 1.7 %; coal, 0.5 %; and geothermal, wind and solar, 0.1 5% in 2015 (IEA, 2017). On the other hand, Ethiopia, the Blue Nile River source in East Africa, faces an increasing population, undeveloped energy sources and insufficient agricultural production (Tan, et al., 2017).

The hydropower plants are clean, affordable and renewable energy sources that are maintained by the ecosystem within some short periods of time (UNFCCC, 2015). However, it requires the proper management of natural resources, by using technology capacity. Furthermore, the reservoir hydropower plant, not only for producing energy but also commercial activities can prosper to enhance the livelihood of the local population, such as food, water, and land resource management, trade from tourism, fisheries and aesthetic enjoyment activities, including recreation (IHA,2017). The energy, water, food security, and integrated ecosystem services management are the main challenges of Ethiopia today.

The nexus approach can enhance water, energy, and food security, and ecosystem services by increasing efficiency, reducing trade-offs, building synergies and improving governance across sectors (UNECE, 2015). The hydropower reservoirs can also regulate water flows for freshwater supply, flood control, irrigation, navigation services and recreation (IEA, 2012). It is at the cross road of human needs such as energy, water, food and ecosystem services. Because of that, the concept of the sustainable energy-water-food-ecosystem services nexus can potentially be applied to hydropower facilities.

This paper aims to analyse the sustainability of the Grand Ethiopian Renaissance Dam by analysing its energy-water-food-ecosystem services nexus. The Growth Transformation Plan (GTP I) (MoFED, 2010) planned by the Ethiopian government entails different multi-purpose hydropower projects, including Genale-dawa and the Grand Ethiopian Renaissance Dam. However, this paper focuses on the Grand Ethiopian Renaissance Dam (GERD).

1.2. Background

Ethiopia is the second most populous country in Africa with 102.4 million citizens, and a population growth of currently 2.5 % (World Bank, 2017). Since 2004, the country's economy grew by approximately 10 percent per year (World Bank, 2015). The country is rich of natural resources, with high potentials for renewable energy source, including hydropower, wind power, geothermal power, solar energy and biomass (Awulachew, 2017).

However, over the last decade, the country has suffered chronic electricity shortages due to rapid economic growth outpacing the development of the energy sector (Guta and Börner, 2015). Apparently, the Ethiopian energy security has been facing to meet increasing 2.5 % population and the demand has increased by 30 % in every year (Asnake, 2015; Guta, 2015), but the energy production is uneven. In response to that, the government planned under the first phase of GTP I to construct multipurpose hydropower plants to increase the energy production up to 10,000 MW in 2015 (MoFED, 2010), and GTP II forecasted a growth in energy production of up to 17,000 MW in 2020 (MoFED, 2016). Yet, the national grid of modern energy production has below one-third of the planned in 2018 (EEP, 2018). Consequently, there had been national grid energy shortages between 2007-2009, then the country lost 3 % of its national GDP (Guta, 2013).

Ethiopia has a shortage of water storage facilities, the demands of institutional and infrastructure investment is high, and the investment ability is low (Grey & Sadoff, 2007). Based on a study by the World Bank, the cost of hydrological variability currently has been estimated to be more than one third of the annual GDP, which indicated that increased investment in multipurpose water infrastructure could contribute to the long term economic development and mitigate the adverse impacts of floods and droughts (World Bank, 2006). However, the GERD is primarily built for power generation and not for other purposes, such as irrigation and water security (Chen and Swain, 2014).

The expansion of the hydropower capacity is based on economic studies which showed that hydropower would be beneficial for the country and region (Schoeters, 2013). The Ethiopian electricity production capacity has been 4,284 MW in 2017, out of which 96.6 % came from renewable sources of energy, including hydropower, wind, geothermal, biomass and the remaining 3.4 % came from diesel (Awulachew, 2017).

Ethiopia has the potential to use the water resource across eight major basins with an exploitable hydropower potential of 50,000 MW (EEP,2018). On the other hand, the international energy agency and other researches mentioned that the country hydropower potential is below, which is 45,000 MW (IEA, 2017; Awulachew, 2017; Tsegaye, 2016). Currently, the installed capacity is of 3,813 MW, generating annually 4,954 GWH so far (IHA, 2017). On the other hand, the country faces enormous challenges to generate and supply electricity (Guta and Börner, 2015).

The country has been implementing different hydropower projects, including the grand Ethiopian Renaissance Ram (GERD) for producing energy (Schoeters, 2013). In fact, the GERD is a multi-purpose infrastructure that can help transform Ethiopia's economy through sustainable provision of cheap power, irrigation systems and storage capacities to protect from floods and droughts while maintaining the environment regulation (Tan, et al., 2017).

In Ethiopia, there are some existing main dams such as Koka, Fincha, Tana Beles and Tekeze with significant reservoir storage capacities, and which were originally all intended for hydropower production (SWECO, 2008). Nevertheless, the country geographical electricity access is approximately 55% in 2015 (Asnake, 2015).

The Ministry of Water, Irrigation, and Electricity (MoWIE) is the responsible organ of the Government of Ethiopia (GoE) for the country's water, irrigation and electricity sector development and expansion. As a state-owned project, the GERD is operated by Ethiopian Electric Power which is a department of MoWIE. Hydropower is the generation of power by exploiting energy from the water resource.

Figure 1: The GERD is being built on the Blue Nile river

Source: The Economist (2016).

According to the dam construction plan, the GERD will be 1,800 m long and 145 m high and the reservoir capacity will be up to 74 BCM with an expected installed energy capacity of 6,540 MW (EEP, 2018; IHA, 2018). The primary purpose of the dam is to generate electricity. In addition, the GERD will have provisional ecosystem services that provide the benefits for tourism and fishery for local people. The GERD commissioning would be expected in 2017, yet it has been completed 63 % (EEP, 2018).

1.2.1. Natural Resources

The UN defined that natural resources are all the land, including minerals, agricultural land, forests, water resource, animals, plants, energy sources and other entities existing naturally in a place that can be used by people for any economic gain (UNESCO, 1964). Water resource is the promising renewable source of hydropower energy because if managed properly, it can be a sustainable source of electricity.

Naturally, Ethiopia is rich in natural resources, such as minerals, including gold, platinum, copper, potassium, uranium, tungsten; natural gas; arable land; water; forests; biodiversity and other renewable energy resources. Since 1995, the country has nine regional administrative federal states and two administrative cities. Guba Woreda is part of Benishangul-gumuz regional administrative states which is rich in natural resources, especially water resources, fertile agricultural land, flora, fauna both in terrestrial and aquatic, and minerals. As mentioned above, this study focused on water resources, biodiversity and ecosystem services around Abbay river (Blue Nile), which is important for many Ethiopians' daily livelihood.

The Blue Nile basin accounts for 20 % of water supply to Ethiopia's land area, for about 50 percent of its total average annual runoff which emanates from the Ethiopian highlands, for 25 percent of water supply to its population and for over 40 percent of its agricultural production (Awulachew, et al., 2007). The river is the source for different hydropower projects, irrigation, ecosystems and food for many communities of East and North-East Africa. The river runs around 900 km down through the Ethiopian highlands just before crossing the borderline, which is 20 km downstream of the GERD, then the river enters the clay plain of Sudan (See figure 1), through which it flows over about 735 km. to Khartoum (International river, 2012)

Moreover, the river exits from the south-eastern corner of Lake Tana and cuts a deep gorge first south then westwards, then joined by many of tributaries: Beshilo, Weleka, Giemma, Beles, Muger, Guder, Fincha, and Dedessa from the east and south; and the Birr, Fettam, and Dura from the north and Dabus from the west (Awulachew, et al.,2007). However, the country consumption of Blue Nile is no more than 2% of its water resources (International River, 2012).

The average annual precipitation over the Blue Nile sub-basin is 1,346 mm, making it the highest among all the sub-basins of the Nile. The lowest rainfall is recorded over the eastern part of the sub-basin where the average annual precipitation does not exceed 800 mm, where the highest values (exceeding 1,900 mm) are found over the southern part of the catchment (International river, 2012). Similarly, on average, an estimated 20% of the rainfall is lost as runoff. Despite that, the Blue Nile basin contributes on average about 62 percent of the Nile water mass at the height of Aswan Dam in Egypt; and together with the contribution of Baro Akobo and Tekeze rivers, Ethiopia accounts for at least 86 percent of the runoff at Aswan (Awulachew, et al., 2007).

The GERD reservoir and its surrounding area are rich in biodiversity. According to data of Metekel Zone Natural Resources Department, the faunal diversity entails the common fox, Bush buck, Eland, Gazelle, Defassa Waterbuck, Duiker, Patas Monkey and Warthog (Ethiopian Road Authority, 2001). Some of the animals, particularly "*Bird species include Secretary Bird (Sagittarius serpentarius), Ostrich (Struthio camelus), Little Grebe (Trachybaptus ruficollis), Black-Necked Grebe (Podiceps nigricollis), Great Crested Grebe (Podiceps cristatus), Great Cormorant (*Phalacrocorax carbo*), Long-Tailed Cormorant (Phalacrocorax africanus), Great White Pelican (Pelecanus onocrotalus) and Pink-Backed Pelican (Pelecanus rufescens)"* (Road Authority, 2001; International river, 2012).

Moreover, international river identified some of the flora diversity that categorized into six physiognomic units, such as forest, wood, bamboo, bush, shrub, and grassland would be affected by the dam (international river (2012). In this case, the dam and reservoir area plant species have been lost, then the local livelihood would change because the indigenous community livelihood dependent on it; for example, the forests were a source of food, traditional medicine, housing materials accessibility and cultural values.

1.2.2. Hydropower in Ethiopia

Hydropower is grouped into three broad categories: reservoir hydropower plants, pumped storage facilities and run-of-river hydropower plants. Indeed, the GERD is suitable for hydropower energy production which characterized by the presence of a large reservoir that can store water for multipurpose use, allowing the facility to regulate its output depending on constraints regarding reservoir levels impacts of water release (Stoll, et.al., 2017).

The reservoir can also regulate water flows for freshwater supply, flood control, drought mitigation, irrigation, navigation services and recreation (Branche, 2015). Therefore, the important considerations for the types of hydropower facilities include the surface elevation of the reservoir—particularly to control flooding, limit potential temperature stratification in the reservoir, and maintain water levels for recreational purposes (Andrade, et al., 2017).

In Ethiopia, there are different multipurpose hydropower plants: Fincha, Koka and the on-going project, Genale-dawa dam. According to the Ethiopian Energy Policy (2013), the country has different dams for producing energy from hydropower, located within the five major river basins which became operational over the last years: Awash, Omo, Wabi-Shebelle, Gilgel Gibe II, III, Tekeze, Tana Beles and Fincha Amerti Neshe. In fact, since 1932 the country has been familiar with hydropower energy.

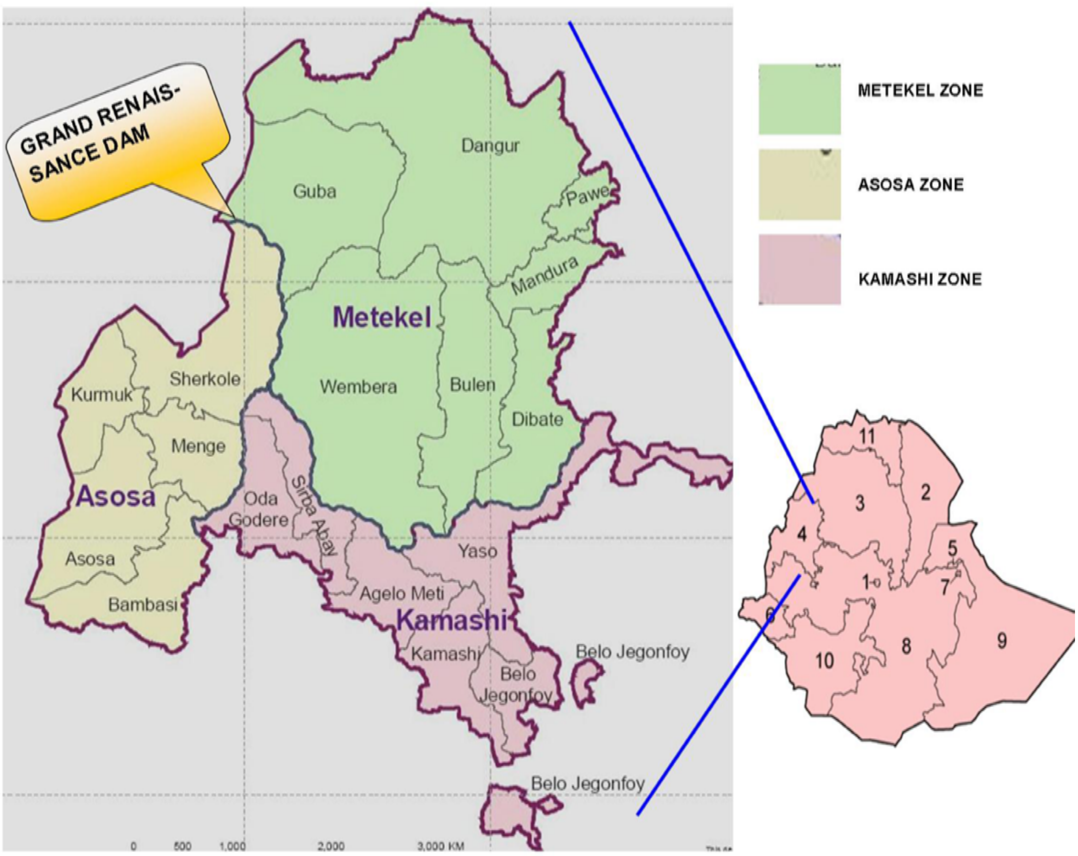
1.2.3. Study Area of the Grand Ethiopian Renaissance Dam

The GERD is being built on the Abbay (Blue Nile) River in a place called Guba, 60 kilometres from Sudan (Tesfa, 2013), commissioned by the GoE, at Benishangule Gumuze Regional Administrative State at Guba woreda (see Figure 2), which is around 830 km road distance, northwest of Addis Ababa (EEP, 2018). The project location is in the geographical coordinates 11° 16' 0" North, 35° 17' 0" East (Belachew, 2013).

The main source of Blue Nile River is located at the foot of Gishe-abay mount in Gojam, which is in the Ethiopian highlands (See figure 1 and 2). From there, the four main small rivers run into Lake Tana; one of them is the little Abbay River (Gilgel Abbay), which is the main source of the Blue Nile. The basin has a catchment area of 199, 812 km^2, covering the largest parts of the current Amhara, Oromia and Benishangul-Gumuz regional administrative states (Awulachew, et al., 2007).

Tana Lake is the largest lake in Ethiopia, which is 78 km long, 67 km wide, maximum 15 m deep, with an average depth of 8 m. Moreover, the catchment area of lake Tana is estimated to be 16,500 km^2 whereas the lake surface area is 3,600 km^2. Nevertheless, the contribution of Lake Tana to the Nile is less than 10% of the Blue Nile annual flow (International River, 2012).

Figure 2. The Grand Renaissance Dam location in Ethiopia.



Source: International River (2012)

The dam project planned during Hile Selassie I reign, and the construction of the GERD on the Blue Nile river has been on the Ethiopian Government's drawing board since the 1958 and 1964 (Woldegiorgis, 2007; Chen and Swain, 2014), but it was launched in December 2010, and officially in April 2011. Indeed, it has been the largest engineering project ever planned in the country, which consumes approximately $US 4.8 billion, but it will be expected that the project will take more budget.

The dam, the reservoir of water storage (see Figure 5) and energy installed capacity have been already upgraded twice; the first plan allowed for 60 BCM volume of water storage with 5,250 MW capacity, with an estimated annual energy production of 15,130 GWH per year in 2011 (Tan, et al., 2017). Later, the project was upgraded to 70 BCM volume of water and an energy production capacity of 6,000 MW. Recently, the project's water storage and installed energy capacity were upgraded again to 74 BCM of water volume and a capacity of 6,540 MW, which would lead to an estimated annual energy production of up to 15,759 GWH per year (IEA, 2017). In addition, the water impounded reservoir length of 200 km was expanded to 246 km (EEP, 2018).

The GERD contract was assigned to two companies; the civil engineering contract has been taken by the Italian company, Salini-Impregilo, and the electromechanical and hydraulic part responsibility has been taken by the state-owned Metals and Engineering Corporation (METEC) (EEP, 2018).

The project has two dams, the main (see Figure 3 and 5) and the saddle dam (see Figure 4 and 5). According to the Ethiopian electric power (EEP,2018):

"The main dam has a maximum height of 145 m in the central part and the river gorge reaches 170 m. The dam crest length elevation is 645.0 m. above sea level and its length is 1.8 km with a total volume of the dam of about 10.1 Mm^3. In addition, the main dam has 225 m of un-gated spillway, 2 bottom outlets with 6 m diameter, and 4 diversion culverts of 7.50 m x 8.30 m for the 16 power waterways.

Figure 3: The front parts of the main dam and the power generating area of the GERD

Source: EEP (2018)

The Saddle Dam is located about 15 km away from the main dam and is a Concrete Face Rock Fill Dam (CFRD) that is 5.2 km long and 50 m high. The water volume is about 15 million m^3. The crest at elevation 644.0 m above sea level is completed by a wave wall until elevation 645.2 m above sea level.

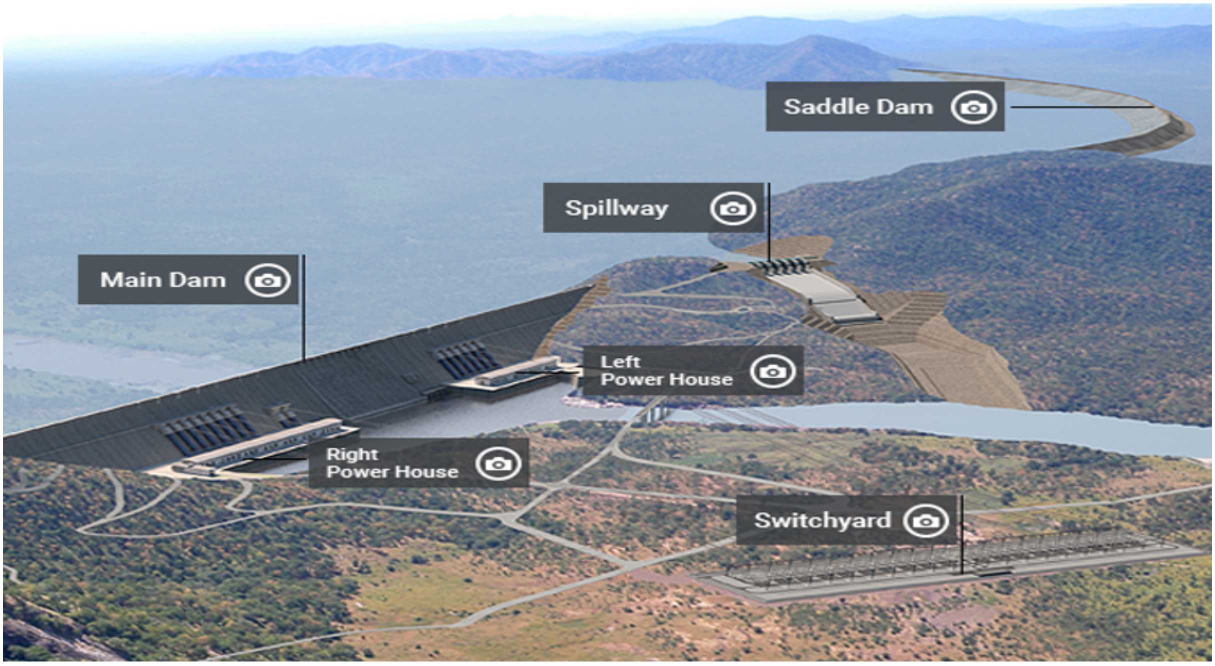
In addition, there is the water discharge system which has a total capacity of 19,000 m^3/s with 3 different spillways, including a gated spillway having 6 bays with big radial gates which is the left bank of the Main Dam" (EEP, 2018).

Figure 4: The Saddle dam, which is the left side of the main dam at the GERD.

Source: EEP (2018).

At the end of the project, the reservoir catchment area will cover 1,874 km^2 at full supply level of 640 m above sea level and will extend from the root of its reservoir to the dam site, over a corridor of some 246 km (EEP,2018).

Figure 5. An overview of the GERD project and water reservoir area.



Source: Hagos (2017).

Electricity production is the main purpose of the dam, but it has the potential to create an opportunity to improve water security, as Ethiopia is short of water storage facilities, the demands of institutional and infrastructure investment are high and the investment ability is low (Chen and Swain, 2014).

The hydropower plant, the GERD indicates that increased investment in multipurpose water infrastructure could contribute to the long term economic development and mitigate the adverse impacts of floods and droughts (World Bank, 2006). Indeed, electricity generation is heavily reliant on hydroelectric power in the country, which is variable due to a host of factors, including: trade-offs with potable, industrial, and agricultural water needs; frequent and intense droughts; the effects of siltation and sedimentation on dams and reservoirs; and international conflicts over water rights (Guta and Börner, 2015). Therefore, this thesis focused on the ways in which the energy- water-food security-ecosystem services nexus can be applied in the GERD in a sustainable manner, considered both local and national levels in Ethiopia.

1.3. Objective

The purpose of this thesis is to analyse how could the GERD, which is currently under construction, be used for sustainable energy, water, food security and ecosystem services in Ethiopia. The aim is to analyse the challenges and opportunities that arise from using the GERD as a more expanded multipurpose project besides hydropower, fishery and tourism, as it is currently planned.

1.4. Research questions

The main research questions that I want to answer are the following:

1. Does Ethiopia have hydropower plants for multipurpose, especially the projects addressing the energy, water, food and ecosystem service nexus? If not, Why?
2. What is the contribution of the GERD for energy, water, food security and ecosystem services integration in Ethiopia?
3. What are and will be the challenges and opportunities of the GERD?
4. How will energy, water, food security and ecosystem services provision interact as part of the GERD project?

Chapter Two

2. Methodology

2.1. Methods

The Research method is the most common tool and technique used for developing scientific outputs (Walliman, 2011). I applied the combination of research methods to analyse the sustainability of the energy-water-food- ecosystem services nexus related to the GERD, Ethiopia.

I first used the hydropower nexus framework (UNECE, 2015), which are discussed in the following sections 2.2. and 2.3., to study the integration of the sectors (energy, water, food, and ecosystem services) in the GERD.

To do this, I modified the common hydropower nexus model by performing a conceptual model that suitable for the analysis of the nexus integrated with sectors and institutional cooperation. This, so that the nexus could be related to the specific case of the GERD project. The reason that the project is creating its new aquatic ecosystem, which connected with water availability for multipurpose. Therefore, it has the potential to enhance water and land resources efficiency and to reduce the environmental, economic and socio-cultural effect. The dam has significance to invites institutional cooperation, to minimize and share the economic cost and the environmental risk.

The new conceptual model is needed because the UNECE (2015) nexus methodology applied on transboundary river within natural ecosystem based. However, GERD will be creating new man-made lake and it is changed the natural terrestrial ecosystem into aquatic. In fact, the project is under-construction on the transboundary river, but my study focused on at national level. The structure showed that the nexus sectors; energy, water, food/land and ecosystem services have been linked each other. In addition, the institutions, Ministry of Water, irrigation and electricity (MoWIE); Ministry of Agriculture and Livestock (MoAL); Ministry of Environmental protection, forest management, climate change (MoEFCC); Ministry of Culture and tourism (MoCT), and Ministry of construction (MoC) cooperate each other. For example, MoWIE more concerned and responsible to water resource management, electricity production and utility, and the irrigation dam; MoAL responsible to managed the agricultural land, agriculture and food production; MoEFCC responsible to environmental protection, forest management, biodiversity, ecosystem of supporting, regulation and provision services, and climate change resilience, responsible to mitigate climate change concern; MoCT responsible to managed the ecosystem services of cultures and aesthetic enjoyment, and MoC responsible to control the quality and strength of the dam and its raw material. I applied this conceptual framework in GERD, Ethiopia.

Afterwards, I applied the SWOT analysis method (Strengths, Weakness, Opportunities and Threats defined by Singh et al. (2012) and further applied by Batisha (2015) and Atilgan and Azapagic (2016) to analyse the challenges and opportunities of the dam and the nexus built around it (Osita, 2014). It has significant to reduce the challenges and risks and creates opportunities to enhance the efficiency of the resources and sustain the dam production.

Finally, I used the Sustainability Method, which is based in the sustainability theory the theoretical frameworks of the sustainability theory (United Nations General Assembly, 1987), to study the economic, environment and social equity aspects of the GERD. Sustainability assessment is very essential to analyse the complexity of the GERD sectoral integration impacts and benefits of economy, environment and social aspects of the GERD.

2.2. Theories used for the methods

2.2.1. The sustainability Theory

Sustainability as a theory puts an emphasis on the harmonious interaction between the elements of systems by focusing on three aspects: social, ecological and economic. Therefore, sustainability should be the state of simultaneous achievement of economic prosperity, a healthy environment, and social equity for current and future generations. On the other hand, system theory suggests that "ecological, social, and economic systems are a group of interrelated, interacting or interdependent constituents forming a complex whole" (Espinosa and Walker, 2011).

The concept of sustainable development is defined in the Brundtland Report as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations General Assembly, 1987). Sustainability theory addresses the availability and resilience of systems and resources, aiming to maintain the stability and capacity of the given system structure. Regarding hydropower plants, it considers the reservoir response and self-reliance, which regulate the interaction between the sectors regarding social, economic and ecological concerns with their environments. The objective of the sustainability approach is promoted and enhancing the interaction of the system development model (Espinosa and Walker, 2011).

The nexus approach focuses on the integration and linkage between sectors, such as energy, water, food or land and ecosystem services (UNECE, 2015). In addition, it shows opportunities to integrate and coordinate the systems with each other. Moreover, the nexus approach emphasized on transboundary water resources, addressing the role of each sector's share and contribution within a system. However, the nexus approach does not pay attention to the role and impacts of the institutional interactions within sectors. In fact, the hydropower sectors integration has significant to enhance the natural resource efficiency and to promote sustainability of the project as well. Nevertheless, without institutional integration, it is difficult to apply the nexus sectors interaction approach to sustainability, because one sector or/and institution affects the other.

Hydropower is an energy source that depends on the water resource availability, and plays a significant role in producing renewable, clean energy that is important to reduce carbon emissions. Moreover, the hydropower reservoir, GERD, is a type of hydropower plant which can be used for multipurpose in a sustainable way because the river water has been stored in a reservoir. The GERD is a hydropower plant project that faces issues regarding the interaction between sustainability pillars, and the integration of the dam nexus sectors.

Furthermore, hydropower facilities cover a broad range of technologies and operational regimes that generate electricity from the water. Nevertheless, the size of these facilities can vary greatly, from those with electricity generation capacity as small as kilowatts (kW) to as large as gigawatts (GW), that depends on the technologies range and operational considerations. However, there has not been universally or widely accepted model and theory that applies the hydropower nexus integration for multipurpose (Branche, 2015).

2.2.2. Other Theories

I applied some other theories, such as security theory that connected to energy security, food security, water security and agricultural production economy (See energy security and food security). The theories were important to analysis of nexus sectors which related to the GERD.

2.3. Data collection

I performed literature reviews about the hydropower plant for sustainable energy, water, food, ecosystem services nexus related to GERD, in Ethiopia. The project, about the nexus, how to use of hydropower projects as multipurpose projects at national level.

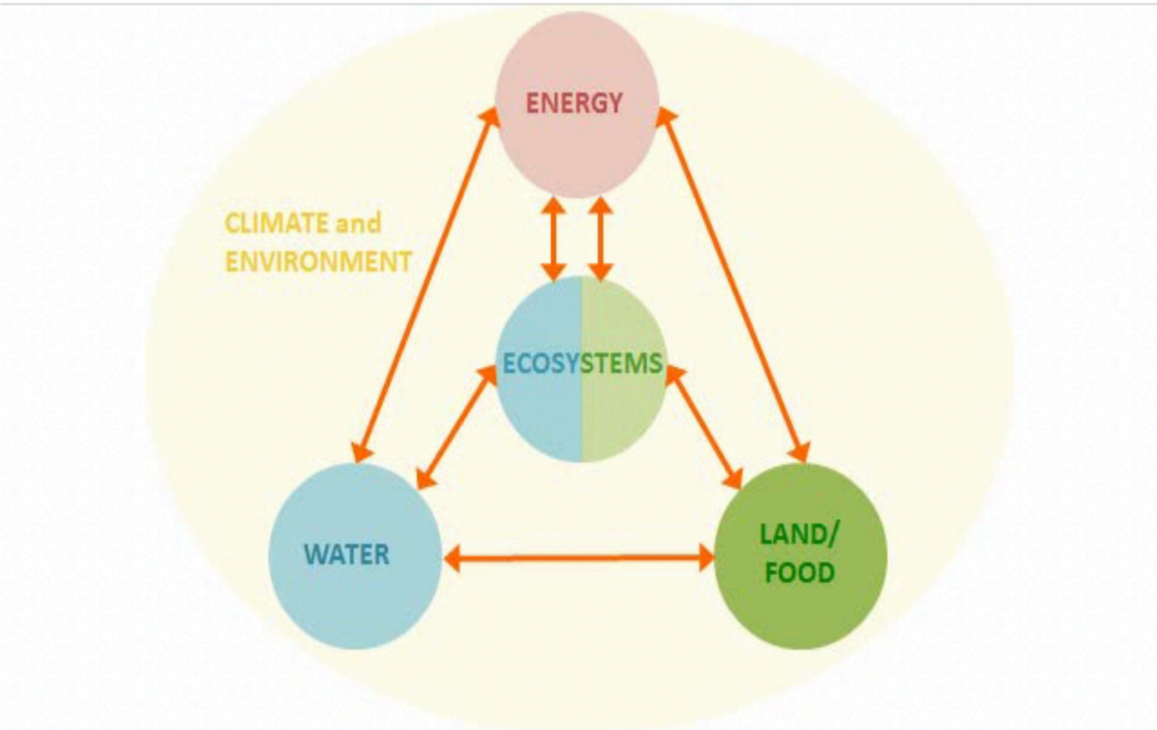
The data were collected from the existing published academic materials, researches, official documents, in both systematic and integrated literature review. I used official documents from the MoWIE, EEP, MoFED, UNECE, IHA, IEA, academic institutions, scientific books and articles, non-governmental organizations report, academic researches, and seminar materials from books, Uppsala University library, and Internet and Google; Academia, Google scholar, Research gate, Science direct and other online data sources.

2.4. Energy-water-food-ecosystem services nexus

As a methodology, I used the water, food, energy and ecosystems services nexus, to analyse opportunities to enhance sectoral integration and institutional cooperation at local and national levels. Indeed, the use of the nexus gives the opportunity to analyse sectoral integration and institutional cooperation on the GERD, that is important to enhance the efficiency of the dam and natural resources management (UNECE, 2015).

The United Nations Economic Commission for Europe (UNECE) applies the nexus approach on Transboundary Rivers, but it is also possible to apply it at the local and national level. The UNECE uses ecosystems as the central component of the energy-water-food-ecosystem nexus (See figure 6) and applies it on natural transboundary rivers (UNECE, 2015; Strasser, et al., 2016).

Figure 6. Conceptual model of the Energy-water-food-ecosystem nexus (UNECE, 2015).

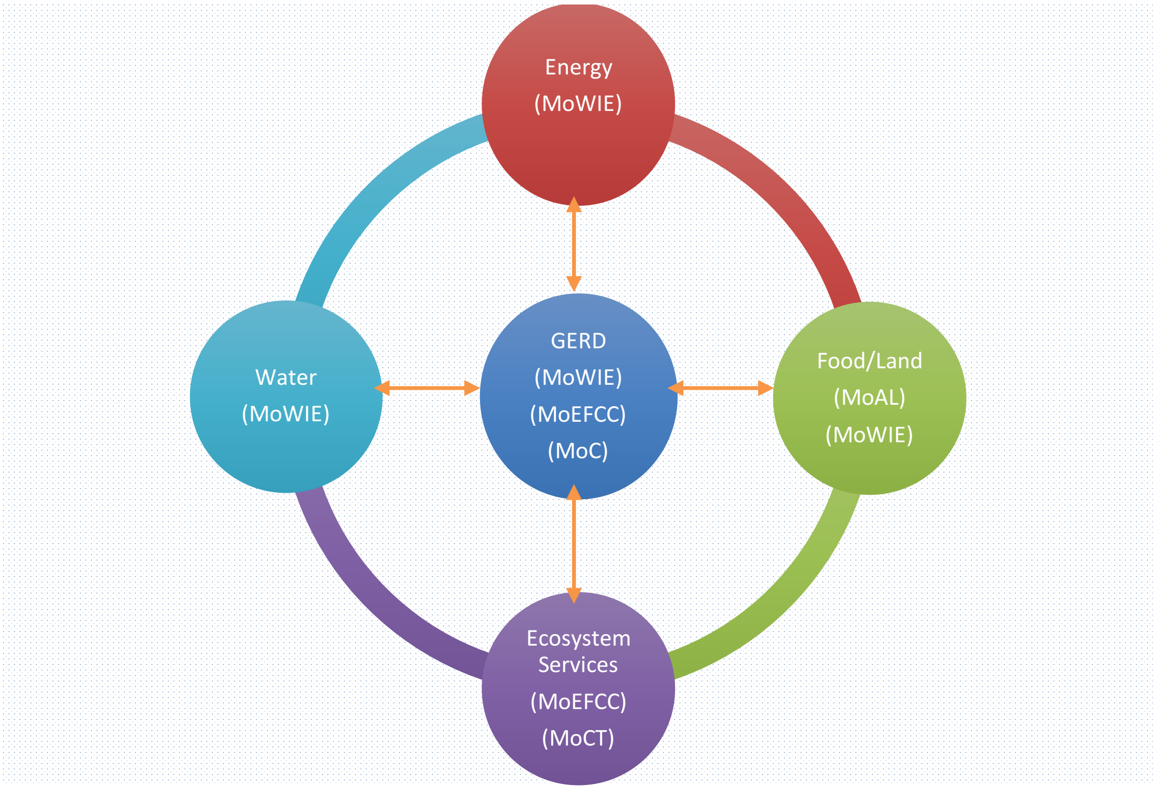


Source: UNECE (2015)

I applied the nexus at the local level, modifying it to suit the given circumstances of this research, as the GERD project consists of a water impounded reservoir that differs from the common natural lake. The GERD reservoir area will change the natural terrestrial ecosystem into a new aquatic ecosystem.

Development of the conceptual model for the GERD Energy-Water-Food-Ecosystem services nexus

Figure 7: Modified conceptual model of the sectors nexus suitable for the GERD.



The GERD is the central component of the energy-water-food-ecosystem services nexus in this project.

The conceptual model (see Figure 7), the nexus sectors, such as energy, water, food/land and ecosystem services connect with the GERD, and each sector also links to each other. The GERD obtaining water from Blue Nile river and its tributaries sources, then supplying the obtained water for different purposes of each sector what they demand their providing services. Moreover, the nexus sectors linkages are dependent on the responsibilities of institutional cooperation at the local level. However, this conceptual model applying for the grand Ethiopian renaissance dam (GERD) at the local level in Ethiopia, but not in transboundary.

The nexus sectoral linkage and institutional cooperation with the GERD, the project primarily responsibility taken by the owner and administered by EEP which is sub-department of MoWIE. However, according to the GoE institutional structural overview, the GERD connect with energy and the reservoir would have been managing by MoWIE and MoEFCC. Indeed, during the construction, the dam standard should be controlling by MoC, which is responsible to check the quality of construction materials and standard for the dam sustainability that depends on the project plan and purpose.

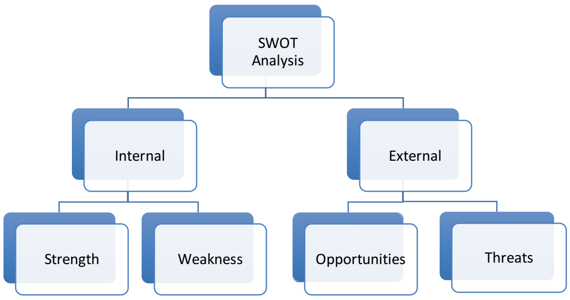
The GERD water security task responsibility would have been taking by MoWIE. The GERD connect with food or agricultural land and irrigation which responsibility taken by MoWIE and MoAL. In addition, the GERD connection with ecosystem services management responsibility taken by MoEFCC and MoCT. In these regard, each institution should assign sub-department for taking their responsibility. The institutional cooperation and sectoral linkages are promising for minimizing the cost, enhancing the project efficiency, promoting sustainability and natural resource management effectively.

In addition, the institutions, Water, irrigation and electricity (MoWIE); Agriculture and Livestock (MoAL); Environmental protection, forest management, climate change (MoEFCC), and Culture and Tourism (MoCT) cooperate each other. For example, WIE is more concerned and responsible for water resource management, electricity production, and utility, and the irrigation dam; MoAL is responsible to manage the agricultural land, agriculture, and food production; MoEFCC responsible to environmental protection, forest management, biodiversity, ecosystem of supporting, regulation and provision services, and climate change resilience, responsible to mitigate climate change concern; MoCT is responsible for managing ecosystem services of cultures and aesthetic enjoyment.

In addition to the nexus, I made a SWOT analysis for the GERD. The SWOT (see figure 8) is a helpful tool that was important for the analysis of the challenges and opportunities of the dam.

Figure 8: Modified The structure of SWOT analysis framework

GERD



The SWOT structure suits for the internal and external analysis of the GERD

2.4.1. Application of the Energy-water-food-ecosystem services nexus to the GERD

The term nexus has been used in a variety of contexts with the aim of advancing an understanding of how sectors are linked, and in turn to inform cross-sectoral governance coherence (Strasser et al., 2016). The nexus approach in the context of water, food (agriculture) and energy refers to these sectors being inextricably linked so that actions in one sector commonly have impacts on the others, as well as on ecosystems services (UNECE, 2015). In fact, the approach requires systemic thinking and understanding of the complex linkages and feedback mechanisms in social–ecological systems for delivering integrated solutions, thus addressing key challenges in sustainable development (Fürst, et al., 2017).

The nexus is the fundamental prerequisite for this integration between institutions and nexus sectors; energy, water, food and ecosystem services. In fact, the methodology emphasized how to use the hydropower sectoral integration on the transboundary river that promotes cooperative work of natural resources; however, it is also possible to apply at the local level. The nexus approach applied in Europe at regional level on transboundary rivers (UNECE, 2015), but it had been possible to applied at national level; Durance-verdon in France and Tennessee-valley in the USA had been applied hydropower plant for multipurpose for energy, water, food from irrigation and ecosystem services at national level (Branche, 2015).

In fact, it is a complex approach that concerns about the connections and interactions among sectors to manage natural resources. In other words, the nexus considers complex interactions as such, resembling the multipurpose analytical framework applied to resources management, including water, energy, land, food and ecosystem services. In this regard, there is potential to apply the nexus approach with a central component role to use the GERD for multipurpose, such as energy, water, food security and ecosystem services both at local and national level. Therefore, it creates opportunities to apply the strength of linkages between the sectors, named energy, water, food security and ecosystem services, and institutions, mainly responsible ministry offices.

Moreover, the analysis of the water-food-energy-ecosystem services nexus is important to enhance inter-sectoral coordination and institutional cooperation, and more generally to inform policy development and management of natural resources (UNECE, 2015). Furthermore, in Ethiopia, energy, water, food securities and ecosystem services are critical issues at the national level. Accordingly, once constructed, the grand Ethiopian renaissance dam will create the opportunities for supply and demand of the country's energy, water, food and ecosystem services.

2.4.1.1. Energy Security

Energy security is a classic and broad concept of policy which addresses energy supply and consumption. The concept of energy security is based on the concept of security in general (Hippel, et al., 2011) that is concerned with preventing or maintaining external threats and intervention of "free from the threat or risk" approaches. Currently, the concept of energy security is widely accepted as a policy framework concept that concerns both internal and external threats to energy production and supply sustainability. "Sustainable" energy security is "the provisioning of uninterrupted energy services in an affordable, equitable, efficient and environmentally benign manner" (Narula 2014; Narula, et al., 2017).

Ethiopia is a non-oil producing country and imports 80% of its total petroleum demand from its neighbouring country, Sudan, the remaining 20 % from Kuwait and Saudi Arabia. However, the country has potential, but not yet functional, fossil fuel sources, such as natural gas, coal and shale oil (Awulachew, 2017). The country has been importing 2.63 million tonnes of petroleum products worth 47.6 billion Ethiopian Birr (at the time approximately US$ 2.16 Billion) in 2015/2016 (Berhanu, et al., 2017), which is significant to its national economy, as fuel imports accounted for 16.4% of total imports of goods and services.

However, the hydropower is the leading renewable sources of electricity production in Ethiopia, but only 7.6 % of its potential is currently being exploited. Ethiopia has an inter-connected system (ICS), its main grid system consists of 14 hydropower, six diesel standbys, one geothermal and three wind farm power plants with installed capacity of 3,810 MW, 99.17 MW, 7.30 MW and 324 MW respectively (EEP, 2018). The current total production reaches up to 4,244.67 MW. Therefore, the renewable energy sources accounted for 96.6% of the total electricity production; the hydropower shared 88.94 % (Awulachew, 2017). In this case, most of the electrical energy has been obtained from the national grid generated by hydropower.

The country's electricity accessibility has been low with the geographical electricity grid connectivity because it has been reached 55 %, but in an individual household at the national level approximately reached 30 % (Tsegaye, 2016). In the country, nearly 88% of the total energy is utilized by the households. The industrial, transport, and the service and telecommunication sectors utilize 40%, 3% and 5% of the total energy respectively (Berhanu, et al., 2017). However, 70 % of the citizens have no access to get electricity.

Moreover, the accessibility and management of electricity connection has been poor and it is difficult to get a 24/7 service in every town and city. On the other hand, the government has built electricity infrastructures to connect the neighbour countries such as Djibouti, Sudan and Kenya. Yet, only Djibouti and Sudan have accessed the Ethiopian electricity connectivity.

In Ethiopia, the annual per capita electricity consumption is 100 kWh per year, however, the rest of Sub-Saharan Africa annual electricity consumption is 510 kWh (Nigatu, 2015). Most of the energy usage is still from traditional energy sources such as wood and animal waste. In comparison, electricity prices in the region are similar, with US$0.06 per kWh for Ethiopia and US$0.055 per kWh for Sudan (Nigatu, 2015). Energy security determines also the accessibility that considers the desired connectivity of electricity per household in KWh per year. Ethiopia providing electricity for the local consumers and the neighbour Sudan, but the energy costs and their national GDP are varied. For example, the two countries GDP per capita income are $706.8, $2,415.0 respectively in 2016 (World Bank, 2018). In addition to energy production and accessibility, the electricity cost highly connected with the consumers' income and affordability, which determined the national energy security.

Table 1: Ethiopia's current energy potential and exploited amount

Energy Source	Unit	Resource potential	Exploited amount	Exploited percentage (%)
Hydropower	MW	*50,000	3,822	7.6
Wind	GW	1.350	324	0.02
Geothermal	MW	*10,000	7.30	0.07
Solar	KWh/m^2	4-6	-	-
Wood	Million tonnes	1120	560	50
Agricultural wastes	Million tonnes	15-20	6	30
Coal	Million tonnes	300	0	0
Oil shale	Million tonnes	253	0	0
Natural gas	Billion m^3	113	0	0

Source: *EEP (2018), Awulachew (2017) and Tsegaye (2016).

The GERD is popular in the country and has been approved by the authorities because it is supposedly environmental friendly, with low carbon emissions when compared with other sources of energy, although this can be debatable. In addition, it is a renewable source of energy, and if managed properly, the project may as well be sustainable. On the contrary, regarding social sustainability at the local level, indeed, the project has impacts on the local societies, with displacement of the indigenous communities and lose of cultural attachment of their livelihood around the reservoir. Indeed, the country's political system has not been participatory, but rather a top-down directive implementation. Because of that, it is difficult to identify the public acceptance and voluntarily public involvements on the project.

2.4.1.2. Water security

Water security is a concept developed in the 1990's, which is linked to specific human security issues, such as military security, food security and environmental security (Cook and Bakker, 2012). The term water security is used by scholars and policy makers in different perspectives. Furthermore, the water storage is the current measure of water security (Melesse, et al. ed., 2014). However, the nexus of water security and the integration to water resource management focuses on the concept of water-centric interlinkages of sectors, i.e. a water security concept in multidimensional resource management (Cook and Bakker, 2012). Water security mainly considers the availability, supply, accessibility, and quality of water. Furthermore, Jepson, et al. (2017) defined that "water security informed by the capabilities approach necessarily attends to water as part of a hydro-social process that is simultaneously material, discursive, and symbolic, differently valued – as not solely material or social, but relational, based on negotiation and interaction at individual and collective scales."

The Global Water Partnership introduced a water security definition in 2000, stating that at any level from the household to the global, every person has access to enough safe water at affordable cost to lead a clean, healthy and productive life, while ensuring that the natural environment is protected and enhanced (Cook and Bakker, 2012; Srinivasan, 2017). Similarly, the UN (2013) definition of water security is "the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability." In this regard, the GERD provides some ecosystem services, namely fishery and tourism for the well-being life. Moreover, Cook and Bakker (2012) argue that water security has become more diverse, expanding from an initial focus on quantity and availability of water for human uses to include water quality, human health, and ecological concerns in different way.

In Ethiopia, water security is one of the main challenges of national security and is highly connected with food security, energy security and the climate change impacts of drought (Mohamed, 2017). In addition, it is one of the main challenges of economic development activities. On the other hand, the country has an adequate water availability, including surface, ground and annual season rain. However, the country's water resource management is poor (Alemu, et al., 2008).

Ethiopia receives little annual precipitation along its northern and eastern coastal regions, the central and western parts of the country can have high rainfalls of up to 2000 mm annually (Stokes, et al., 2010). Water is the main concern of the agriculture, industries and municipality services. As a result, spatial disparities in water availability exist in the country, and water management is very poor because the largest agricultural production is dependent on the annual rainy season. The total irrigated land area is only 0.46 % (FAO, 2016), and less than one percent of smallholder farmers use irrigation techniques (Cockrane, 2011). However, water storage is the current measure to address water security (Melese, et al, 2014).

2.4.1.3. Food security

GERD has potential to use for irrigation, which maximize food production. In this regard, agricultural production economics theory is suitable to apply on the dam for national food security. The theory is concerned primarily with economic theory as it relates to the producer of agricultural commodities (Debrtin, 2012), which is important to maximize food production. Moreover, agricultural productivity is the measurement of the quantity of agricultural output produced for a given quantity of input or a set of inputs (Mozumdar, 2012). Indeed, the agricultural production economics concern not only for an increment of food production but also the famers goals and objectives as well.

In fact, the concept of food security defined that the security exists when all people, always, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO, 1996). In addition, the concept contains food availability, food access, and food utilization. In fact, since 1961, Ethiopia is one of the most food-insecure and famine affected countries in the World (FAO, 2017). In addition, a large portion of the country's population has been affected by chronic and transitory food insecurity (Mohamed, 2017). Water resource is one of the most important factors for food security, because it is an input for agricultural production (Cook and Bakker, 2011). Indeed, the situation for chronically food insecure people is becoming more and more severe. The food security situation in Ethiopia is highly connected to recurring water shortage which associated to recurrent drought (Mohamed, 2017). Consequently, 31 million people were affected by food shortage and undernourished in 2015.

In general, Ethiopia has 1.104 million km^2 total land area, but its agricultural land has 362,590 km^2 and covered 36.26% of the total area in 2014. (FAO, 2016). Agriculture is the main source of economy and livelihood, which accounts for almost 47 percent of GDP, 60 percent of exports, and 80 percent of employment (Braun and Olofinbiyi, 2007).

The country arable land area has been no more than 15.12%, and the permanent cropland area is 1.14 % (FAO, 2016). In addition, the forest area covers 12.5 % and other vegetation 51.3 % (FAO, 2016). Moreover, in the rural area, small land farmers use traditional farming systems to produce food for their demand as well as for other consumers. The Ethiopian food security has a linkage with the water and energy security: water security is closely related to food security, given that water is needed for irrigation in agriculture. An insufficient annual rainfall and lack of water resources are highly affecting food production. Therefore, water resource scarcity has an impact on decreasing food production, because it is the main input for agricultural products (Cook and Baker, 211).

In addition, it has been a linkage between food security and energy security in Ethiopia; the reason that the large scale agricultural land was transferred from farmers to investors for biofuel farming purpose (Rahmeto, 2011; Beyene, et al., 2011). In fact, biofuel production is a new development initiative in Ethiopia (Beyene, et al., 2011), but it has an impact on food production. In Ethiopia, smallholder farmers have been relying on biofuel production for their livelihood. As a result, from the total land area 1.5 to 2 million hectares are assigned for biofuel; and indeed, some of the land area cultivation is assigned or under negotiation (Beyene, et al., 2011).

According to Awulachew, et al., (2007), the agricultural irrigation area is found behind the reservoir (See Figure 9). However, it has good opportunity to use for land management and agricultural purposes.

Blue Nile brings an opportunity to enhance the agricultural food production and water reservoir usage in Ethiopia, because the project area, Assosa and Metekel Zone, including Guba Woreda, and the neighbour administrative North Gonder Zone, West Gojam and Awi zone have good availability of agricultural land which is important for enhancing food production. In fact, the data have showed that the GERD was not planned for irrigation purposes, but rather for generating electricity, fishery and tourism. However, it has also potential to enhance agricultural food production around the reservoir area.

2.4.1.4. Ecosystem services

According to UN Water, an ecosystem is a dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit (UN, 2018). In biological terms, an ecosystem includes all living things, including plants, animals and micro-organisms in each area, as well as their interactions with each other, and with their non-living environments, such as water, weather, Earth, sun, soil, climate, and atmosphere. Each organism in an ecosystem has a role to play and contributes to maintaining the health and productivity of an ecosystem.

The ecosystem services are the benefits the people obtain from ecosystems, which identified four categories; provisioning services, such as food production; regulating services that maintain a benevolent environment and protect against its disturbance, such as flood defence; supporting services, such as sediment consolidation, and cultural and aesthetic services, including reflects cultural, religious values and recreational practices. (MA, 2005). In this regard, the GERD and its surrounding area have the existence of natural and cultural ecosystem services.

The projects area has plenty of water resources, including Blue Nile, Beles and other tributaries. The GERD will be providing a new artificial lake that is important to obtain food from fishery and agricultural products from irrigation around the area. However, the dam will be affecting the natural ecosystem, destroying the forests and natural food resources from the reservoir area. In this case, the people will not get food, timber, fibre and genetic resources from the terrestrial ecosystem which existed before the implementing of the project, because the forests and other terrestrial ecosystem will be changed by the GERD aquatic ecosystem.

Unless, the project owners and the responsible institutional sectors apply management activities such as reforestation around the basin area, soil and natural resources conservation, in the long-term the area may be affected. The Blue Nile basins, particularly the Amhara, Benishangul-gumuz and Oromia regional administrative states are vulnerable from soil erosion around the tributary rivers of the Blue Nile (Awulachew, et al., 2007). In addition, the reservoir's stagnant water is comfortable for communicable disease, including malaria. Nevertheless, the possibility to control flood and water quality when the project is constructed exists.

During the commissioning of the project, some of the indigenous communities' cultural values will be affected by the new and modern cultures brought to the area by the project, that related with the new livelihood on the artificial lake for recreation, navigation and other aesthetic enjoyment, including water sports. Regarding supporting ecosystem services, in the short-term the dam is affecting the soil formation, pollination and nutrient cycle because the reservoir area vegetation's are cleared and thus the insects and other wild animals disappear and migrate to others place for their safety. In this case, the project has negative impact on the supporting of ecosystem services. In the long-term, there will also be a possibility to attract migrated insects, birds and animals when the ecosystem services are managed properly.

2.5. The Challenges and Opportunities of the GERD (SWOT)

The GERD will have different challenges and opportunities. Some of the challenges include the lack of financial grant or loan, experience, knowledge, security and public participation for the benefits of local communities. In addition, the project has been built over the Blue Nile which is the Transboundary River and the major tributary of the Nile river, with 62 % of its water course being shared (Awulachew, et al., 2007). In this case, there has been high pressure of security matters on the dam from different interest groups of the downstream countries. As a result, there is a security threat, particularly from Sudan and Egypt. The reason is that the downstream country Egypt is concerned more about the sustainable flow of Nile river volume. There have been also other interest groups, those who have investments in Nile downstream countries. Nevertheless, Ethiopia has assured that the project does not have negative impact on the other riparian countries, only benefits (EEP, 2018).

The project has opportunities for the project owner, Ethiopia and the neighbours, including the downstream countries, Sudan and Egypt (EEP, 2018). At the national level, it has opportunities to rise the national water storage capacity, the annual GDP, to expand industries and attract investments, to provide clean and affordable energy, generating additional hard currency and to facilitate the integrated market domestically and internationally in the Nile region. Next, the discussion of the challenges and opportunities of the GERD with its nexus sectors based on SWOT at national level will take place.

2.5.1 The Strength, Weakness, opportunities and Threats of the dam

The GERD is one of the engineering mega projects in Ethiopia which is currently under construction on the transboundary Abbay (Blue Nile) river. Because of that, it could be possible to analyse the internal and external dimensions of the GERD strengths, weaknesses, opportunities and threats.

2.5.2. The strengths and weaknesses of the project

The dam is a multipurpose project, providing clean energy, fishery and tourism (EEP, 2018). According to the plan, the dam reservoir will have a volume of water storage of 74 BCM. It creates an opportunity for the nexus and institutional sector linkage for good governance of natural resources management. In addition, it is possible to transfer technologies and knowledge for the future. Most of the time, such type of mega projects is financed by either the donor grants or loans, but the GERD has not been financed by donors, and rather financed by Ethiopian Electric Power, public donations and bonds. All these are the strengths of the project, because it is possible to apply the nexus approach.

For weaknesses of the project it is worth consulting a not yet published environmental and social impact assessment (International river, 2012). According to the data, the project plan marginalized the responsible stakeholders, institutions and nexus sectors integration to use the dam for multipurpose in a sustainable way. Of course, public participations were not realized besides the ones related to financial donations and visits. Without public awareness, the on-going dam was upgraded twice in terms of the reservoir water volume, the energy installed capacity and the size of its artificial lake. In addition, the estimated cost is expected to be larger than the planned budget.

2.5.3. The Opportunities and Threats

The GERD is an opportunity for the country to contribute to the global efforts to reduce greenhouse emissions (Jusi, 2010). The GERD will contribute to the reduction of greenhouse gas and carbon emission, flood control and water vapour regulation. In the short-term, the dam construction will create 10,000 job opportunities (EEP, 2018). In fact, the dam has opportunities for both intra and inter states because it has a potential to create energy market integration between the Nile basin states and the rest of East African region (EEP,2018). When commissioning the project, the GERD will provide the affordable clean energy necessary.

The Soil erosion from upstream areas of the basin and the subsequent sedimentation in the downstream area is an immense drawback, and is a threat which exists for the future water resources development in the basin (International river, 2014). Therefore, the deposition of large amounts of sediment in reservoirs will be reducing the capacity and lifetime of the dam.

Furthermore, since Ethiopia began the GERD construction on April 2011, Egypt concerned the annual flow of Nile and claims the exclusive rights implementation based on the 1929 agreement signed between Egypt and Anglo-Egyptian (Sudan), shared 48 BCM and 4 BCM; and the 1959 agreement signed between Egypt and Sudan; 55.5. BCM and 18.5 BCM annual flow of Nile river respectively, and the parties estimated that the evaporated water of the Nile would be 10 billion cubic meters (Deng, 2007; Woldegiorgis, 2007). Even though, Ethiopia rejected the validity of the agreements in 1959, because the upstream Nile sources countries were not involved with the two parties' agreement. However, it can be one of a threat to fill the water in the reservoir in a short period of time to use its maximum effort for energy production.

2.6. Adding Sustainability to the GERD nexus

The GERD sustainability assessment mainly concerns the project economic, environmental and social equity impacts and benefits. In addition, as a multipurpose project, it considers a seasonal pattern of water availability, precipitation, evaporation, drainage and other geographical and weather characteristics of the project location (Andrade, et al., 2017).

Regarding the social concern, the Benishangul-gumuz region the project affected area, Metekel Zone has a total population of 276,367 (CSA,2007). Metekel administrative Zone contains the Bulen, Dangur, Dibate, Guba, Mandura and Wenbera Woredas administrative districts. According to the 2007 censuses, the main affected area, Guba Woreda is one of Metekel zone administration part and it has 14,907 inhabitants (CSA, 2007; International rivers, 2012). The project is mainly built in Guba Woreda, and partially the surrounding areas of Wonbera and Sirb Abay woredas are also affected by the water reservoir which will cover 264 km behind the dam (EEP, 2018). The settlement patterns of the GERD indicate direct economic dependence on the rivers, particularly on the fisheries resources, traditional gold mining, semi-agricultural and forest products (International rivers, 2012).

During the construction, the dam has affected three local administrative districts; Guba, Sirb-Abbay and Wonbera woredas. Within the project area, the number of people is 20,000, most of them tribal and indigenous people from different social groups (International Rivers, 2013). Moreover, at the end of the project, there is an expectation that more people will be displaced from the water reservoir and power generating area. Environmental impact assessment is one of the sustainable development criteria of any hydropower project. Indeed, the hydropower project is well-known as environmental friendly energy source, although this can be debatable. It is suitable for the reduction of air pollution, carbon and greenhouse gas emissions. In this case, the GERD would share the common features of most hydropower dams. On the other hand, the Grand Ethiopian Renaissance Dam causes direct and indirect impacts on the biodiversity, particularly in the reservoir area and its surroundings, physical and chemical features of the river and the environment where it is located (Soliman, et al., 2016).

According to the FDRE constitution's article 92 and the environmental impact assessment proclamation number 299/2002, the GERD required an environmental and social impact assessment. The Environmental Impact Assessment proclamation 299 (15) clearly stated that "the Authority or the relevant regional environmental agency shall make any environmental impact study report accessible to the public and solicit comments on it. The authority or the relevant regional environmental agency shall ensure that the comments made by the public and in particular by the communities likely to be affected by the implementation of a project are incorporated into the environmental impact study report as well as in its evaluation."

However, the implementation of GERD neglected the reservoir area biodiversity, because the data did not show that the genetic resources of the biodiversity should be either protected or collected by responsible bodies, which has not been done. In fact, the project planned a top-down approach; it has been lack of voluntarily public participation than forcefully financial contribution and visiting the project, but not allowed to raise the conducted data that shows sustainability impacts and benefits of the project.

The previous terrestrial ecosystems of the reservoir area are being changed into aquatic ecosystems, which means that the dam is creating a new aquatic ecosystem. In the long-term, it is expected that the reservoir's terrestrial biodiversity such as forests, wild animals, insects, birds will either disappear or migrate to the closed border of the neighbouring country, Sudan.

Economic consideration is a central aspect in the decision-making processes associated with the hydropower plants sustainability (Jushi, 2010). The GERD considers not only generating income and raise the national GDP, but also fair distribution of economic benefits to all concerned society at national level (MoFED, 2015). In fact, economic instruments in use to manage the nexus sectors make pollution costly, save investment costs, promote flexibility, allocate water and water-related risks, and stimulate the diffusion of innovation (UNECE, 2015). In the short-term, the project is consuming US$4.8 Billion from the country which affects the national economic activities because the project is fully financed by the nation and the state-owned company, EEP. In fact, during the project construction, the dam has been creating job opportunities for 10,000 employees (EEP, 2018). Indeed, in the long-term it has the potential to generate an income of approximately US$1 billion per year (Drake, 2016), but not yet known the local community benefits.

2.7. Climate change and the GERD

Climate change is an increase in the normal temperature of the Earth's atmosphere and the oceans which are highly connected to greenhouse effects. The main anthropogenic factors of GHG, such as carbon dioxide (CO_2), Methane (CH_4), nitrous oxide (N_2O), Chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs) affect greenhouse gases (Katman, 2014). Indeed, the gases lock some of the thermal energy disseminated through radiation from sun and earth, leading to an increase in the temperature of the Earth's atmosphere.

The biogeochemical processes leading to GHG emissions are very complex and emission measurements are cumbersome (World Bank, 2017). Naturally, there is a biogeochemical process in the atmosphere and the reservoir dam. Nevertheless, the hydropower energy source has a contribution to reducing carbon emission of GHG effect, because it produces environmental friendly sources of energy.

However, the hydropower reservoirs have been estimated to absorb 2.5% of anthropogenic carbon emissions globally (Parek, 2004). In this regard, the GERD would have the contribution to reducing the greenhouse effect. On the other hand, the climate change impact affects the water availability of the dam, then the water supply and energy production will be decreased.

Chapter Three

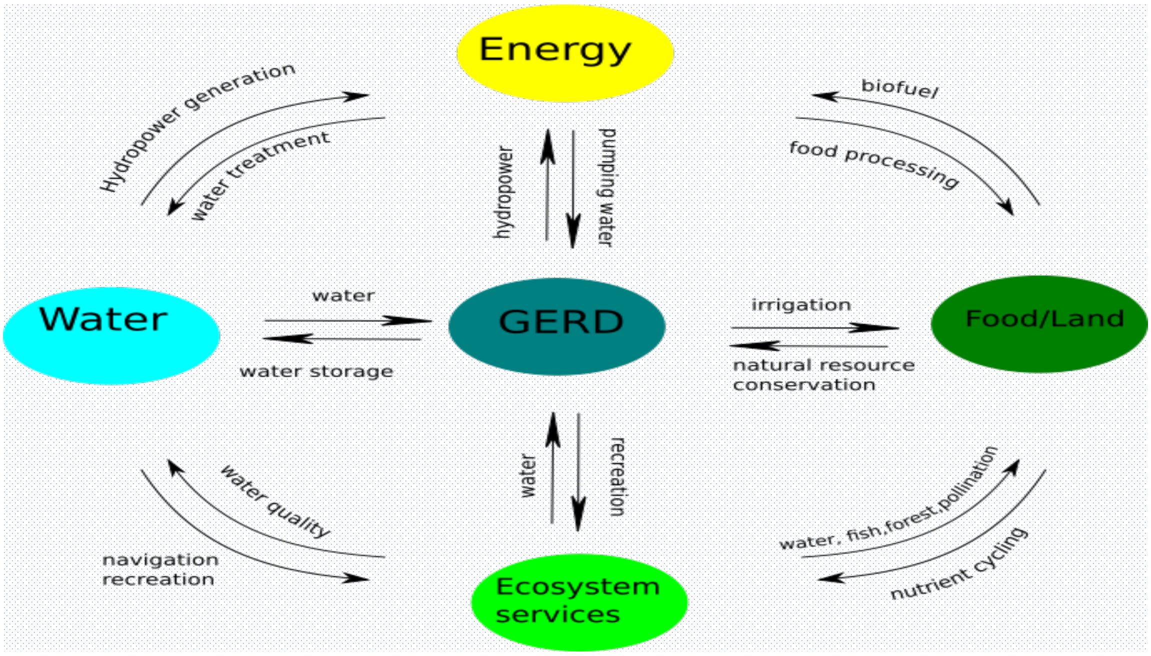
3. Results

The results of this study are obtained from the existing data available on the Grand Ethiopian Renaissance Dam and energy, water, food and ecosystem services connected to it. The data showed that the GERD is a multipurpose hydropower plant for generating electricity and providing fishery and tourism services. The project is owned by the government through the Ethiopian electric power under the responsible body of the Ministry of Water, Irrigation and Electricity. Nevertheless, the project has marginalized the role of responsible institutions and nexus sectors, impacting its sustainability. The project is expected to contribute to other services, including water supply, flood and drought management, irrigation, navigation, fisheries, environmental services and recreational activities, as it is usual for other hydroelectric projects (Branche, 2015).

3.1 Conceptual model of the GERD nexus

The model to analysed the integration of nexus sectors in GERD. In addition, it showed that the importance of institutional cooperation and sectors; energy, water, food and ecosystem services nexus at national level (See methodology of conceptual framework, figure 7).

Figure 9: The analysis of the GERD for sustainable energy-water-food-ecosystem services nexus in GERD



The sectoral linkages of the GERD nexus analysis

The sustainability of the GERD has been sectoral integration and institutional cooperation (see Figure 7 and 9). Moreover, the sectoral nexus has the complex system shows that the GERD directly connected with the energy, water, food/land and ecosystem services (see Figure 10). GERD is the central component of integration, which has a linkage with each of the nexus sectors and created a new aquatic ecosystem. In fact, GERD obtaining water from the ecosystem services which has been provided by natural ecosystems of Blue Nile and its tributaries. Similarly, the GERD is man-made aquatic ecosystem which regulates flood and supports recreational and aesthetic values for natural ecosystems and human well-being. Food or land sector obtaining water for irrigation and the reverse it regulates natural resources conservation which is important to assist water resources management.

The GERD providing water for energy security to produce electricity. Energy sector supports the dam for purifying and pumping water for municipal or agricultural uses. Regarding water security, the GERD supplies water for different uses. The GERD stored water for multipurpose water security; the water security supporting and providing water to the GERD. In addition, ecosystem services regulating flood, providing water for irrigation, fish and support forest and pollination for agricultural land and food security; the irrigated land support the nutrient cycle of the ecosystem services sustainability. Water security supporting cultural, navigation, aesthetic and recreational values to the ecosystem services; the reverse, ecosystem services support the quality of water security and its system.

The irrigation land and food security providing biofuel to maximizing green energy that produced from agricultural wastes and biofuel plants; the energy supporting food processing which helps to enhance production and quality of food security. Water security supply water for hydropower which helps to produce energy that connected with energy security. On the other hand, energy security supports for water treatment to maintain the quality of water that links with water security. In these regards, sectoral integration has potential to enhance the GERD efficiency, reducing environmental risks and climate change impact, then it could be promoting sustainability of the dam.

3.1.1. Energy security

In Ethiopia, energy is the vital issue revolving around development activities. The primary energy consumption is biomass (see Figure 11 b) and accounts for about 91% of the total energy consumption (Tucho, et al., 2014). The biomass is obtained from forests, agricultural areas and from animal wastes. According to the data, the country has 50, 000 MW hydropower energy potential, but the current installed capacity accounts only 3,810 MW with 7.6 % of its potential. In fact, Ethiopia has plenty of diversified energy sources availability.

According to the data, most of the people have been obtained energy from biomass. In this case, the GERD has the potential to enhance the exploitable electricity production in the grid. At the end of the project, the dam is expected to generate 6,540 MW electricity, which would enhance the current electricity capacity grid by 140 % (EEP, 2018; MWIE, 2017) and increase the hydropower share to 95.4 % of total production. However, the capacity of the dam is sized for the average peak flow rate of the Blue Nile river expected to produce 2000 MW (Beyene, 2013), which indicates less than one-third of its maximum capacity of electricity production.

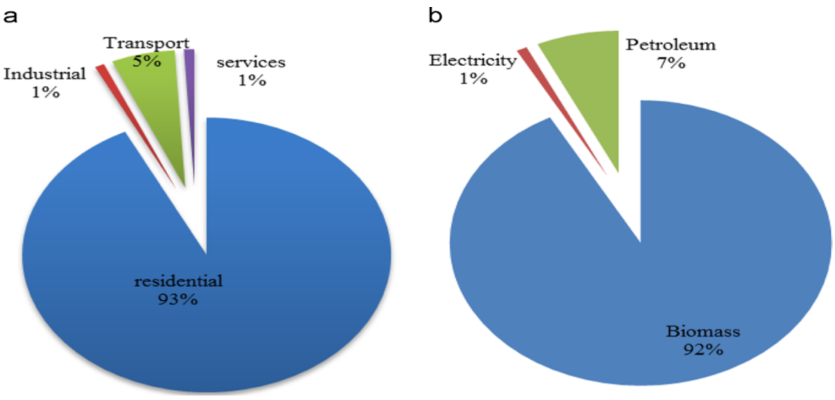
The consumption of energy for productive uses, such as for manufacturing, machineries for agriculture, irrigation and transport is negligible, is less than 1% of the share in total energy consumption of the country (Berhanu, et al.,2017). In this case, many people have been dependent on petroleum energy source for cooking and lightning.

3.1.1.1. Trade-offs for Ethiopian petroleum energy consumption

About 6% of the urban and 0.5% of the rural population use kerosene for cooking. Kerosene is mostly used for lighting and about 8.6% of the urban and 64.9% of the rural use the fuel. However, most of the petroleum used for residential purpose (see Figure 10 a and b). It has an impact on the national energy security and hard currency. The reason that an imported petroleum was estimated to increase by 7.14% in 2015/ 2016 (Berhanu, et al., 2017). Furthermore, 37.5% of the light petroleum products and Liquefied Petroleum Gas has been used by households, and the remaining light petroleum is used for transportation. In these case, the expansion of renewable energy source and consumption diversities are very essential to managed fossil fuel dependency.

In fact, the petroleum contribution per capita consumption is 0.52 bbl per day per 1000 people, whereas the electricity consumption per capita is 46.06 kWh per person, which is lower than in the rest of the world (Berhanu, et al., 2017). However, it consumes more currency than any other imported commodities, which affects the national energy security and the economy as well. The reason that 82% of the petroleum is used for transportation, followed by 12% and 6% usage by the residential and industrial sectors, respectively (Berhanu, et al., 2017). Comparatively, petroleum accounts for 99.8% of the transportation fuel, with biofuel filling the relatively insignificant.

Figure 10: a) Energy consumption sectors b) Functional energy source share



Source: Berhanu, et al. (2017)

The accessibility of the electricity depends on energy infrastructure and its connectivity. Accessibility of energy is a key factor for sustainable development in a modern society. The GoE had been planning to connect the rural community under the universal access program (MoFED, 2010). However, currently, 52 % of the county geographic area has been connected, and 30 % people have accessed electricity in household at national level in 2016 (Awulachew, 2017). In addition to energy availability and accessibility, affordability also affects energy security. Energy affordability is determined by the consumer's income and demand, so the cost of electricity should consider the consumers capacity, income and demand.

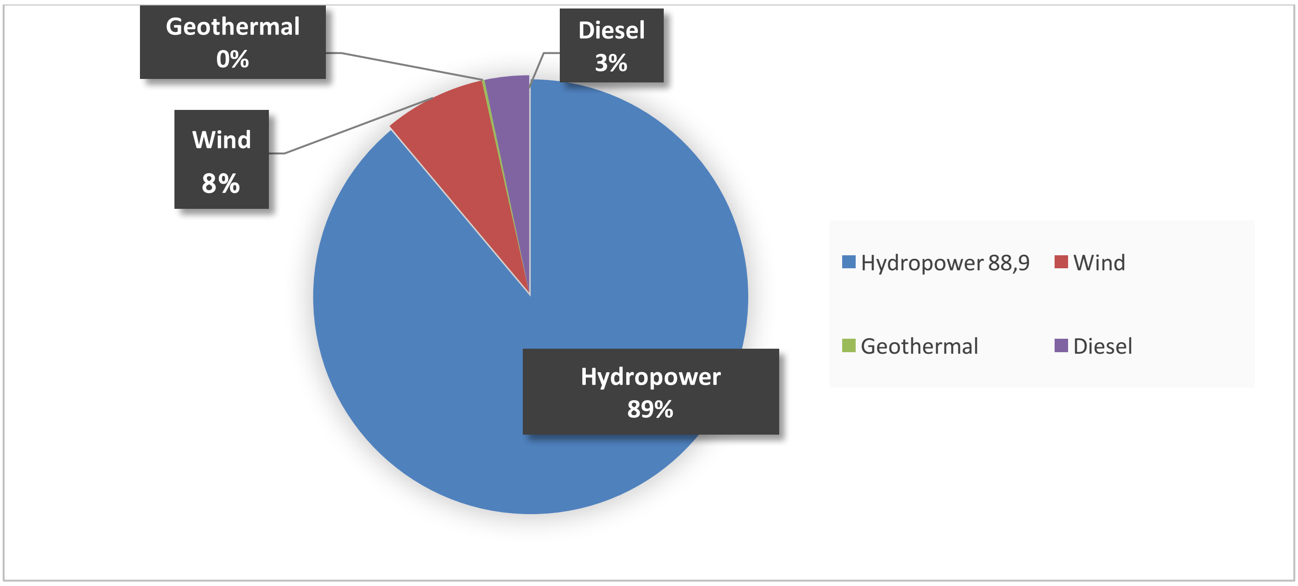
From an environmental perspective, the Grand Ethiopian Renaissance Dam is acceptable because it will not cause environmental air pollution. However, the projects neglect the sustainability of terrestrial ecosystem biodiversity. In addition, there is a gap between the nexus sectors and institutional cooperation. Mainly the project has been done to provide and utilize electricity.

The GERD will be generating clean energy. This offers the potential contribution to reduce and mitigate climate change impacts. The Ethiopian government is expected to earn US$ 1 Billion per year from exporting energy to the region and neighbour countries. It will have an impact on urbanization and industrial development, with the possibility to create jobs and increase production. From the socio-cultural perspective, the GERD has potential to integrate the new ecosystem, minimizing the women burden of collecting and using traditional energy sources, such as wood and agricultural wastes would be possible to replace by the modern clean energy source.

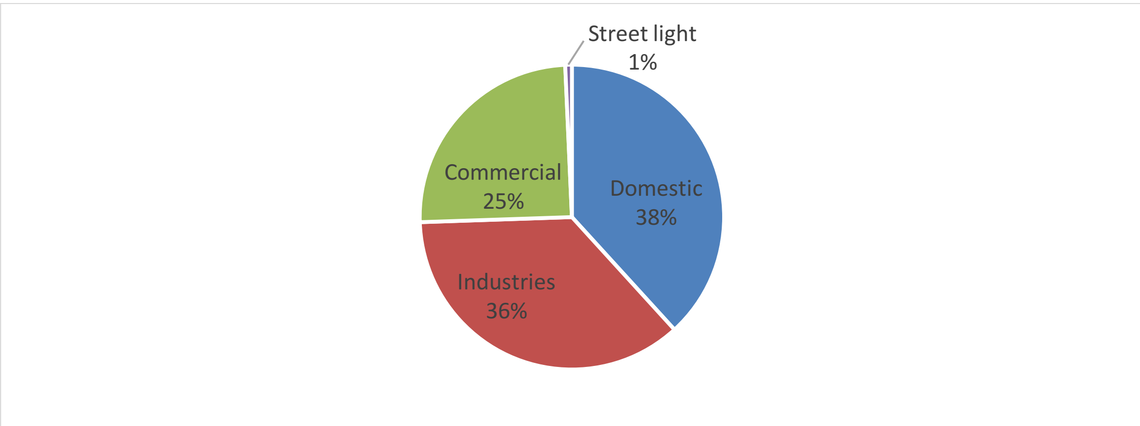
Energy is important for water treatment that connects with water security, which provides safe drinking water to the consumers. In addition, it helps to pump water from the reservoir dam to the arable agricultural area. Lack of water treatment is one of the Ethiopian challenges in providing safe drinking water. In fact, during the construction, the dam is and the reservoir area forests have been destroyed, then it will be changed into new ecosystems that affect the existed environment.

However, at the end of the project, it can be possible to promote reforestation and to conserve the natural resources; otherwise, the dam water availability, energy production, and capacity will not be sustainable. The agricultural and food industries demand adequate, consistent energy supply for their food productions, and the energy of the GERD can be used for this purpose. Currently, the hydropower is the main source of electricity with 89 % (Table 2 and see Figure 11 a) and exploited 95.2 % (see Table 2) of the total grid of electricity production. However, most of the electricity production used for the domestic purpose (see Figure 11 b), following industries, commercial and street lights.

Figure 11: The current percentage of modern exploited electricity sources and consumption in 2017.



a) The national modern electricity production of energy diversity share capacity in the grid, 4, 284 MW.



a) The current modern electricity consumption (Berhanu, et al. (2017).

Figure 12. (a) illustrated that the current diversified modern electricity production sources share in Ethiopia; (b) showed that the electricity consumption share at national level.

Table 2: At the end GERD project, an estimation of Ethiopian electricity analysis

Energy source	Estimated exploitation amount	Estimated exploited percentage
Hydropower	10,362 MW	95.2
Wind	324 MW	3
Geothermal	7 MW	0.07
Diesel	143 MW	1.32

An estimated electricity generation capacity in the grid will be 10,846 MW.

3.1.2. Water security

The country has water resources, but there has been economic scarcity of water resource to use for its national demand. According to the data, the country has 124.4 BCM of river surface water, 70 BCM in lakes and 30 BCM in ground water resources (Awulachew, et al.,2007). The annual flow of the Blue Nile River is 54.8 BCM at the Sudan border. The GERD will have 74 BCM water storage, which increase the annual water resource storage at national level. In this case, the grand Ethiopian renaissance dam will have a significant impact on the water storage capacity of the country.

In Ethiopia, the water storage per capita is only 43 m^3 and the goal should be 755 m^3 per capita like in South Africa (Melesse, et al, 2014). In fact, water resources have linkage with other sectors, particularly food production, because the country is located on the El Niño drought affected area with insufficient annual rain water (Mohamed, 2017). Consequently, 27 million Ethiopians became food insecure because of the 2015 drought and 18.1 million were dependent on relief food assistance in 2016, of which 7.9 million were supported by the Ethiopian government Productive safety net program (Mohamed, 2017).

The majority, 92 % small household farmers are totally dependent on season rain-feed agriculture (FAO, 2016). As a result, a large portion of the country's population has been affected by food insecurity. In addition to generating electricity, the dam makes it possible to provide water supply services for surrounding livestock, industry and other water users' demand.

However, it will take 5 to 7 years to fill the water in the reservoir for producing its maximum energy capacity (International river, 2014). The reservoir is important to supply water for energy, irrigation, safe drinking water, fishery and other municipality and domestic utility services. In addition, it has the potential to control flood and to manage land use change.

3.1.3. Food security

The average Ethiopian annual population increased by 2.5 % every year since 2000 (World Bank, 2016). Similarly, the human population continues to increase rapidly, and there has been an expansion of diverse human activities that have dramatically reduced cropland and pasture land (Pimentel et al., 2009) for cash crop and biofuel purposes. In this case, the rapid population growth affects food availability, because the food production is uneven compared with the demand.

In fact, in Ethiopia poverty-environment linkages are related to: lack of access food, safe drinking water and for other uses water, environmental health concerns related to malnutrition, polluted water and indoor air pollution; vulnerability to natural disasters and climate change; lack of secure tenure to land and other natural resources (César and Ekbom, 2013). The country food supply is highly seasonal and is largely dependent on local production, cereal imports by the GOE, and food aid imports (FEG, 2015).

The agricultural sector represents 42.3% of the GDP of the country and about 87% of the country's population earns their livelihood through agriculture (Berhanu, et al., 2017). The Blue Nile River has the potential of 977,915 for irrigation to increase food production, but the country uses only 21,010 ha land, one percent of its water resources (Alemu, et al., 2008). Therefore, the GERD will also have potential to enhance irrigation and agricultural products at national level. Ethiopian food security is highly connected with water scarcity, because the country is located on the El Niño drought affected area with insufficient annual rain water (Mohamed, 2017).

The agricultural land area increases every year, but food production fluctuates. Moreover, the Ethiopian agriculture appears to be locked into a downward spiral of low and declining food productivity, caused by an adverse combination of agro-climatic, demographic, economic and institutional constraints, trends and shocks (Stephen, 2000). However, since 2000, the annual food production changed between -0.36 % and 1.8 %. On the other hand, the arable agricultural land was transferred to commercial investors for biofuel production from sugarcane, Jatropha, palm oil and castor seed (Beyene, et al., 2011). This affects 92 % smallholder local farmers, because biofuel land competes with agricultural food production.

On the other hand, Ethiopia is rich in water resource potential for sustainable food production, but this is only used in less than one percent (Alemu, et al., 2008). In addition, Blue Nile river has potential for irrigation to maximizing food production, yet the country irrigated 2.1 % in 2008 (See Table 3). As a result, a large portion of the country's population has been affected by food insecurity.

Blue Nile river has potential to use irrigation in Ethiopia, which is important to enhance food production (See Table 3). Nevertheless, the country irrigated 2.1 % of its potential (Alemu, et al., 2008).

Table 3: Ethiopian major river basins potential and irrigated areas

River basin	Irrigated potential (ha)	Irrigated land (ha)	Irrigated %
*Abbay (Blue Nile)	**977,915**	**21,010**	**2.1**
Awash	204,400	69,900	34.2
Omo-gibe	450,120	27,310	6.1
Wabi-shebele	204,000	20,290	9.9
Rift Valley	122,300	12,270	10
Genale-dawa	437, 300	80	0.02
Baro	748, 500	350	0.05
Tekeze	312, 700	1,800	0.07
Dankhel	3,000	-	-

*Abbay (Blue Nile) river. Source: Alemu, et al. (2008).

In Ethiopia, food accessibility decreased between 2000 and 2016 from 362 k calories per capita per day to 201 k calories per capita per day (FAO, 2016). However, because of the poor infrastructure and economic disparity, many of the poorest people live in the rural area that they disconnected from the national and global market (Godfray J. et al, 2010). In fact, the urban poor societies also affected by food price and its quality. In this case, in Ethiopia not only lack of sufficient production but also its quality of healthy diet affect food security, even the country has progressed in food utilization especially, children under 5 years of age stunted 46.7 % in 2000 reduced to 28.8 % in 2016 (FAO, 2016). As a result, Ethiopia ranks low compared to the global food utilization standard.

The GERD has potential to use irrigation for an agricultural purpose and thus increase the national food production. In addition to food security, the irrigation has impacts on increasing biofuel energy production, but it has been affecting food security because it competes with agricultural food production. In fact, agricultural land not only produces food, but also facilitates the nitrogen cycle for soil formation that is important for controlling land degradation and ecosystem services. In addition, it has given a good opportunity to conserve and govern water and natural resources. In this regard, the security sector has the linkage with energy, water and ecosystem services.

3.1.4. Ecosystem services

The hydropower is highly connected with the natural ecosystem, which provides the ecosystem services. The ecosystem services to maintain and support the water supply for the dam. In this case, the dam would be the vital to conserve and manage the water and land recourses properly. For example, afforestation and soil conservation have reduced sedimentation and increasing water flow from different tributaries to the dam. However, the data did not show that GERD realized the ecosystem services contribution for its sustainability.

Moreover, the ecosystem services have linkage with the sectors; energy, water, food and the reservoir. The dam contributes to energy security and to supply and maintain water resources. In addition, it limits erosion and land degradation, retaining and reducing sedimentation; because the Blue Nile basin highlands have been affected by soil erosion (Melesse, et al.,2014). The ecosystem services also have an impact on the water sector and GERD to maintaining water resources, water quality, minimizing sedimentation. Regarding the food sector, it supplies water for irrigation, pollination for plant reproduction, fishery and forestation.

3.2. The challenges and opportunities for Sustainability of the GERD (SWOT)

Sustainability assessment is mainly concerned with the interaction between the pillars of sustainable development of the dam. Naturally, hydropower does not discharge carbon pollutants into the environment, but methane. Therefore, it does not mean that they are free from the adverse of environmental effects. However, the GERD has internal and external challenges with threats and opportunities (See Figure 8).

The reservoir area forests have been cleared. As a result, forests, wild animals and other biodiversity are being destroyed and are disappearing from the reservoir area. This alters the project and its surrounding area ecosystem. Consequently, it is affecting the local environment significantly. However, the GERD has its own strength, weakness, opportunities and threats (see Table 4) that depends on the nexus sectoral integration and institutional cooperation that associated with the dam.

Moreover, at the end of the project, there is an expectation that more people will be displaced from the water reservoir and power generating area. The local communities' livelihoods dependent on the project area land and water, and they get their food source, shelter and income from it. In addition, their culture and life totally depend on the land and its resources. The other challenge, filling the water in the reservoir, it could take 5 to 15 years (Conniff, 2017), for a decade which would be affected the dam water storage, supply and energy production.

Table 4: The SWOT Analysis of GERD

Internal		External	
Strengths	Weaknesses	Opportunities	Threats
Renewable energy source Reduced carbon emission	Poor environmental and social concern Neglected biodiversity	Local and national Institutional cooperation and coordination	Climate change and water scarcity

Promising increasing GDP	Marginalizing institutional cooperation and coordination	Market integration	Downstream countries Security challenge
Financing by the nation and the state	Weak nexus sectoral integration	Maximizing agricultural and industrial production	Lack of financial grant or loan
Multipurpose	Lack public participation	Mitigating, adapting and resilience of climate change	Filling the water to the reservoir time
Build trust between institutions	Lack of transparency and responsibility	Earn foreign currency	Anthropogenic and natural Uncertainties

3.6 The GERD to sustainability: the SDGs and climate change

The hydropower dam has a varied contribution for the UN sustainable development goals at national and global levels. Indeed, the intent for multipurpose in hydropower reservoirs is to ensure that positive aspects are maximised and negative impacts avoided, minimised, mitigated or compensated (Branche, 2015). Therefore, the GERD is promising in order to achieve some of the UN Sustainable Development Goals (SDGs) at national level.

The applicable sectoral integration of the GERD would have the contribution to some of the UN 2030 agenda of SDGs (UN, 2015), such as:

(i) Producing affordable and clean energy (SDG 7).
(ii) promoting sustainable cities and communities (SDG 11).
(iii) producing energy for the expansion of industry, innovation and infrastructure because these sectors are important driving factors of economic development and employment (SDG 9).
(iv) The reservoir supply water and energy for the use of clean water and sanitation, which has an impact to minimize water scarcity for the local municipal purpose (SDG 6).
(v) The production of sufficient clean energy attracts more investments, then possible to decrease unemployment rate for decent work and economic growth (SDG 8).
(vi) The reservoir can be used for irrigation that has a positive impact on maximizing food production, then possible to reduce poverty and hunger (SDG 1 and 2).
(vii) Producing clean energy, which has contribution to reduce carbon emission that connected with climate action (SDG 13).

However, it has a negative impact on life on Earth because of its construction and the reservoir, the existed forests and other biodiversity destroyed (SDG 15). As a result, the dam affects the local environment and the terrestrial ecosystem. In addition, without proper consultation and adequate compensation, the indigenous communities those who have been there would be displaced (International river, 2012).

Climate change affects the degree and pattern of precipitation, temperature and water availability (Desai and Potter, 2014). The GERD has an impact on climate action. The reason is, that it provides clean energy, avoiding air pollution and mitigates the climate change response. In fact, climate change is the long-term weather variation that affects the living organism and our planet. The dam contributes to the reduction of greenhouse gases because, during operation, its carbon emission is very low when compared with other sources of energy. In this case, the GERD is promising for climate change contribution to minimizing carbon emission because the hydropower plant regulation of water flow may be important to climate change adaptation (IEA, 2012).

Moreover, the multipurpose stored water in the reservoir could help adapt to climate change; hydropower is climate-sensitive and it is also very important for the energy security and economic development of the country because the water flows are vital for healthy ecosystems and their services (Branche, 2015). Contrary, the reservoir dam, it would have a contribution to emit CH_4 from the decomposition of biogeochemical cycles in the reservoir. In this case, the fraction of carbon entering reservoirs that are converted into CO_2 and CH_4 and then released to the atmosphere (Parkeh, 2004). Therefore, it needs further study to quantify the climate impact of the GERD and how it affects the supply of nutrients to the biogeochemical cycling in the reservoir dam to affect the atmosphere.

Chapter Four

4.Discussion

The literature review of this study showed that GERD is suitable to apply the nexus sectors integration. However, in the Ethiopian context without concerned institutional cooperation and coordination, opportunities will not be maximized. For example, the state-owned company, Ethiopian Electric Power is the responsible organ of the dam and for its energy production and supply. The institution is accountable to the Ministry of Water, Irrigation and Electricity. The Ethiopian Electric Power is a part of the ministry department. In this case, another sub-department; the water resource management and irrigation has not played a role, although they are one of the main responsible departments for related issues. According to EEP (2018), the primary objective of the dam is producing energy and, as a secondary for fishery and tourism. However, Ethiopian electric power and even its Ministry office are not responsible to manage and facilitate fishery and tourism. In Ethiopia, the Ministry of Agriculture and livestock is responsible for fishery; and that of Culture and tourism are responsible to facilitate and administer tourism sectors.

According to the GoE (2018) power structural overview, the GERD sectoral interaction share would be taken by responsible institutions, such as Ministry of water, irrigation and electricity (MoWIE); Ministry of environment, forest and climate change (MoEFCC); Ministry of agriculture and livestock (MoAL), Ministry of culture and tourism (MoCT) and Ministry of Construction (MoC). Each government organ has significant relevance on the implementation of the Grand Ethiopian renaissance dam sectors integration for sustainable energy, water, food and ecosystem services. It would be recommendable and possible to cooperate and coordinate between these institutions. I recommended that the ministry of water, irrigation and electricity can manage the dam construction, water resource, electricity production. The agriculture and livestock ministry can take the responsibility of land management, agriculture for food production and processing, and fishery.

The Ministry of environment, forest and climate change is the responsible organ to manage on environmental and social impact assessment, biodiversity protection, climate change mitigation and resilience. Since the planning of the project, MoEFCC should have been involved in the project, because it is the responsible institution to protect and collect biodiversity resources of the existed terrestrial ecosystem and the new aquatic ecosystem of the reservoir and its surrounding area. Moreover, it has responsibility to manage the Blue Nile river catchment area ecosystems and its provision of services. The Ministry of culture and tourism is responsible to maintain the communities' cultural interaction and tourism in a sustainable way. Otherwise, if the whole dam responsibility is taken by a single institution, it will be an additional burden because it might have not strong enough financial, human and natural capital. As a result, it is difficult to maintain the sustainability of the GERD.

Institutional cooperation and coordination are important to share and manage the natural resources properly. In addition, they have the potential to facilitate and manage the nexus sector in the GERD. Indeed, each institution has inputs to and expects products from the dam. In this case, they should work together based on their duties and responsibilities on the project. The cooperation and coordination of institutions have an impact on the integration of the nexus sectors. The institutional cooperation and nexus sectors integration have the potential to promote sustainability, maximizing productivity, minimizing negative impact and waste material, creating opportunities for sharing duties and responsibility, promoting climate resilience, maintaining the ecosystem and managing natural resources properly.

4.1. Energy

Enhancing energy supply and production does not the guarantee for energy security and sustainability, because it requires sectoral integration when promoting sustainability. Currently, it is estimated that over 15 million households rely on traditional biomass for cooking in Ethiopia. In this case, hydropower energy can reduce carbon emission, deforestation, traditional biomass energy because both rural and urban communities, it is women and girls who cook and spend time near the fire.

The GERD will provide clean energy that could be used for cooking and would significantly reduce the disproportionate health burden of indoor air pollution on women. The renewable energy production supported programs could be reduced the women burden and kitchen drudgery, because firewood collection, water fetching as well as grinding grains are consuming time and affecting the women health (MoWE, 2012).

Based on the national GDP per capita income, clean energy demand is high but it is not affordable, particularly for low income consumers and those who live in rural areas. Comparatively, Ethiopian electricity cost is more expensive than in the neighbouring Sudan. On contrast, Sudanese GDP per capita income is higher than Ethiopian with US$ 2,400, US$ 700 respectively. In this regard, the electricity cost should consider the societies income. Otherwise, energy availability and accessibility is not guaranteed to enhance energy security and affordability can impact energy supply and production.

4.2. Water security

The management of water resources in an effective, efficient, equitable and sustainable manner is necessary to maintain hydropower production and national water demand.

The dam will have large volume of water stored as it increases the national water amount and supply. It has an opportunity to attract the local farmers to use irrigation for agricultural investment, but it requires energy and water pump technology, because at the downstream of the dam there is not a large amount of land that suitable for irrigation. Even though, in Ethiopia, water security is highly connected with water scarcity because 92 % of farmers are dependent on water from the rainy season. The dam will be a driving factor for water resource management. The dam creates the opportunity for riparian countries to cooperate and coordinate work together on Nile basins.

4.3. Food security

The reservoir water is important for the supply of water for irrigation to maximize food production. However, the GERD was not planned for irrigation (EEP,2018). Ethiopia has not only an energy security concern, but also a food security one. However, food security has not been considered when designing or constructing the dam. Moreover, the agricultural sector is the main contributor of the national GDP with 46 %.

Food security is one of the main challenges in Ethiopia. Some of the root causes of uneven national food production is water scarcity, unfair distribution of land, lack of knowledge and agricultural technologies and climate change impact of drought. Furthermore, 90 % of farmers' agricultural processes are dependent on season based annual rainfall. In this case, GERD has potential to enhance Ethiopian water storage capacity, irrigation system and agricultural production. However, the agricultural investment close to the reservoir is not recommended, because during the rainy season and flooding, the chemicals would affect the quality of the reservoir water and the life of aquatic ecosystem in the reservoir and downstream. However, small-scale organic farming has the potential to minimize water quality impact.

4.4. Ecosystem services

The reservoir hydropower has been dependent on the natural ecosystems, which provides services for the benefits of it. On the other hand, the GERD would have the negative impact on the existed terrestrial ecosystem of the reservoir area, because the project did not have evidence that concern of the authorities for the impacts on the terrestrial biodiversity. Unless the dam is concerned about the sectoral linkage, including ecosystem services, indeed, the GERD's available power output, based on the mean flow rate (the average of river flow throughout the year) and the dam height (145 meters), is about 2,000 MW (Beyene, 2013) because the energy production directly dependent on the annual water flow and availability. Therefore, the dam should consider the impact of ecosystem services to maintain the sustainability of its maximum energy production capacity. Similarly, the quantity of water correlates to ecosystem services; to providing, supporting and regulating the availability of the water.

The GERD should consider the quality and sustainability of water ecosystem. Currently, the lake Tana, 10 % contributor of Blue Nile river invaded by dangerous invasive alien species of aquatic weeds, water hyacinth (*Eichhornia crassipes*), which dramatically increases its surface area. Consequently, it affects navigation, water flow, recreational use of aquatic systems, and poses of mechanical damage to hydroelectric systems (Admas, et al., 2017), which is possible to connect the GERD water quality and sustainability.

Moreover, the invasive alliance species of water weeds, including water hyacinth and the eroded area sedimentation will have a negative impact on minimizing the quantity and quality of water flow. Consequently, water supply and energy production will be decreasing, because the ecosystem services are highly connected with sustainable hydropower plant. In this case, without proper management of ecosystem services in natural resources, clean and renewable energy is not a guarantee for sustainability of the dam and sustainable development in general.

4.5. The Challenges and Opportunities of the GERD

GERD has financial challenge because the project not yet got either grant or international loan. In addition, the threat, the riparian countries, particularly Egypt has concerns about the water volume and Nile flow that would reach Aswan dam when constructed and operated. In this case, Egypt claimed exclusive right of 1929 and 1959 agreement that signed between Britain and Egypt, and Sudan and Egypt respectively (Woldegiorgis, 2007). However, the upstream countries, including the major source, 86% Nile river sources shared, Ethiopia have not been accepted any agreement that marginalized the Nile source countries benefits.

Egypt concerned about the maintaining of the flow of Nile and the reduction of the GERD water volume and its filling period. In fact, it is not a guarantee for sustainable water flow, because in addition to anthropogenic factors, also natural disasters and climate change have impact on the flow and volume of water in the Nile. For example, Egypt faced water scarcity in the year of 944 to 953, 1059 to 1066, 1180 to 1182 and 1201 (Woldegiorgis, 2007). Nevertheless, at that moment the Nile source countries, including Ethiopia, had not been water resource development activities on the river. However, since 2011, the Nile basin countries have started looking for new alternative ways of sustainable water supply, which is cooperative water resource management.

In addition to securing national energy demand, it has opportunities for integrated water resource management at national level. In addition, it will be creating local and regional power infrastructure connection, market integration, institutional and states cooperation for common interests. The other challenges of the GERD are environmental problems that connected with the climate change uncertainties, soil erosion, deforestation and aquatic system disturbances, such as water weeds and sedimentation.

4.6. The benefits of nexus sectors integration in GERD

The nexus sectors; energy, water, food and ecosystem services integration and institutional cooperation would have several sustainability benefits. The sectoral integration is not only enhancing the efficiency production and natural resources management, but also it builds trust among the responsible institutions and stakeholders. (UNECE, 2015; Branches, 2017). In this regard, economically, it protects and increases viability of economic activities, such as fishery tourism, energy security, water supply and revenue from energy and agricultural product markets. In addition, it contributes to increase the capacity of climate change adaptation, named drought control capacity, resilient and diversified energy and agricultural sectors. Similarly, it has potential to decrease the economic costs of infrastructure developments and water related hazards, including flood. In the long-term, it is promising for sustainability of the national economic growth, GDP.

The dam would have environmental benefits, such as improving the status and suitability of the new ecosystems, water quality, reducing greenhouse gas and carbon emission and its related impacts. Social benefits expected are the empowerment of gender equality, reduction of poverty, protecting resources based livelihood, increase the accessibility of sustainable energy and water supply. In this regard, the dam completion with the application of sectoral integration and institutional cooperation; indeed, it has the potential to provide sustainable energy, water, food and ecosystem services.

During the construction, the burning of the reservoir forests releases CH_4 gas into the atmosphere (Teodoru, et al., 2016), which has an impact to affect the climate. In addition, during the hydropower operation, the dam has a potential to buried carbon and methane through the aquatic biogeochemical cycle. However, it needs further study to know about its contribution to increasing of GHG effects in the atmosphere that associated with climate change impacts.

Therefore, GERD has a significant role to produce clean energy which contributes to reducing carbon emissions. In addition, it would have an impact on minimizing the air pollutant from the burning of fossil fuel to generate electricity in the national grid system. On contrary, unless the responsible to take sustainability measurement, the dam will be affected the climate change that directly connected with water availability and energy production. Trapping of riverine input of sediments and nutrients by dams can affect the long-term silica budget of the oceans, decreasing the effectiveness of the biological pump that sequesters CO_2 in deep waters (Parekh, 2014).

Chapter Five

5. Conclusion

In this project, I analysed how could the GERD be used for sustainable energy, water, and food security in Ethiopia. I also discussed the challenges and opportunities to use the GERD as a more expanded multipurpose project besides hydropower, fishery and tourism.

The Grand Ethiopian Renaissance Dam has the potential for sustainable energy, water, food and ecosystem services generation. Primarily, the objective of the dam is to maximize the capacity energy production from hydropower source. Secondary, to be used for fishery and tourism purposes. In this regard, GERD is multipurpose hydropower project. The dam has not been applied the nexus sectors integration and institutional cooperation. In addition, the project, not yet considered the importance of nexus sectors integration for sustainable output. Nevertheless, it has potential to applied nexus sectors integration and institutional cooperation for sustainable product. The reason that the dam will be creating artificial lake with 74 BCM of water storage. In addition, it has 246 km. length behind the dam, which has been creating some opportunities to contribute the nexus sectors integration at local and national level as well.

In fact, at the end of the project, Ethiopian hydropower energy production will account to 20.0% of the total grid electricity. However, according to the data collected and analysed in this project, there has not been institutional cooperation and sectoral integration in the construction and planning of the GERD at local and national level. Moreover, if there has been the participation of responsible institutional cooperation and coordination, indeed, it was possible to apply nexus sectors; energy, water, food and ecosystem services integration with the grand Ethiopian renaissance dam, but not yet applied on it.

The advantages of the GERD project include an impact on climate change mitigation and agricultural resilience because it will be producing clean energy and is suitable for irrigation. Regarding water security, the dam has the contribution to increase the annual storage capacity with 74 BCM that can supply water for multipurpose. The project has also weaknesses, especially, during the implementation of the dam, economically, it has an impact on the financial resources of the state and the public; environmentally, it affects the existing terrestrial ecosystem biodiversity, and socially, the local and indigenous communities that have to displaced without adequate consultation and participation.

In the long-term, it will have economic benefits for the energy market. Nevertheless, in the short term, it has been consumed more finance ever in the country's single engineering project, which affects the national economic activities. However, the researcher had not been got environmental and social impact assessment at local which conducted by the owner and the responsible institution of the dam. Moreover, its sustainability would be determined by sectors integrations, particularly, energy, water, food or land and ecosystem services nexus, because each sector is depending on the other. In this case, it is possible for maximizing the project efficiency, minimizing environmental risks and saving extra economic cost.

Regarding the challenges, it has financial, knowledge, experience, political instability, lack of accountability, transparency, institutional capacity and security challenges. In addition to the assessment of environment, economic and social equity; the construction quality and process have factors on the sustainability of the hydropower plant. In this regard, the state-owned military company, METEC has not been experienced even to installed electromechanical work or construction on small hydropower project because without any official public biding it has been taking the major portion of the project contract, including to installing electromechanical work, clearing forests from the reservoir and steel structure works.

The dam has opportunities for regional energy market integration and water resource cooperation. Furthermore, it would have the uncertainty of climate change, water flow sustainability, and security threats from riparian countries, particularly from Egypt, because the project has been building on one of the controversial transboundary river, the Blue Nile which accounts 62 % of the Nile river share. In addition, the negligence of the ecosystem services, interaction, values and significances, the GERD would have been affected by soil erosion, sedimentation, flooding, aquatic weeds. As a result, the sustainability of water supply and energy production would be affected. In general, the proper management of natural resources and ecosystem services interaction with the GERD and its sectors can be determined the sustainability of the project. The dam has the contribution to sustainable development in environmental, economic and social perspective. Moreover, it needs further study about the dam overall sectoral integration significance of the water flow sustainability with the Nile basin environment and biogeochemical cycle in the reservoir. Indeed, the project is highly connected to environmental sustainability and climate change resilience. However, producing clean energy is not a guarantee for sustainability, because it has negative impact on the existed biodiversity, terrestrial ecosystem and the local communities.

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