Ethiopian power grid

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Ethiopian Power Grid

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Introduction
Ethiopia, mostly known in Europe for the famine, has been one of the fastest growing economies in the world the last few years in their GDP. In spite of their strong growth, their GDP per capita is one of the lowest in the world. Energy is one of the essential components for development and in reducing poverty, which is one of Millennium Development Goals (MDG). The challenges in Ethiopia are common in many other countries in Africa, few households have access to modern energy (including electricity), poor reliability and power quality of the electrical grid. The current situation is degrading the flora around villages and cities, because most households use biomass for light and cooking. On the other hand Ethiopia has been blessed with an abundance of natural and renewable resources. In this report, we will look at the current situation and future plans of the electrical system from generation, transmission till distribution in Ethiopia.

In chapter 1 talks about Ethiopia and the current situation in general, the grid and the connectivity of households to the grid. Chapter 2 will continue with the goals set for the electrical grid by the government. Chapter 3 will go deeper in the generation possibilities in the country. Then in chapter 4 will take a closer look at the local distribution level. Chapter 5, will look at the global transmission level, the interconnection through HVDC lines between Ethiopia and their neighboring countries and the East African Electrical Hub. Chapter 6 finishes with a closer look at the reliability and the power quality of the electrical system in Ethiopia.
1. ETHIOPIA Current status

Ethiopia, is located in the horn of Africa on a high plateau with mountains divided by the east African rift valley. The great diversity of terrain determines wide variations in climate, soils, natural vegetation, and settlement patterns. The country has a multi-ethnic population of 91 million inhabitants (83% rural) living on area of 1.097 million km². The estimated population for 2030 is 130 million people (Federal Democratic Republic of Ethiopia, 2012). Although most people live in rural areas, there is a trend of urbanization. More people move to urban areas like the capital, Addis Ababa. The climate of Ethiopia ranges from deserts, tropical forests till moderate temperature areas. Just as the rest of Africa, Ethiopia is blessed with certain natural resources. It has abundant amounts of sunlight, water and wind for possible renewable energy sources, but also some sources of natural gas, coal and biomass.

![Figure 1](source: Unknown)

From 2004 till 2009, the economy of Ethiopia was one of the fastest growing countries in the World, growth has decreased over the last couple years. In spite of recent growth the GDP per capita is one of the lowest in the World. Most people live from agriculture, based on human and animal power. Their domestic energy is mostly met by biomass, in the form of wood, animal dung and agricultural residues. Biomass accounts for 88% of the total energy consumed in the country. In urban areas 75,3 % of the residents use electricity for lighting, while in rural areas kerosene 80.1% and firewood 18.5% are predominant. In rural areas electricity is not common in many villages. Access to electricity in rural areas is about 1%, for whole the country this is 10% (Erbato & Hartkopf, 2011). Annual per capita consumption of electricity is 100 kWh per year (Ministry of Water and Energy, 2012), when 500 kWh per year is considered the average minimum level consumption per capita for reasonable quality of life (EEPCO, 2007). In the Netherlands, the average use of electricity per person was around 7000 kWh in 2010 (Google).
The installed power generation as of January 2012 was 1937.1 MW, from which 93.1% came from renewable sources (Ministry of Water and Energy, 2012). In the Netherlands, the installed capacity is around 22 GW, with around 9% coming from renewable sources in 2009 (CBS). The main source of electricity in Ethiopia is from hydropower, with 1850 MW installed. The power is distributed mainly through interconnected system (ICS), this is the main grid. A small part is distributed through self-contained system (SCS), small mini grids (Ministry of Water and Energy, 2012).

As of 2007, there were around 8000 km transmission lines and around 72000 km distribution lines installed (EEPCO, 2007). The Netherlands have more than 12,000 km of high voltage transmission lines. Then there is also the problem of the poor design of the distribution network, which is responsible for high losses between generation and consumption of electricity (Ministry of Water and Energy, 2012). The current situation of the electrical grid can be summed up with a lack of access for consumers to the electrical grid. For those consumers that do have a connection, experience low reliability in the form frequent interruptions and poor power quality.
2. Future goal

The current problems in Ethiopia with the electrical energy system are being recognized by the government. One of the programs launched by the government to increase the access to electricity is the Universal Electricity Access Program (UEAP) to be implemented by the Ethiopian Electrical Power Cooperation (EEPCO). Besides programs to increase the electrical grid within Ethiopia, there are plans to interconnect the grid with neighboring countries, through HVDC lines and form the East African Power Pool (EAPP). Other projects are underway to address the issues of reliability, mostly large hydro power plants are built to increase the power capacity.

This chapter will first explain the economy in relation to the current situation of the electrical grid and the future plans. Second, the technical and electrical issues related to the current and future plans. Third and last the impact of the current and future plans on the society and the environment.

2.1 Economic

The current situation limits the economic growth of the country in several ways. First the limited access to electricity, hampers the informal sector. The informal sector consists of small and micro enterprises, which are not registered. This sector is an important source of employment and form the main source of income for the poor. A large part of their profit goes to energy costs (Karekezi & Majaro, 2002), for which at the moment mostly kerosene and charcoal are used. These forms of energy are more expensive compared to electricity, because they are low quality fuels and are purchased in small quantities at the end of the supply chain. The problem with electricity are the very high upfront cost of connection, especially for the poor. This could be solved by spreading out the fixed cost over a longer time and the introduction of compact ready boards. The importance of electrification can be found in a dramatic increase of enterprises in the informal sector, which offer a variety of services (Karekezi & Majaro, 2002).

Second, rural areas suffer from so-called “vicious circle” of energy poverty. Their lack of energy means that it’s difficult to operate machine and so they achieve low productivity. Which results in small profits, from which it is hard to buy improved energy services. Their dependence on the use of firewood for cooking and light, further degrades the surrounding natural resources (Ministry of Finance and Economic Development (MoFED), 2006, p. 137)

Third, there is the cost of poor reliability and power quality, which limits the economic growth. In Ethiopia, electric power interruption is becoming a daily phenomenon (Tesega G., 2011). Frequent power outages result in significant losses in forgone sales, and damaged equipment. Power outages impose significant costs on business (Foster & Steinbuks, 2009).

The goal of Ethiopia is to become a middle income country in 20 – 30 years. The growth should come from industrial development (Embassy of Japan in Ethiopia, 2008). To achieve this, a stable supply of green energy is required. Ethiopia has set the objective to transform Ethiopia into climate resilient green economy by 2025 in the Climate Resilient Green Economy (CRGE ) Strategy. This means to become carbon neutral by 2025. This is based on four pillars. First improving the crop and livestock production practices to increase food yields, hence food security and farmer income, while reducing emissions. Second, protecting and re-establishing forests for their economic and ecosystem services, including as carbon stocks. Third, expanding electric power generation from renewable sources of energy fivefold over the next five years for markets at home and in neighboring countries. Fourth and last pillar, leapfrogging to modern and energy-efficient technologies in transport, industry, and buildings (Federal Democratic Republic of Ethiopia, 2012).

The Growth and Transformation Plan (GTP) policy Matrix is a benchmark set in place for the government since 1996 as Monitoring and System. It tracks several key indicators for several sectors
of the economy, including the energy sectors. It provides the government a way to check the progress made on targets set in the future.

Ethiopia is experiencing increased energy consumption and demand. To meet these demands Ethiopia by providing sufficient and reliable power supply that meets international standards. This will be achieved by accelerating and completing the construction of hydroelectric power and other energy generation projects. By expanding and strengthening the existing transmission and distribution lines to provide improved access to rural villages all over the country (UEAP). Modernizing the distribution system to reduce power losses (Ministry of Water and Energy, 2012).

Electricity demand has a historical elasticity of 2.15 to changes in GDP. EEPCo forecast a 17% electric energy demand growth for the coming years. With a GDP growth of 7-10% (EEPCo, 2011).

Ethiopia imports all of its oil, a surge in oil price, increases the governments costs to almost equal the country’s income of exports. Worsening the account balance of the government. Exporting the surplus of electricity to neighboring countries, is a good way to improve the account balance (Embassy of Japan in Ethiopia, 2008). Ethiopia is constructing transmission grids to neighboring countries, mostly HVDC lines, to export electric power

A list of programs during the PASDEP period will follow in the next part. The costs of this are programmed to be around 51 billion Birr (Around £2 billion). The construction of the generation units will take 61% and the Universal Electricity Access Program (UEAP) will use 25% of the total investment costs. Then there are some additional investments in the transmission and distribution network. This will be financed through revenue generated by EEPCO for 39%. Local and foreign loans will cover 55% and the last 6% comes from government treasury and community contributions (Ministry of Finance and Economic Development (MoFED), 2006, p. 139).

The cost of power is around 0.067 USD per kWh, 0.0455 USD per kWh for the generation, 0.014 USD per kWh for transmission and 0.007 USD per kWh for distribution. The consumer tariff is 0.06 USD per kWh, which it’s has been since 2006. The gap between the cost and tariff has raised concern and a EEPCo has requested the Ethiopian Electricity Agency to increase the tariff to system cost recovery level (Ministry of Water and Energy, 2012).
2.2 Electrical/ technical

Three important elements for Ethiopia’s electrical grid are strengthen energy security, access to electricity and decrease greenhouse gas emissions. Ethiopia is blessed with large renewable sources, such as hydro, wind, solar, geothermal, biomass etc. Ethiopia has not been able to take full advantage of these sources for economic development.

The electrical grid has two electric energy supply systems. These are the Inter Connected System (ICS), which is the national grid and the Self Contained System (SCS), which are local grids. The capacity of EEPCo as of 2011 was 2052MW, divided as follows 1848.75MW in hydropower plants, 142.82MW in Diesel, 7.3MW in Geothermal as of 2012 an additional 52MW came from wind power. The annual energy production was 4980.08GWh (Asress, Simonovic, Komarov, & Stupar, 2013). The ICS consists of 11 hydropower plants, 13 diesel power plants and one geothermal power plant. The SCS has three small hydropower plants and several diesel power plants (Asress, Simonovic, Komarov, & Stupar, 2013).

As of 2010, the electrical grid consisted of 8868km high voltage transmission lines, 126000km distribution lines and 123 substations (EEPCo, 2011). About 5866 towns and rural villages were electrified, which means an electricity access rate of around 46%. (Asress, Simonovic, Komarov, & Stupar, 2013). This number is calculated by the population living in the electrified area, but many households cannot afford the connection from the distribution lines from the grid to their home (Embassy of Japan in Ethiopia, 2008). The actual electricity access rate is therefore probably much lower than 46%. The number of consumers with access to electricity was 2.03 million in 2009/2010 (Ministry of Finance and Economic Development, 2010). The SREP report mentions that 17% of the households are directly connected to the grid. (Ministry of Water and Energy, 2012)

The electricity losses were around 20% in 2008, while the international average was 13.5%. Most of the losses are from the distribution from the grid to the end user, according EEPCo (Asress, Simonovic, Komarov, & Stupar, 2013). According to the GTP in 2009/2010, the losses for transmission and distribution was 11%, the losses at substations was 5.34%, this would mean a total loss of 16.34% for the electrical grid in 2009/2010 (Ministry of Finance and Economic Development, 2010).

The per capita energy consumption at the end of 2011 was around 60KWh/yr, this much lower than the average minimum level of 500 – 1000KWh/yr for a reasonable quality of life (Asress, Simonovic, Komarov, & Stupar, 2013).

The short term plan of Ethiopia to achieve a green economy by 2025 is explained in Scaling – up, Renewable Energy Program Ethiopia Investment Plan (SREP) and in the Growth and Transformation Plan (GTP) 2009/2010 – 2014/2015. This includes the further development of alternative energy from renewable sources such as solar, wind, geothermal and biomass, but also energy efficiencies measures to reach this goal.
The Greenhouse gas Emissions in 2010 were 150Mt CO$_2$ per year, this translates to 1.8 t CO$_2$ per capita in 2010. For 2030, the goal is 1.1 t CO$_2$ per capita and 145Mt CO$_2$ with an expected population of 130 million people (Federal Democratic Republic of Ethiopia, 2012). This is a 64% reduction compared to the business as usual case. The business as usual case, includes the use of renewable energy and in this case Ethiopia emits around 400 Mt CO$_2$ per year in the year 2030 (Federal Democratic Republic of Ethiopia, 2012).

To reduce these emissions in comparison to a business as usual case, more efficient stoves can make a positive impact of 50 Mt per year. This reduce the burning of wood and other biomass for cooking. Higher livestock productivity can reduce another 45Mt for the agriculture sector. In the industry sector, modernizing the cement factories could reduce GHG emissions with 16Mt. The transport and building sector contribute to 15Mt reduction. The reduction of GGH through the generation of renewable energy has already been included in the business as usual case and add nothing to reduction of GHG emissions in 2030. But Ethiopia could achieve a surplus of green energy, which could be exported. This would reduce GHG by 19Mt CO$_2$ (Federal Democratic Republic of Ethiopia, 2012).

To reach their goals, Ethiopia has some short term plans. The Universal Electrification Access Program (UEAP), strive for universal coverage of 100% of the country by 2020, this means a coverage of 75% by 2014. This translates to the following expansion of the transmission grid. The construction of 500 kV D.C. lines of 434 km, 945 km of 400 kV, 3475 km of 230kV and 1262 km of 132kV, which adds up with the existing infrastructure to over 17000km of transmission lines till 2015 (EEPCo, 2011). The distribution network is expected to grow from 126.000 km in 2010 to 258.000 km in 2015 (EEPCo, 2011).

Until 2015, Ethiopia is expected to continue to grow at high single digits economic growth. Total power demand is projected to grow from 4 TWh in 2010 to a maximum of nearly 70 TWh in 2030. The steep increase in demand (14% per annum) reflects both the growing electrification of the country – the target for 2020 is to expand access to grid connection to nearly 100% of the country (measured in area coverage) – and rapid growth of electricity-intensive industries – projected at a rate of more than 15% a year, outpacing the overall GDP growth rate (Ministry of Water and Energy, 2012). To cover this new demand, the generation of hydro electric energy is expected to grow to 10000MW in 2015 (Ministry of Finance and Economic Development, 2010) with the addition of wind and geothermal power plants to complement the hydro power plants (EEPCo, 2011).

In addition to expansion of the electrical grid and the generation of electricity, emphasize is also on improving the transport of electricity to the consumer in an efficient and reliable manner. The losses for transmission and distribution are to be 5.6%, and the losses at substations 3%, this would mean a
total loss of 8,6% for the electrical grid in 2015 (Ministry of Finance and Economic Development, 2010).

Ethiopia is rich in water and potentially could export part of their electrical energy to neighboring countries. As for most countries in the region, the energy markets are too small to benefit from economies of scale. Power system interconnection programs are being developed as an alternative to displace expensive thermal generation in regional and international power markets and to strengthen regional ties to contribute to economic development and stability. Ethiopia is part of the East African Power Pool (EAPP). The Ethiopia-Djibouti interconnection line between Ethiopia and Djibouti is completed and power has been exported since 2011. The interconnection with Sudan is finished and power flow is expected to have started in 2012. The 2000MW HVDC interconnector to Kenya is at the initial stage of construction (Ministry of Water and Energy, 2012). The feasibility study of the 3200MW interconnection starting from 2018 with Sudan and Egypt has been finished (Ministry of Water and Energy, 2012).

2.3 Environment and social development

Renewable energy issues has been addressed in Ethiopia in the national energy policy of 1994. The important elements of the energy policy are: The development of indigenous resources, with a recommendation for hydropower, the development and utilization of green energy sources, focus on energy efficiency and conservation measures and create public awareness on energy issues (COMESA, 2012). Important aspects of the current situation in Ethiopia regarding the environment and the energy sector are the large influence of hydro in the generation of electrical energy, and the over reliance on biomass for energy in mainly rural areas and a lack of modern energy.

This over reliance on biomass fuels in rural areas, has several environmental drawbacks as the consumption has far exceeded the supply, leading to deforestation, general environmental degradation and a source of GHG emissions. A scarcity in fuel woods has increased the time that rural households spend in collecting fuel wood, causing a loss in human productivity. From which the woman and girls suffer mostly, as they are mostly in charge for the collection of firewood and cooking. The time could have been used for economic activity (woman) and studying (girls) (Ministry of Water and Energy, 2012). Unavailability of electricity has resulted in a lack of social, economic and educational facilities.
The energy problem in Ethiopia is not from over reliance on non-renewable energy sources but in the rate at which the population consumes fuel wood as their source for energy, while the great potential of the renewable energy sources (hydro, wind, solar) in Ethiopia are underdeveloped.

In general, the prevailing pattern of energy supply and consumption shows many elements of unsustainability. The energy problem in the country arises not from excessive reliance on non-renewable energy sources, but rather that the main source of energy for the population - fuel wood - is being consumed at an unsustainable rate, while the vast potential of other forms of renewable energy (solar, wind, geothermal, hydropower, etc) remains virtually undeveloped (Ministry of Water and Energy, 2012).

Several important issues for the implementation of renewable energy are: policy and regulatory framework do not provide sufficient incentive for increase production and use for distributed applications, currently there are no regulations for feeding power into the grid (COMESA, 2012). The initial investment cost for access too electricity are too high for most households, with the addition of low reliability additional back power is required, thus increasing the cost and unlikely that all the rural households will be connected to the grid in the coming 10 years (Ministry of Water and Energy, 2012).

In order to promote a green economy and jump start the movement CRGE has selected four initiatives to focus on for a reduction in GHG, promote Ethiopian’s leading role in sustainable growth and attracting climate finance for the implementation. First exploiting the Hydro power potential of the country. Second large scale promotion of advanced cooking technologies. Third, improvements to the livestock value chain. Fourth and last, the reduction of emissions from deforestation and forest degradation (Ministry of Water and Energy, 2012). Over time a comprehensive program will be developed concrete proposals to encompass all sectors.

The current direction of the energy sector, are development of renewable energy, expansion of the energy infrastructure and the creation of an institutions that can manage the energy sector developments. The energy policies set by the government are (COMESA, 2012)

- High priority for Hydro power
- Encourage energy mix (Solar, wind, geothermal, etc.)
- Set appropriate policy measure for a smooth transition from traditional fuels to modern energy.
- To pay close attention to ecological and environmental issues at energy policies
- To set standards and codes for efficient energy use
- To develop human resources and establish competent energy institutions
- To provide to the private sector with support and incentive to participate in development of energy projects.
3 Generation

3.1 Introduction to generation

A year or ten ago, around 2000, the generation didn’t grew very fast because the rural areas of Ethiopia were not electrified. This was 85% of the total population in that year. By then the total generating capacity was around 450MW, which was 7W of electrical energy per capita. The resources to generate this energy were natural gas, biomass, hydropower, imported oil and dung. (Wolde-Ghiorgis, Renewable energy for rural development in Ethiopia: the case for new energy policies and institutional reform, 2002, p. 1096)

In that same year the exploitable hydropower reserves were estimated on 30GW, a huge opportunity for the future. (Wolde-Ghiorgis, Renewable energy for rural development in Ethiopia: the case for new energy policies and institutional reform, 2002, p. 1097) Ten years later, in 2012 this estimation was increased to 45GW hydropower. After looking to other renewables 10GW wind power, 5.26kWh per square meter per day solar power and 5GW geothermal opportunities were estimated as big key players for the future. A total of 60GW renewable without including sun!

The generation and distribution of electrical energy has grown fast and is still rising. With an electricity access rate of 46% and a generation capacity of about 2GW in the beginning of 2012, a big tripling in ten year time has been made. In 2015 a 10GW installed capacity is planned. (Mulugeta Biadgo Asress, 2013, p. 367) An overview of the amounts of sustainable sources planned for the future can been seen in table XX. In table XX the ratios of renewables and fossil fuels for now and in the future are given. (Mulugeta Biadgo Asress, 2013)
Table 2: Source: (Mulugeta Biadgo Asress, 2013) P377

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Table 3: Source: EEPCO, Corporate Planning Department

### 3.2 Hydropower

With a total amount of 45GW of exploitable potential as mentioned earlier, hydropower is the dominant resource for generating electricity. The ratio of hydropower generated is enormous, with the highest ratio in 2006 of 99.69% of the total generation capacity. (Mulugeta Biadgo Asress, 2013, p. 369) The government want to decrease this ratio to be less dependent on hydropower. One of the
reasons is because before the start of the annual rainy season hydropower potential drops to a low point, while wind power is strong during the dry season. (Mulugeta Biadgo Asress, 2013, p. 376)

3.2.1 Hydro future
Of all generation in 2015 the hydropower share will drop to 91% and in 2030 to 87% according to governmental plans. (Ministry of Water and Energy, 2012, p. 5) To drop this percentage more other (sustainable) sources must be exploited faster than hydro. These other resources need to grow fast because in the beginning of 2012 only 2000MW (around 4%) of the 45GW exploitable potential was used, so a lot more hydro will come in the future which will keep the percentage of it high. (Ministry of Water and Energy, 2012, p. 17)
Hydro dams planned and already constructed are shown in Figure 5.

![Figure 5](image)

3.2.2 Grand Ethiopian Renaissance dam 6000MW
This dam is the biggest of all in Ethiopia looking to electrical power generation, but it has another big strength. The location in the Blue Nile, which will end up together with the White Nile into The Nile river, has a strong political power. Because Sudan and Egypte are heavily dependent on the water supply of the Nile, especially their capital cities Khartoum and Cairo respectively. The dam is able to hold a part of the water flow, which is very critical for the water supply of the ‘dessert type’ cities Khartoum and Cairo (Stratfor, 2013)
Figure 6 Source: http://www.ethiogermany.de/headlines/is-the-grand-ethiopian-renaissance-dam-economically-feasible
3.3 Wind energy
This energy source in Ethiopia is exploiting now in these years. One of the main reasons it didn’t happen earlier was lack of wind measurement studies in the past. Now, recent studies show that the country has substantial potential to generate electricity from wind. From the period 2011 to 2015 a total of 1116MW of wind energy is scheduled to be build divided over eight wind farms. (Mulugeta Biadgo Asress, 2013, p. 372)

3.3.1 Wind studies
Before these wind farms have gotten a location, wind studies have to be made. The first useful study which was precise enough was performed in 2007 by SWERA. They used mesoscale model approach to develop a wind speed map of Ethiopia. This model uses a grid size of 2.5 x 2.5 km² and 250 x 250 km². As inputs SWERA used data sets like meteorological data from NMSA, measured data from a few stations and modeled ocean winds derived from satellite data. (Mulugeta Biadgo Asress, 2013, p. 370) Finally a wind speed map was created as seen in Figure 7 left.
This is the whole area of Ethiopia. Of course on some spots it is not possible to place a wind farm, because of reasons as: natural parks, forests, financial not feasible terrain, not in the neighborhood of a HV grid connection around the time of construction, no roads or on the location of water bodies. If that information is combined with the wind data, the map of Figure 7 right is made.

As a result of this the eight wind farms spoken above are placed in the geographical locations of Figure 8.

![Figure 8 (Mulugeta Biadgo Asress, 2013, p. 374)](image)
3.4 Geothermal energy

The exploration of geothermal energy already started in 1969 in Ethiopia. Over the years following, inventories were made about possible locations. From these analyses about 120 different and independent locations were believed to have their own heating and circulation systems. All of these were found in the Ethiopian rift valley with most of them in the Afar region.

The exploration work peaked in the mid 1980’s when exploration drilling was carried out at Alutu. Later in the mid 1990’s in Tendaho as well. Three deep and three shallow wells were drilled in a depth range of 200m to 600m.

Resource utilization was delayed until 1999 because of operational difficulties at a 7.3MW plant at Alutu-Langano. The causes were lack of appropriate field and plant management and operation skills. In 2007 after problem identification activities, the plant was put (partially) back into operation to a 4MW plant. Quite some of the needed activities were funded by external parties like the European Development Fund. (Kebede, 2012, pp. 5, 6)

As already mentioned at the start of this chapter, there is an estimated 5GW of exploitable reserve of geothermal in Ethiopia. These are located in the two regions of the Ethiopian rift valley as shown in figure xx. They are divided in five different stages where the feasibility study is the latest stage because this depends on current and future circumstances. (Mulugeta Biadgo Asress, 2013, p. 375)

At this moment three exploration and development projects are being done. The first is a five year project entitled ‘Strategic Geothermal Resource assessment in the Ethiopian rift valley’ which started in 2009. The project has target areas as: Tendaho, Aluto Langano, Gedemsa, Dofan, Fentale, Meteka and Arabi. The objectives of this project are to locate and identify areas (sites) for deep drilling by acquiring data that can supplement the already available ones, and upgrade and synthesize all existing information in order to establish a geothermal exploration conceptual model for future feasibility studies.

Second project is in collaboration with Japan and the World Bank. Here in 2010 a feasibility study for the expansion development of the Aluto Langano geothermal field proved the expansion plan to be
feasible. Then this project started for resource evaluation by drilling of three appraisal deep wells and one reinjection well.

The third and last project is at Tendaho. Here a project proposal has been prepared to develop the geothermal resource to 100MW at various phases. The previously drilled deep wells were not deep enough to encounter the main reservoir. (Kebede, 2012, p. 13)

The future planes for geothermal energy consist of 77MW in 2015 and a 1GW production in 2030. (Kebede, 2012, p. 3) What we can see from these numbers is that geothermal is growing, but has even a lot more potential (5GW) than planned at the moment. This could be a very nice opportunity for private investors as they are allowed to participate in these projects.
3.5 Solar energy

Investments in solar energy is a wise decision for the future to be less dependent of hydropower. If there is too much relayed on hydropower in times of climate change, the increasing risk of drought can make the energy sector vulnerable. Together with the increase of the lifetime and efficiency of solar panels and the reduction of the costs, it’s a more and more financial attractive sustainable energy source. (Mulugeta Biadgo Asress, 2013, p. 377)

However there must not be forgotten that solar panels need maintenance to keep their promised lifetime. This can form a problem with the scarcity of both technicians and the managerial capacity of organized distributed service. (The distributed service should keep the maintenance costs as low as possible) Because of this scarcity the effective life time of the panels is reduced and so accentuate their capital intensity. (Collier, 2012, p. S78)

Although the high average of 5.26kWh per square meter per day solar power (around two times the amount of Europe) as mentioned in the introduction in of this chapter, is still not used in large scales. Compared with hydro, wind and geothermal is the price per kWh higher. Another reason can be the lack of measured irradiation of the sun on different locations in the country. At the moment only properly measured irradiation is available of the capital city Addis Ababa. Three other locations are an estimate of sunshine duration data and appropriate empirical relationships. (Bekele, 2010, p. 488)

The application of solar power is therefore currently only viable for households and small firms in conditions of extreme shortage and with a very high shadow-price of energy. (Collier, 2012, p. S78)

3.6 Fossil fuels

Fossil fuels are used in a very small scale compared to the whole energy production in Ethiopia. They are used in small diesel power plants and diesel generators. The latter are connected to micro grids in rural areas. There they facilitate small amounts of energy to weak grids. Some (production) companies are using diesel generators as well, because of poor power quality which disturbs the (production)process heavily. They create their own grid with a diesel generator to be less disturbed by voltage dips and outage of the government grid. Other fossil fuels are not discussed, because they are not used to generate electricity and thereby are out of this reports’ scope.

3.7 Biomass

Biomass is not used to generate electricity in Ethiopia, but is shortly noted because its commonly used in the rural areas. Trees are cut down and collected by women as firewood for cooking. This is often done on a very inefficient ‘three stone fire’. Furthermore dung is used to create fires. These fires can also be used to get rid of insects in houses and nomad tents. Using rest materials from sugar factories to generate electricity is expected to begin in the nearby future. (Yewondwossen, 2012)
3.8 Social and environmental aspects

3.8.1 Sustainable energy sources
The electrical energy sector in Ethiopia is very ‘green’ compared with Europe, this is mainly the cause of the dominant hydropower as seen in Table 2. In the same table are the future numbers depicted and show an even more sustainable energy supply. This is good for people and their environment, it also meets the millennium goal to ensure environmental sustainability. (UN, 2000)

3.8.2 Better life for woman and less deforestation
The expansion of the grid to the rural areas which is known as the UEAP (Universal Electricity Access Program) brings large social and environmental benefits. At the moment firewood is commonly used in these rural areas as energy source. This is cut down and collected by women and girls. There are two disadvantages of this, namely they spend large parts of their day time with this activity and it brings deforestation. If they don’t have to spend (large amounts of) time with this activity the women have the chance to use their time for working purposes to earn money and the girls can use the time for study purposes to get a better chance in society. A better life for women and girls (in third world countries) is also one of the millennium goals to achieve together with a more sustainable living environment. This is expected to be reached by electrifying the rural areas, because now they lack on this energy source and have to use others available. (Gebreegziabher, 2011) (Ministry of Water and Energy, 2012, p. VI) (UN, 2000)

3.8.3 Better irrigation of cultivating land
The hydropower dams are most of the time multipurpose dams. They create a lake which can be used to irrigate cultivating land. Hereby the life standard of the farmers increase because their land will be more productive and the amount of labor needed for irrigation will decrease.

3.8.4 More food production
The multipurpose dams which create better cultivating land, will create more food. This will decrease the poverty and hunger of allot of inhabitants. Another advantage is the lake created by the dam which creates new fishing opportunities and thereby more food. The better irrigation of cultivating land and more food production will contribute to the first millennium goal, eradicate extreme poverty and hunger. (Barrow, 2011, p. 10) (UN, 2000)
4 Local distribution

Ethiopia is the 10th largest country in Africa, with more than 80% of the people living in rural areas (Hartkopf & Erbato, 2011). In these rural areas around 1% has access to electricity (Hartkopf & Erbato, 2011). Most urban areas have been electrified, but the goal is to reach universal access to electricity for all the people. This means that even the remote rural villages must have access to electricity. Micro grids that make use of the abundance of renewable energy sources could be used to increase access to modern energy.

Currently most rural villages do not have access to electricity because the cost of extending the transmission lines to remote village over large distances is much greater than the need for electricity. Rural areas are considered to have low load density and low economic income (Hartkopf & Erbato, 2011). The local energy needs are in large part covered by biomass from the local areas (table 4.1 importance of fuel sources). This means that the needs for cooking and light are gained from the local environment, leading to forest degradation.

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Total Ethiopian Energy Consumption (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel wood</td>
<td>77</td>
</tr>
<tr>
<td>Dry dung</td>
<td>9</td>
</tr>
<tr>
<td>Agro residues</td>
<td>8</td>
</tr>
<tr>
<td>Petroleum products and electricity</td>
<td>5</td>
</tr>
<tr>
<td>Charcoal</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5 Relative importance of different energy source in Ethiopia (Hartkopf & Erbato, 2011)

Just extending the Inter-connected System (ICS) is economically not a viable option, besides being expensive with low return; the losses would increase as well from the transmission over long distances. Ethiopia has vast amounts of renewable energy, which could be harvested in electrifying the rural areas through Self-Contained Systems (SCS). Which in a later stadium could be connected to the ICS.

The following renewable energy sources could be implemented with the SCS:

- **Micro Hydro Power:** The large variations in altitude and a favorable climate gives rise too many small rivers. There are at least 5000 locations which are suitable for Mini and Micro Hydro Power (Hartkopf & Erbato, 2011)
- **Solar Energy:** Ethiopia receives around 3000 hours of sunlight of 5.0 kWh/m^2/day
- **Wind Energy:** The mechanical energy could directly be used for pumping water and irrigation. Because of the unpredictability of wind, it must be integrated with other energy sources
- **Biomass:** Currently the main source of energy for rural areas. Oil of the seeds of Jatropha tree could be used for biodiesel and biogas
- **Geothermal energy:** There are vast amounts of Geothermal, it is currently not used for decentralized generation. It is capital intensive, but it could play an important role in decentralized electrification.
All rural areas in Ethiopia have access to all or a combination of the above mentioned energy sources. In addition the micro grid could make use of modern technologies of electric power generation like electric storage devices and CHP’s (Hartkopf & Erbato, 2011).

This bottom up approach with micro grids has several advantages:
- Knowledge and technology transfer
- Gradual adaptation of the technology, accompanying their economic growth
- Increase in local jobs and decreasing the migration towards urban cities
- Less firewood is needed, protecting the local environment
- Coverage of modern energy increases
- Improving the power quality. Black outs are reduced as local loads are supplied through the micro grid reducing peak hour demand surge

One major disadvantage of all renewable technologies is the high cost, which leads to long payback periods. Government should address this within their energy policies. Import tax on PV panels was 30% in 2002 (Wolde-Ghiorgis, Renewable Energy for Rural development in Ethiopia: The case for new energy policies and institutional reform, 2002).

It is important to be aware of the situation, when the goal of universal electrification will exacerbate the financial problems of the energy sector. Diverting scarce capital towards the expansion of the grid could lead to a situation, where the investments barely generate enough revenues to maintain the grid in operation without additional capital. This could drain the capital reserves of the utility companies (Eberhard & Shkarton, 2012). Tradeoffs have to be made to allocate the capital. In certain situations, it might be better to opt for local solution, like SCS instead of nationwide coverage through ICS.
5 Global connection

Sub-Saharan Africa, which Ethiopia is part of, has severe power problems. The demand has risen relatively compared with the supply, leading to severe power outages (African Development Fund, 2012). The capacity of the 48 countries that form Sub-Saharan Africa is around 80GW; Spain, a single country has more (Eberhard & Shkarton, 2012). The electricity costs for the region are high, which is a result of costly emergency power generation, low economies of scale, inefficient utilities and low level of regional integration (Eberhard & Shkarton, 2012). Droughts, conflicts and high oil prices increase the problems (Eberhard & Shkarton, 2012).

The region has a large potential of solar, wind, hydro and geothermal energy, but few countries have sufficient demand to invest in large power plants, to make use of economies of scale and the least expensive sources are far away from major centers of demand. 61 percent of the hydropower for the region is found in two countries of Sub Saharan Africa: Democratic Republic of Congo and Ethiopia (Eberhard & Shkarton, 2012).

To address the power problems in this part of Africa and make use of the potential resources, four regional power pools have formed; Ethiopia is part of the East Africa Power Pool (EAPP). EAPP was formed in 2005 and consist of 10 countries. The goal is to facilitate and secure power supply to the countries of the Eastern African Region at the lowest possible cost (Gebrehiwot, 2013). This is achieved by pooling of resources for optimal exploitation of the energy sources in the region, facilitation and coordination of power exchange between the members. Fig. 5.1 gives an overview of the current situation of interconnections between the members (Gebrehiwot, 2013).

Ethiopia, with its large potential in hydropower would become an important part in the EAPP. The integration of the power systems of the members will enable Ethiopia to invest in the large hydropower resources it possesses, for export to the neighboring countries. Currently Ethiopia is forming interconnections with neighboring countries, like the Ethiopia-Kenya electricity highway with HVDC. Fig 5.2 gives an overview of the interconnections within the EAPP in 2023/2028.
And fig. 5.3 gives a geographic picture of the possible interconnections between Ethiopia and its neighboring countries.
The benefits of these interconnections are:

- Economy of scale: Power system costs would be between 3 to 10% lower for the trading regions (Eberhard & Shkarton, 2012)
- Development of large scale renewable power plants
- More hydropower projects become profitable; although on a side note these projects require multinational cooperation and hydropower must compete with other water demands. Therefore it requires a legal framework to facilitate international cooperation (Eberhard & Shkarton, 2012).
- Stimulate economic growth
- Promote power trade
- Regional economical and political integration, creating stability between members
- Supply more households and businesses with electric power, possibly reducing poverty levels
- Possible interconnection between North and South Africa and possibly Europe and Asia
6 Power quality of the Ethiopian grid

6.1 Introduction
As widely known, the weaker the grid, the more worse the PQ. The Ethiopian grid and the generation capacity is expanded quickly in the last years and continues growing in the upcoming years. The relative low amount of generation together with a small amount of interconnections create a grid with poor PQ. Studies show that problems in the industry of the capital city Addis Ababa and around occurred, where the IEEE Standard 1159-1995 was violated. These violations were found in voltage variations (under-and overvoltage), frequency fluctuations, voltage unbalances (caused by faults on transmission and distribution lines) and to high THD currents. Although these problems, there are no standards that state the minimum reliability of the electric power. No problems were found in flicker and voltage unbalances caused by industrial three phase loads. Voltage variations and interruptions are the worst and most damageable factors for the industry, which will be discussed below. (Tesega G., 2011, pp. 2,81,82)

6.2 Voltage variations
The voltage variations are divided in under- and overvoltage. From measurements in big factories around Addis Ababa has been noticed that the voltage variations are exceeding the IEEE specifications of ±10% in both under- and overvoltage. These voltage variations are disturbing manufacturing processes in certain factories. For example the St. George Brewery was forced to purchase equipment that shuts down sensitive equipment when the voltage goes out of the ±10% boundary. Since the installation the protection isolated the sensitive loads ten times in three weeks. There were even times that the protection worked four times a day, only due to voltage variations. As anyone can imagine, the financial losses during manufacturing because of this are huge. (Tesega G., 2011, p. 41)

These voltage variations are not only problem causing in the industry but as well in households. The lifetime of light bulbs decreases, electric stoves don’t function (well), stews can’t be made and water can’t be boiled. The efficiency and performance of high power appliances are decreasing because of these variations. Some over voltages even damage or burn electric equipment and light bulbs. (Tesega G., 2011, p. 25)

6.3 Interruption time
In the capital city Addis Ababa were measurements taken in 2010 on the 15kV feeders where the industries are directly connected to. These measurements include short and sustained interruptions. However, the auto-reclosure feature of the breakers at Addis center substation is intentionally disabled that all interruption phenomena are changed into sustained interruptions. (Why they did this is unknown) Afterwards some reliability indices were calculated.

- **SAIFI (System Average Interruption Frequency)**
  How often the average customer experiences a sustained interruption over a predefined period of time.

- **SAIDI (System Average Interruption Duration Index)**
  Shows the total duration of interruption for the average customer during a predefined period of time.

- **CAIDI (Customer Average Interruption Duration Index)**
  Represents the average time required to restore service.

- **ASAI (Average System Availability Index)**
  Represents the fraction of time that a customer has received power during the defined reporting period.
Taking these values of eleven feeders in the city, Table 6 is created.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Line/ Feeder</th>
<th>Monthly average no. of interruptions</th>
<th>Monthly Average interruption Duration (Hr)</th>
<th>SAIFI</th>
<th>SAIDI (Hr)</th>
<th>CAIDI (Hr)</th>
<th>ASAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Arbegnoch</td>
<td>18.0</td>
<td>14.3</td>
<td>18.0</td>
<td>14.3</td>
<td>0.8</td>
<td>0.98013</td>
</tr>
<tr>
<td>2</td>
<td>Kaliti</td>
<td>14.6</td>
<td>8.3</td>
<td>14.6</td>
<td>8.3</td>
<td>0.6</td>
<td>0.98852</td>
</tr>
<tr>
<td>3</td>
<td>Mekanisa</td>
<td>15.0</td>
<td>6.2</td>
<td>15.0</td>
<td>6.2</td>
<td>0.4</td>
<td>0.99144</td>
</tr>
<tr>
<td>4</td>
<td>Sabata</td>
<td>24.4</td>
<td>14.4</td>
<td>24.4</td>
<td>14.4</td>
<td>0.6</td>
<td>0.97994</td>
</tr>
<tr>
<td>5</td>
<td>Adowa</td>
<td>2.4</td>
<td>1.3</td>
<td>2.4</td>
<td>1.3</td>
<td>0.5</td>
<td>0.99824</td>
</tr>
<tr>
<td>6</td>
<td>Kolfie</td>
<td>14.6</td>
<td>11.0</td>
<td>14.6</td>
<td>11.0</td>
<td>0.8</td>
<td>0.98468</td>
</tr>
<tr>
<td>7</td>
<td>Old-Bole</td>
<td>12.4</td>
<td>5.5</td>
<td>12.4</td>
<td>5.5</td>
<td>0.4</td>
<td>0.99236</td>
</tr>
<tr>
<td>8</td>
<td>Kera</td>
<td>8.8</td>
<td>8.3</td>
<td>8.8</td>
<td>8.3</td>
<td>0.9</td>
<td>0.98853</td>
</tr>
<tr>
<td>9</td>
<td>Churchille</td>
<td>14.4</td>
<td>3.3</td>
<td>14.4</td>
<td>3.3</td>
<td>0.2</td>
<td>0.99547</td>
</tr>
<tr>
<td>10</td>
<td>Abaware</td>
<td>4.8</td>
<td>4.0</td>
<td>4.8</td>
<td>4.0</td>
<td>0.8</td>
<td>0.99442</td>
</tr>
<tr>
<td>11</td>
<td>New-Bole</td>
<td>11.8</td>
<td>10.1</td>
<td>11.8</td>
<td>10.1</td>
<td>0.9</td>
<td>0.98598</td>
</tr>
</tbody>
</table>

Table 6 Source: (Tesega, 2011, p. 44)

Now with the design target values per annum in Table 7 the interruption data can be compared. What can be seen is extremely high interruption values compared with the design targets, these will be discussed according to the before named indices.

<table>
<thead>
<tr>
<th>Design Target Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAIFI</td>
</tr>
<tr>
<td>SAIDI</td>
</tr>
<tr>
<td>CAIDI</td>
</tr>
<tr>
<td>ASAI</td>
</tr>
</tbody>
</table>

Table 7 Source: (Tesega, 2011, p. 45)

SAIFI of one per annum as design target and a highest measured SAIFI of 292.8 times as much. (24.4 per month) This shows that the interruption frequency is extremely high compared with the design value.

SAIDI of 14.4 hours per month is 173.3 hours on yearly basis. This is 115 times the maximum value of 1.5 hour as design parameter. This shows that the electric power is interrupted for a long total period of time in the year.

CAIDI values of maximum 0.9 hours are measured. These are not exceeding the design target of one to 1.5 hours. That indicates that the feeders have small mean times to repair, which is an indicative of frequent interruptions that arise from non-permanent disturbances upon the power system.

ASAI values are below the target value of 0.99983. This shows that the feeder lines have a lower amount of availability then designed, because they get interrupted for a long total duration, out of the time that they are required for customer demand.

These four measurements together tell that the interruption targets are not met except the repair time to restore service. That indicates on a very high frequency of interruptions. Often said is that the
cause of heavy rainfall and hard wind. This would mean that in August during the rainy season the worst interruption data must be measured, what is not the case. September is the worst what indicated other factors than heavy rainfall and hard wind. (Tesega G., 2011, pp. 42 - 46)

6.4 Environment
Looking to the environmental aspects of PQ in the Ethiopian grid, then grid losses will be the only important environmental problem, which will be discussed below.

6.4.1 Grid losses
Losses in the grid where 20% of the generation in 2008, which is much higher than the international average of 12 – 13%. The most of this loss happens during distribution from the national grid to the end users. (Ethiopia, 2008, p. 10) The goal for 2015 is decreasing the losses to 13.5% to the international average. (Mulugeta Biadgo Asress, 2013, p. 369) These 7% extra losses above international average is just wasted energy. In 2012 this 7% is 140MW lost power, but in 2015 already 700MW lost power if the losses are not solved by then. (Which will be a really difficult job with the quick and large scale expansion of the network)
Conclusion

In the last ten years has the Ethiopian electricity grid grown exponentially. This will continue in the upcoming years. The goal of this grid expansion is boosting the national and international economy. The government wants Ethiopia to become a middle income and green economy. This grid expansion for the rural areas is designed in the Universal Electrification Access Program. With this program the wealth will increase of the people in the rural area’s, because they can replace their current energy sources for electricity. These current energy source are labor intensive and degrade the local environment. So by replacing the current energy sources by green electricity will the environment and the people benefit. Additionally, is the replacement of wood used for energy an increase for the woman’s wealth. Girls can go to school and woman can work and earn money for the family.

The ecological setup of the country with all the mountains and rivers is a large engine for this green revolution. Additionally, will the amount of wind, geothermal and solar power expand as well. This creates a more divers and sustainable energy generation. Besides this, is the reliability of the available resources spread over the year and weather situation.

Choices have to be made within the Universal Electrification Access Program between expanding the national grid (ICS) or creating a local micro grid (SCS). The costs for national grid expansion to remote areas can be large compared to the amount of transported energy. Therefore it might be more beneficial to create a local micro grid. When the power demand will increase within that micro grid is it possible to connect it to the national grid later.

Ethiopia has a very large potential for green energy generation. There is too much potential compared with the local demand. This combination generates a large potential export market for green electricity to neighbor countries. The interconnection has different benefits. First of all, it generates a stable financial income for Ethiopia. Second, the grid stability increases for Ethiopia and the neighbor countries. Third, because the neighbor countries get more access to electricity will their local economy expand. This creates a snowball effect for the whole region and accelerates all connected economies.

The power quality of the national grid before the large growth was already not that good. The expansion of the grid and amounts of generation made the frequency more stable. The whole grid consists almost of overhead lines, which are quit vulnerable. Therefore are dips and interruption the order of the day. The large lengths especially in low and medium voltage lines create a high grid impedance. Grid losses are relative high because of this high grid impedance. Additionally, will harmonic current distortion create a larger harmonic voltage distortion. The high grid impedance has an negative effect on the voltage level depending on the location in the grid, looking to the distance from a substation. Control of reactive power flows is crucial for controlling the voltage levels within a certain range from the nominal voltage.

Finalizing can be concluded that a proper expansion, control and quality of the electricity grid is crucial for the environmental and social economic growth of the country. Hereby Power Quality will be an important aspect, which have to be taken into account already during the design phase to reduce (financial) losses in the future.
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