UN Sustainable development goals from a Climate Land Energy and Water perspective for Kenya

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Abstract

In September 2015 UN announced 17 Sustainable Development goals (SDG) where achieving food security, ensure availability of water for all, access to modern energy for all and combat climate change are four of the 17 goals. In Kenya only 23% of the population have electricity access and in the rural areas 93% lack access to electricity and the improved water availability only reaches 59% of the population. In Kenya 72% of the agricultural land is rain fed which makes the food availability sensitive to droughts, which happened in 2009, and in 2012-2014 22% of the population was undernourished.

The main objective for this master thesis is to analyse how to achieve the Sustainable Development Goals aforementioned for Kenya with an integrated resources planning following the CLEWs framework. The toolset used for this analysis is ONSSET, OSeMOSYS and WEAP which, where possible, are interlinked to see how the resources in Kenya can be allocated to reach the SDG.

The universal access to electricity by 2030 was modelled for two levels of demand where the grid demand, modelled in OSeMOSYS, found the least cost electricity mix for Kenya to be mainly geothermal and natural gas. The off-grid analysis showed that for the low electricity consumption the stand-alone solutions of PV and diesel was most cost effective. When the residential demand increased the mini-grid solutions was preferred. The pressure points that the modelling showed were in the water access and irrigation plans for the Tana catchment where the irrigation scheme in the upstream parts of the river, which represents 25% of the irrigated area, would have months of unmet demand. The CO2 emissions for both scenarios was found to be less (6 resp. 9 MtCO2eq) than the projected BAU emissions, 18.4 MtCO2eq, in the National Climate Change Action plan.

Key words: SDG, Kenya, OSeMOSYS, WEAP, CLEWS, optimization, ONSSET

FRONT PAGE PHOTO FROM HTTP://WWW.NATHAB.COM/AFRICA/KENYA-MIGRATION-PHOTO-SAFARI/

Sammanfattning

I September 2015 kungjorde FN de 17 globala målen där ingen hunger, tillgänglighet till vatten för alla, ren och modern energi för alla samt bekämpande av klimatförändringar var fyra av de 17 målen. I Kenya har endast 23% av befolkningen tillgång till elektricitet och i landsbygdsområden så har endast 7% av befolkningen tillgång. Även tillgång till rent vatten är en brist där i Kenya endast 59% av befolkningen har tillgång. Sett till jordbruket så är 72% av åkrarna regnbevattnade vilket leder till dåliga skördar vid torra år så som i 2009 vilket slog hårt mot Kenya. Under 2012-2014 så uppskattades 22% av Kenyas befolkning vara undernärda.

Det huvudsakliga syftet med detta examensarbete är att analysera hur FNs globala mål, som nämnts ovan, kan nås för Kenya genom en CLEWs metod där klimat, land, energi och vatten modelleras och sammanlänkas där det är möjligt för att se hur de gemensamma resurserna kan användas på bästa sätt. De modelleringsverktyg som används är OSeMOSYS, ONSSET och WEAP.

Modelleringen visade att universal access till elektricitet till 2030 kan uppnås, där två olika nivåer av behov modellerades. För elektricitetsnätet så optimerades det billigaste alternativet för Kenya där gasturbiner och geotermisk energi var de bästa alternativen. Vidare för de områden som inte är kostnadseffektiva att nätansluta visade analysen att solpaneler och diesel var billigaste alternativen vid låg energiförbrukning medans vid högre så var det mer kostnadseffektivt med s.k. ”mini-grid” där fler hushåll kan ansluta sig. Sett ur vattentillgången för Tana åns uppsamlingsområde så påverkade Kenyas stora planer på bevattningssystem för jordbruket uppströms de urbana områdenas vattenbehov. Sett ur klimatperspektivet så släpper de föreslagna energimodellerna (6 resp. 9 MtCO2eq) ut mindre än vad the nationella klimatplanen estimerat för 2030 på 18.4 MtCO2eq.

Nyckelord: SDG, Kenya, OSeMOSYS, WEAP, CLEWS, optimering, ONSSET

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Abbreviations

Acronyms

CLEWs – Climate, Lands, Energy and Water system

COP21 – 21st Conference of Parties, Paris France 2015

GHG – Greenhouse Gas

INDC – Intended Nationally Determined Contribution for COP21

LCOE – Levelized Cost Of Electricity

OSeMOSYS – Open Source energy MOdelling SYStem

ONSSET - OpeN Source Spatial Electrification Toolkit

UNDESA - United Nations Department for Economic and Social Affairs

SDG – Sustainable Development Goals

WEAP – Water Evaluation And Planning system

List of units

GWh - Gigawatt hours

Ktoe - kilo tonne of oil equivalent

kWh - Kilowatt hours

tCO2eq - Tons of carbon dioxide equivalent

1. Background

In 2012 1.1 billion people still live without access to electricity where the majority is in Sub-Saharan Africa (excluding South Africa) (World Bank, 2013). Electricity access is one of the most critical parameters from an economical, environmental and developmental perspective that the world is facing today. Electricity access is a way out of poverty, increasing the productivity and improved health from a population perspective. Current energy system is inadequate to meet the demand and is also increasing the concentration of greenhouse gases (GHG) which leads to increasing temperatures. Almost 3 billion people rely on biomass for heating and cooking which gives health consequences as the buildings often are not well ventilated and with incomplete combustion. The use of biomass also often requires long hours of collecting wood which can lead to down prioritizing education, especially for women in the developing world (AGECC, 2010). Looking from Kenya's perspective only 23% have access to electricity, and 93% of the rural population lack electricity access (2012) which leads a majority of the population to rely on solid fuels for energy (World Bank, 2016).

At the same time over 700 million people does not have access to improved water source (World bank, 2016) and in over 50% of the countries in the world people suffer from food deficit (World bank, 2016). For Kenya 41% of the population does not have access to improved water and 22% of the population is undernourished (World bank, 2016) (Food and Agriculture Organization of the United Nations (FAO), 2016).

Natural resources like water, food and energy are scares in many parts of the world and critical for any society, but they are also interlinked. As seen in Table 1 there are several interdependencies which, when developing policies, requires a systems perspective as they use common resources (Bazilian, et al., 2011) (International Atomic Energy Agency, 2009).

TABLE 1. THE ENERGY, WATER AND FOOD NEXUS (DEVELOPED FROM (BAZILIAN, ET AL., 2011))

	Water	Food	Energy
Water		• From the anthropogenic water use as much as 60-70% is used for irrigation, and in developing countries it can amount to 90%.	• Thermal power plants use large amounts of water for cooling. • Hydropower plants use large land areas and disturb the natural water flow. • Oil refineries and synthetic textile industry uses large amounts of water in their processes.
Energy	• About 7% of commercial energy production is used to maintain the fresh water supply. • After usage it is treated and sometimes recycle which also requires energy.	• The OECD countries the agricultural sector consumes 3,5% of the final energy. • For the food processing and transport, the consumption is up to 7% of the total final consumption	

In September 2015 17 sustainable development goals (SDG) was announced by the UN to replace the Millennium development goals with a goal to achieve 169 targets by 2030 (United Nations General assembly 2015). The goals which have been defined related to the CLEWs nexus are:

- Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture.

- Goal 6. Ensure availability and sustainable management of water and sanitation for all

- Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all

- Goal 13. Take urgent action to combat climate change and its impacts* (UN General assembly, 2015).

The indicators developed by Inter-Agency Expert Group on SDG Indicators (IAEG-SDGs) are in total 330 indicators, and out of them 4 are defined to be of interest from a CLEWs perspective from goals 2, 6 and 7. For Goal 13 the CO2eq emissions from the electricity production will be considered and for Goal 7 also the renewable share of electricity production is of interest as the total final energy consumption includes all energy.

TABLE 2 LIST OF INDICATORS RELATED TO CLIMATE, ENERGY, LAND AND WATER (UN DESA STATISTICS DIVISION, 2016)

Indicator 2.1.1 Prevalence of undernourishment (% of population)
Indicator 7.1.1: Percentage of population with access to electricity
Indicator 7.2.1: Renewable energy share in the total final energy consumption (%)
Indicator 6.1.1: Percentage of population using safely managed drinking water services

As part of the Kenyan governments long term development policy they have established “Vision 2030” which has as main objective to transform Kenya into a newly industrializing, middle-income country where the economic goal is to achieve an average economic growth rate of 10% per year (Kenya Vision 2030, 2016).

As part of the Vision 2030 they also aim to secure:

- Universal electricity access to all by 2020 (Republic of Kenya Ministry of Energy and Petroleum, 2015).
- Improved water access to all by 2030 (Japan international cooperation agency, 2012).
- Improve food security and decrease vulnerability to droughts by large irrigation schemes (Republic of Kenya Ministry of Agriculture, Livestock and Fisheries, 2015).

Looking from the SDG, Kenya has today major gaps compared to the global average, as seen in Figure 1, which are 1) Access to electricity 2) Prevalence of undernourishment and 3) Percent of the population with access to improved water sources.

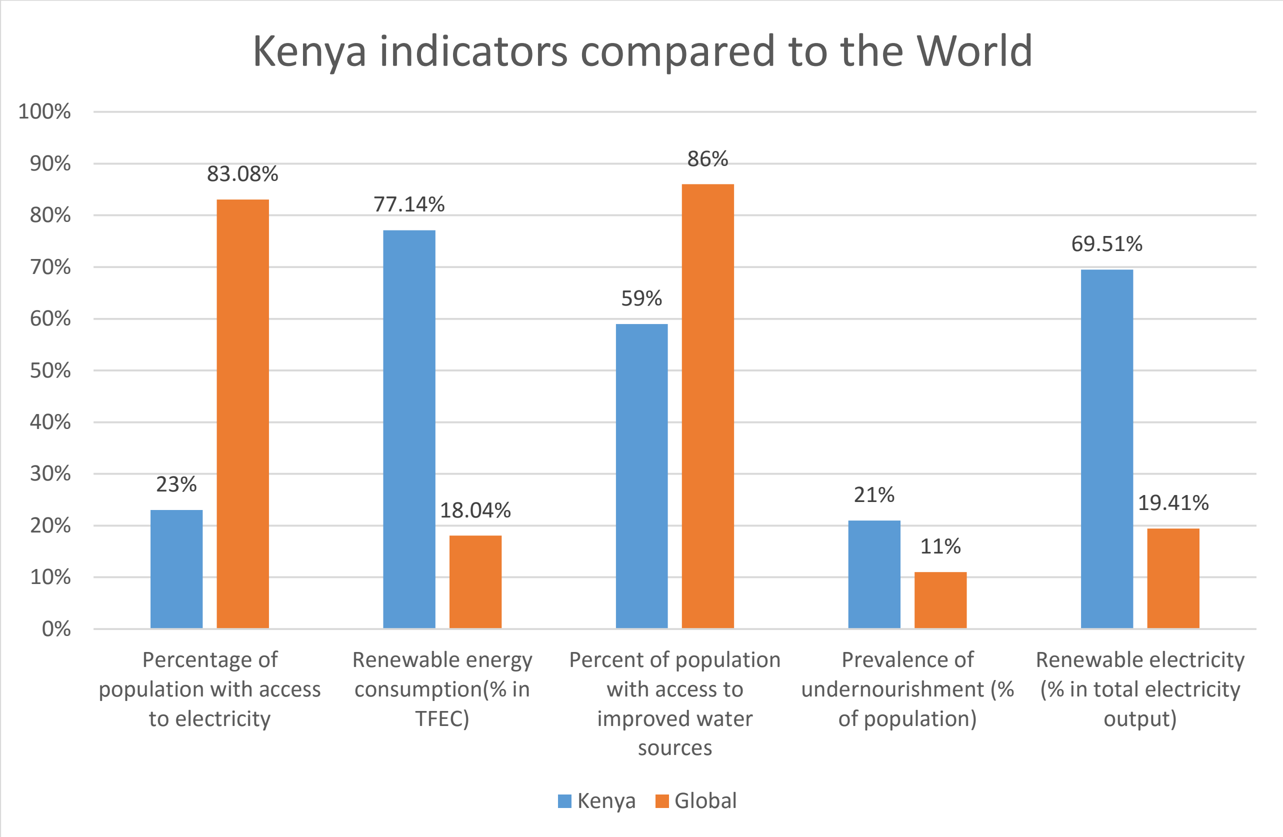

FIGURE 1. INDICATORS FOR KENYA COMPARED TO THE GLOBAL AVERAGE (WORLD BANK, 2016), (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO), 2016), (WORLD BANK, 2016)

1.1 Previous research

Looking from the CLEWs perspective there has not been any studies conducted for Kenya which models the long term nexus of Climate, Land, Energy and Water.

For Mauritius a study by (Welsch, et al., 2014) following the CLEWs framework was conducted where modelling tools were LEAP (Long range Energy Alternatives Planning System), WEAP (Water Evaluation And Planning) and GAEZ (Global Agro-ecological Zones). The interlinkages between agriculture, energy and water were made for several areas e.g. irrigation water demand, water for cooling thermal power plants, hydropower, electricity demand for pumping water. The study found that by interlinking the climate, land-use, water and energy affected the outcome of modelling results compared to Current practice where e.g. rainfall reductions from climate changes affect the water supply which is not considered in current practices.

For Nigeria a study by (Mentis, et al., 2015) developed the methodology for OpeN Source Spatial Electrification Toolkit (ONSSET) and applied it to Nigeria where 55% of the population lack electricity access. The results showed that electrifying all of Nigeria would have a LCOE ranging between 0.15 $/kWh – 1.4 $/kWh, and the total cost would amount to US$15.4 billion (US$11.4 billion for grid, US$3.9 billion for mini-grid and US$ 0.06 billion for stand-alone).

Furthermore, for all countries in Africa an ONSSET model was built based on the World Bank Tier framework for residential electricity access where also an electrification model for Kenya is available on UNDESA Modelling tools webpage (UNDESA, KTH dESA, 2016).

A study by (Zeyringer, et al., 2015) analyses the possibilities for grid/off-grid connection for households in Kenya considering PV panels for off-grid solutions. The approach divides rural from urban (excluding Nairobi and Mombasa) and through a regression analysis defines the household demand and projects the demand until 2020 by key indicators GDP, population and education years for population over 15 years. The supply optimization is based on a Geographical Information System (GIS) approach where the cost of extending transmission km^{-1} and grid cost is compared to PV stand-alone per "cell". The study found that in 2020 17% of the population could cost effectively install PV panels.

Furthermore a study by (Taliotis, et al., 2016) modelled electricity trade between trade pools in Africa where Kenya is part of the East African Power Pool (EAPP) and found that by increasing trade between the African countries it could reduce electricity generation costs.

From a hydrology perspective several studies have been performed on different catchments in Kenya e.g. for the Mara river by (LVBC & WWF-ESARPO, 2010), and the Tana estuary by (Kitheka, et al., 2005). For the Mara River which runs into the Victoria Lake a study by (Mwangi, et al., 2016) studied the changes of the discharge considering climate change compared to land-use and found that land-use changes impact the discharge more (with 97.5%) than climate change (2.5%).

Looking from the SDG and policies in Kenya aiming to increase both energy, water and food security the systems perspective with the CLEWs framework can reveal pressure points and even contradictory policies which otherwise would be veiled.

1.2 Problem definition

The links between Climate, Land, Energy and Water are clear and as the policy formulations in Kenya efforts to increase the energy, food and water security a development without an integrated and coordinated approach the policies can end up counterproductive and incoherent.

1.3 Objective & Research question

The main objective of this master thesis is to evaluate the Climate Land Energy and Water (CLEWs) nexus for Kenya through the CLEWs framework and propose how to both increase the energy supply together with food and water security which is connected to the SDGs and the aim of the policies established in Kenya.

Following the CLEWs framework where would the pressure points be and how could a holistic policy development and achieving the Sustainable Development Goals for both increasing energy, food and water security look for Kenya?

2. Current situation and policies for Kenya

In this chapter the current situation and policies in Kenya for Climate, Land, Energy and Water are described.

2.1 Climate

The CO2 emissions is relatively low and in 2010 amounted to 73 $MtCO_2eq$ where 75% came from changes in Land Use- Land Use Changes and Forestry (LU-LUCF). A majority of the population is dependent to wood as primary fuel which leads to deforestation if not managed. This together with increasing demand for cultivated land together with development of urban areas increases the Land use changes as well as Changes in Forestry. The other sectors which contributes significantly to the GHG-emissions are the transport and energy sector (Republic of Kenya Ministry of environment and natural resources, 2015). For the electricity sector emissions have a projected growth from 2.2 MtCO2e to 18.4 MtCO2e by 2030 for the BAU scenario in the National Climate Change Action Plan (Cameron, et al., 2012).

In Kenya's Intended Nationally Determined Contribution (INDC) for the COP 21 in Paris France their mitigation target is to abate its GHG emissions by 30% relative to the BAU scenario (of 143 MtCO2eq) by 2030. Even though mitigation is important adaptation will be addressed by activities within e.g. agriculture with more resilient crops, better water restoration by reforesting and rehabilitating the main water towers (Republic of Kenya Ministry of environment and natural resources, 2015).

2.2 Land

Kenya is a tropic but also an arid land, where 80% of the land area is arid or semi-arid where annual precipitation is 200-750 mm and in the humid area the precipitation is around 1,800 mm annually. In 2009 there was a drought which affected the food availability for many people as 72% of the agriculture is rain fed (Food and Agriculture Organization of the United Nations (FAO), 2016).

As a part of the government in Kenya's Vision 2030 the irrigation should be further developed from the current irrigated area of 150 000 ha to 1 341 900 ha by 2030 to reduce the vulnerability for drought and increase the food production (Republic of Kenya Ministry of Agriculture, Livestock and Fisheries, 2015).

2.3 Energy

The renewable total energy consumption is 77%, where 55% is Primary solid biofuels, but for the electricity production the renewable share amounts to 69% with geothermal and hydropower as main sources as seen in Figure 2 (International Energy Agency, 2013). Current residential electrification in Kenya is 51 kWh/person/year based on the electricity consumption in the residential sector defined in the energy balance divided by total population (International Energy Agency, 2013) (World Bank, 2013). The average household is in 2012 5.9 people per household (Energy Regulatory Commission, 2011) which amounts to 300 kWh/household based on World Bank Tiers would be just above Tier 2 at 224 kWh/household (Nerini, et al., 2016) (Angelou, et al., 2013). One of the policies from the government is universal electricity access by 2020 to enhance the economic development which is connected to Vision 2030 (Republic of Kenya Ministry of Energy and Petroleum, 2015).

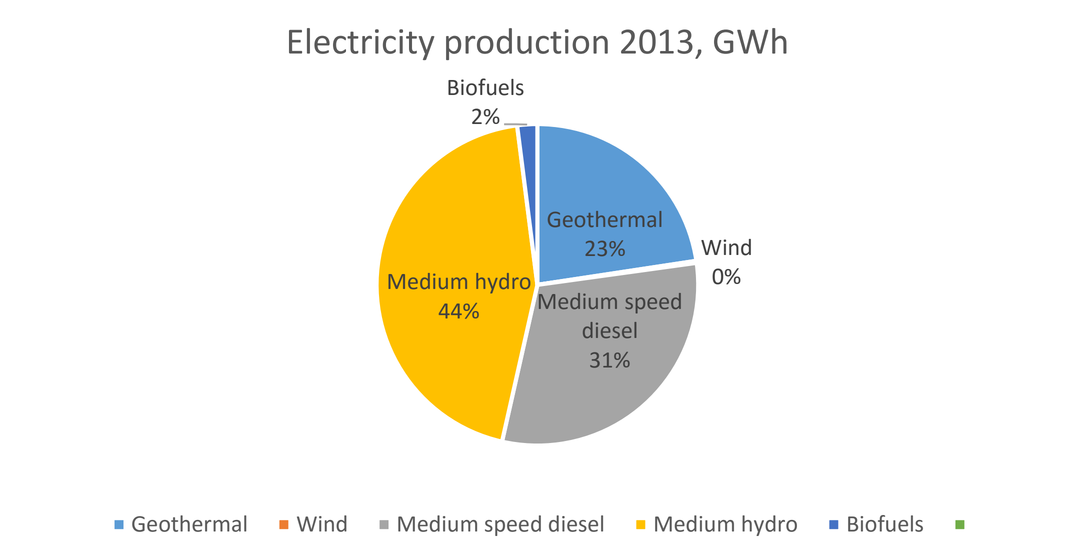

FIGURE 2. ELECTRICITY PRODUCTION BY TECHNOLOGY IN KENYA 2013 (INTERNATIONAL ENERGY AGENCY, 2013)

As part of Vision 2030 Kenya aims to be a middle income country by 2030 and in Table 3 a comparison of electricity consumption to three countries from World bank definition of high-middle income countries (World Bank, 2016). A low, medium and high level of electricity consumption per household was chosen: Peru, Turkey and Bulgaria. To achieve electricity levels compared to Peru Kenya would need to increase the residential electricity with 378% by 2030.

TABLE 3. HIGH-MIDDLE INCOME COUNTRIES ELECTRICITY CONSUMPTION PER HOUSEHOLD

Country	*Residential electricity consumption per household (International Energy Agency, 2013)*
Peru	1434 kWh/household
Turkey	2465 kWh/household
Bulgaria	3481 kWh/household

The Ministry of Energy and Petroleum has plans to expand the electricity production with coal (4.5 GW in 2030) and Geothermal (5.5 GW by 2030). As for hydropower there are plans to expand the hydropower plants and the government estimates the unexploited potential to be 1249 MW of large hydro power plants and 850 MW of small to medium hydro. The government also wants to promote nuclear power generation and have establish a nuclear electricity programme and aims to install the first nuclear power plant in 2025 of 1 GW (Republic of Kenya Ministry of Energy and Petroleum, 2015).

2.4 Water

The actual renewable water per capita amounts to 711 m^3 which compared to the global availability at 6000 m^3/capita is very low. People living without improved water source amounts to 41% or 17.2 million people. Out of the total water consumption 59% can be attributed to agriculture where 50% is irrigation (Food and Agriculture Organization of the United Nations (FAO), 2016).

As part of the Vision 2030 the government aims to provide improved water and sanitation for all of the population by 2030. Also the water service providers (WSP) should use only piped water supply and the water supply should amount to suitable level for all population (Japan international cooperation agency, 2012).

In Table 4 a matrix of the nexus for Kenya is illustrated for Climate Land Energy and Water.

TABLE 4. CLEWS NEXUS FOR KENYA

	Climate	Water	Food	Energy
Climate			75% of the CO_2 emissions are from the land use, land-use change and forestry (LULUCF) and agriculture sectors (Republic of Kenya Ministry of environment and natural resources, 2015)	25% of the CO_2 emissions are from the energy sector (excluding deforestation for biofuel) (Republic of Kenya Ministry of environment and natural resources, 2015). The government have plans to install coal power plants (4.5 GW) which will increase the CO_2 emissions from electricity production (Republic of Kenya Ministry of Energy and Petroleum, 2015).
Water	Evapotranspiration will accelerate as the temperature increases which will negatively impact the surface water availability, but at the same time the rainfall will accelerate in Eastern Africa with climate change (Bryan, et al., 2013).		From the anthropogenic water use 59% is used for agriculture where 50% is for irrigation in Kenya. Most of the agriculture is rain fed at present (Food and Agriculture Organization of the United Nations (FAO), 2016)	The main primary energy source in Kenya is biomass but the deforestation in Kenya's "water towers" increases the volatility in water supply and droughts (Akotsi, et al., 2006). From electricity production thermal power plants use large amounts of water for cooling, where in Kenya the thermal power plant amounts to 31%. Hydropower plants use large land areas and disturb the natural water flow and in Kenya the hydropower production amounts to 44% (Bazilian, et al., 2011) (International Energy Agency, 2013).
Food	In East Africa, there are expected increases in rainfall but they are not likely to increase agricultural productivity due to unfavourable spacing and timing of precipitation. The increased temperature will increase the evapotranspiration which will lead to less surface water (Bryan, et al., 2013).	22 percent of the country's population is undernourished in 2012-2014. Drought is a major reason when the bimodal rainfall is not enough for the crops to grow. Rainfall is the main method of watering crops (72%) (Food and Agriculture Organization of the United Nations (FAO), 2016). There is plans to expand land under irrigation to 1 341 900 ha by 2030 in line with Vision 2030 (Republic of Kenya Ministry of Agriculture, Livestock and Fisheries, 2015)		

Energy			The energy use for agriculture is mainly Fuel oil and gasoline, but no electricity (International Energy Agency, 2013).	

3. Methodology and model build

In this chapter the approach used for the CLEWs analysis is described with a methodology discussion with validity and reliability aspects of the chosen methodology.

3.1 CLEWs approach and Reference Energy System (RES)

The CLEWs approach used for this thesis is an iterative process where the modelling starts in OpeN Source Spatial Electrification Toolkit (ONSSET)[1] to define the residential electricity consumption. The ONSSET toolkit use GIS to optimize the residential electrification pathways including both grid, mini-grid and stand-alone solutions. From the ONSSET modelling the residential grid demand is modelled in Open Source Energy MOdelling SYStem (OSeMOSYS)[2] together with Industry and Other demand to optimize the grid production. The Levelized Cost Of Electricity (LCOE) for the grid will be iterated to ONSSET for the optimized grid cost from OSeMOSYS.

From the OSeMOSYS modelling the hydro dam demand will be modelled in Water Evaluation And Planning (WEAP)[3]. WEAP is a long term modelling tool which can be used to model a single catchment to assess impacts on the water balances for different scenarios. Due to lack of data for the water modelling the model will cover parts of the system which can give an indicative result for modelled catchment.

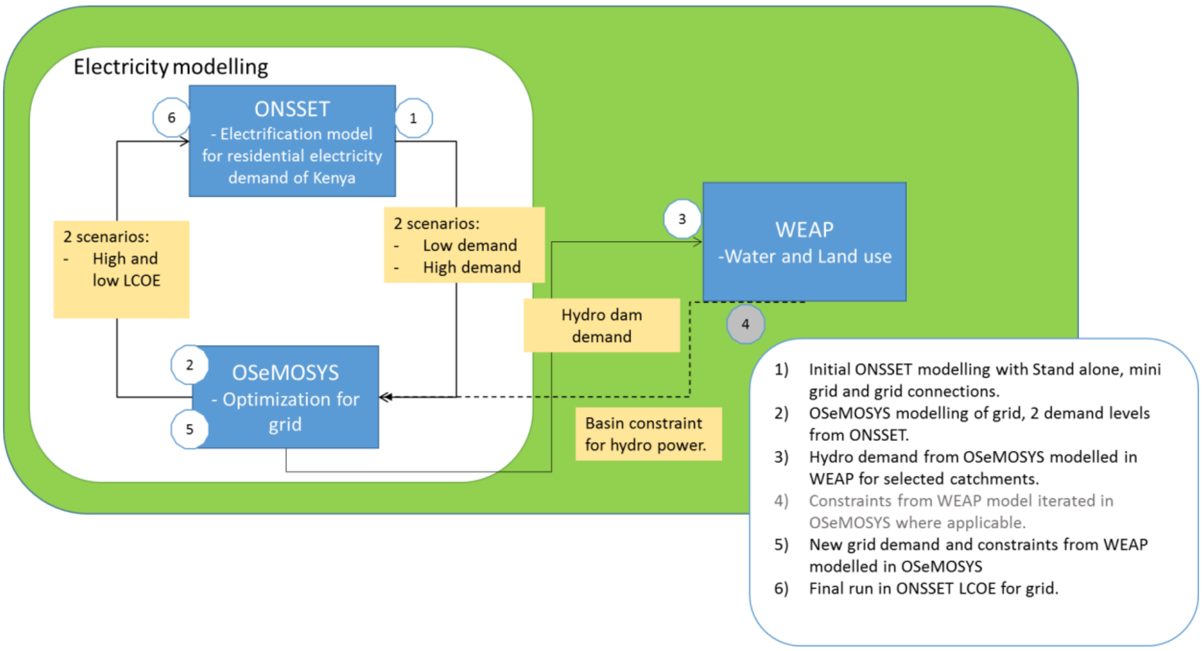

FIGURE 3. CLEWS APPROACH FOR KENYA

The Reference Energy System (RES) for Kenya is illustrated in Figure 4 which includes both the ONSSET and OSeMOSYS energy system. The WEAP area is highlighted in blue for modelled hydropower plans in OSeMOSYS. As the residential demand has a possible supply not only from grid but also from Mini-grid and Stand-Alone the distribution to the residential sector is separated from the Industrial and Other electricity demand as these demands is not part of the ONSSET modelling. For simplification the Oil refinery in Kenya was excluded from the model as this is not the focus point for the analysis. Also export and import between neighbouring countries are excluded from the analysis.

[1] For more detailed information on ONSSET please see (Nerini, et al., 2016), (Mentis, et al., 2015).

[2] For more detailed information on OSeMOSYS please see (Howells, et al., 2011), (Welsch, et al., 2012).

[3] For more detailed information on WEAP please see (Stockholm Environment Institute, 2016).

Electricity (From Power Plants To Transmision level)	KEEL1
Electricity (From Transmision to distribution)	KEEL2
Electricity (From Distribution to Final consumption)	KEEL3
Electricity (From Tranmission to Distribution) Residential	KEELR2
Electricity (From Distribution to Final consumption) Residential	KEELR3
TECHNOLOGY (Power Plants)	**ID**
Wind power 25% capacity factor	KEWI25ph
Diesel Medium Speed - Combined cycle	KEHFCCph
Hydro power plant (river run-off) Small	KEHYRRph1
Hydro power plant (Dam) Medium	KEHYDMph2
Hydro power plant (Dam) Large	KEHYDMph3
Masinga Hydro power plant (Dam) Large	KEHYDMph3MA
Kamburu Hydro power plant (Dam) Large	KEHYDMph3KA
Gitaru Hydro power plant (Dam) Large	KEHYDMph3GI
Kindaruma Hydro power plant (Dam) Large	KEHYDMph3KIN
Kiambere Hydro power plant (Dam) Large	KEHYDMph3KIA
Mutonga Hydro power plant (Dam) Large	KEHYDMpn3MU
Low Grand falls Hydro power plant (Dam) Large	KEHYDMpn3LGF
High Grand falls Hydro power plant (Dam) Large	KEHYDMpn3HGF
Geothermal power plant, Binary Steam Power Plant	KEGOBIph
PV connected at the transmission level (>1MW)	KESOU1ph
Biofuel power production	KEBMCHph
Wind power 30% capacity factor	KEWI30ph
Diesel Medium Speed - Combined cycle	KEDSCCph
Natural Gas - CC	KENGCCpn
Coal fired power plant	KECOSCpn
Nuclear (Light Water)	KENULWpn
CSP (Concentrated Solar Tower with storage)	KESOC3pn
BACKSTOP	KECOBSpn
DS micro grid	KEDSMGpn
Mini-hydro <10MW	KEHYMGpn
PV 1750 Mini grid	KESOMGpn1
PV 2250 Mini grid	KESOMGpn2
Wind Mini grid CF 20%	KEWIMGpn0.2
Wind Mini grid CF 30%	KEWIMGpn0.3
Wind Mini grid CF 40%	KEWIMGpn0.4
Diesel Stand alone	KEDSSApn
PV Stand alone 1750	KESOSApn1
PV Stand alone 2250	KESOSApn2
Geothermal power plant, Flash Steam Power Plant	KEGOFSph

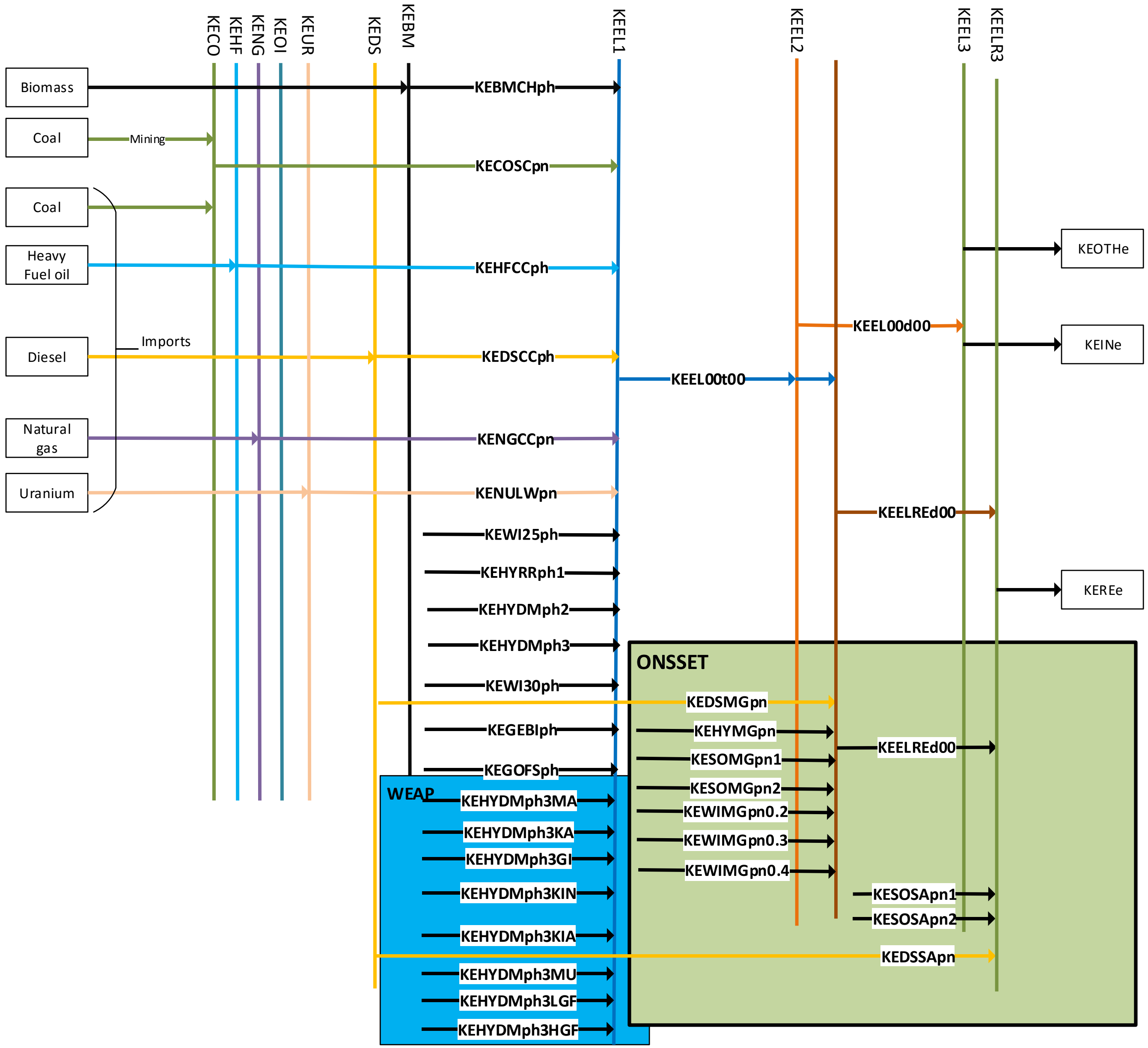

Figure 4. Reference Energy System, Kenya

3.2 Basic assumptions and parameters

For the three models the basic assumptions and parameters are in common which will be applicable throughout the modelling.

3.2.1 Basic assumptions

- The discount rate applied is 6% for all models.
- The monetary unit is million US$, Energy unit PJ, Capacity unit GW, MtCO2eq.
- Populations growth is assumed to follow medium growth according to (UN DESA Population division, 2015).
- Residential demand is divided in to urban and rural households.
- The OSeMOSYS and ONSSET model only considers electricity demand, (transport and heat is excluded).

TABLE 5. BASIC PARAMETERS FOR KENYA

Parameter	*Metric*	*Value 2012*	*Value 2030*	*Value 2040*
Population, total	People	42 542 978 (UN DESA Population division, 2015)	65 412 000, medium growth projection (UN DESA Population division, 2015)	80 091 000 (UN DESA Population division, 2015)
Urban population	Percent of total population	25 % (United Nations, Department of Economic and Social Affairs, Population Division, 2013)	32% (based on >2000 people/km^2 (Kenya National Bureau of Statistics, 2010)	38% (based on >2000 people/km^2) (Kenya National Bureau of Statistics, 2010)
Rural population	Percent of total population	75% (United Nations, Department of Economic and Social Affairs, Population Division, 2013)	68%	62%
Urban growth	Percent growth per year	4.34% (UN Statistical division, 2016)	4% (assumed value, based on total population 2030)	3.2 % (assumed value, based on total population 2040)
Rural growth	Percent growth per year	2.14% (UN Statistical division, 2016)	2% (assumed value, based on total population 2030)	1.4 % (assumed value, based on total population 2040)

Electricity access	Percent of total population	23% (World Bank, 2016)	100%	
Electricity access, urban	Percent of urban population	58.2% (World Bank, 2016)	100%	
Electricity access, rural	Percent of rural population	6.8% (World Bank, 2016)	100%	
People per household, urban	People per household	5 (Energy Regulatory Commission, 2011)	4 (Energy Regulatory Commission, 2011)	-
People per household, rural	People per household	6.5 (Energy Regulatory Commission, 2011)	6.5 (Energy Regulatory Commission, 2011)	-

3.2.2 Electricity demand

The demand modelled in both OSeMOSYS and ONSSET follows for the residential demand the World Bank Electrification Tiers (Angelou, et al., 2013) (Nerini, et al., 2016) where there are two scenarios modelled with a Low and High demand as seen in Table 6. For the Industry and Other demand the growth rates from (Energy Regulatory Commission, 2011) and for low and reference scenario is applied 2012-2031 and for 2031-2040 the 2031 growth rate is assumed to stay steady at 10% annual growth.

TABLE 6. LOW AND HIGH RESIDENTIAL DEMAND (RURAL/URBAN)

Scenarios	*Total electricity consumption (2030)*	*Rural electricity consumption*	*Urban electricity consumption*
Low electricity consumption	812 kWh/household	224 kWh/household	1800 kWh/household
High electricity consumption	1777 kWh/household	1800 kWh/household	2195 kWh/household

The annual growth from 2012-2030 for the modelled low scenario is 9.4% but as seen in Figure 5 the modelled demand for Kenya does not reach the levels that the Energy Regulatory Commission have forecasted. This can be explained by the 224 kWh/household residential demand for rural households in 2030 which is a low demand considering the household size in the rural areas are 6.5 people/household.

Looking at the historical annual growth between 2000-2012 the demand has grown 5.4% on average, and the exponential trend line in Figure 5 shows the continuation of the historical growth which would be approx. 3 times lower in 2040 than the modelled demand.

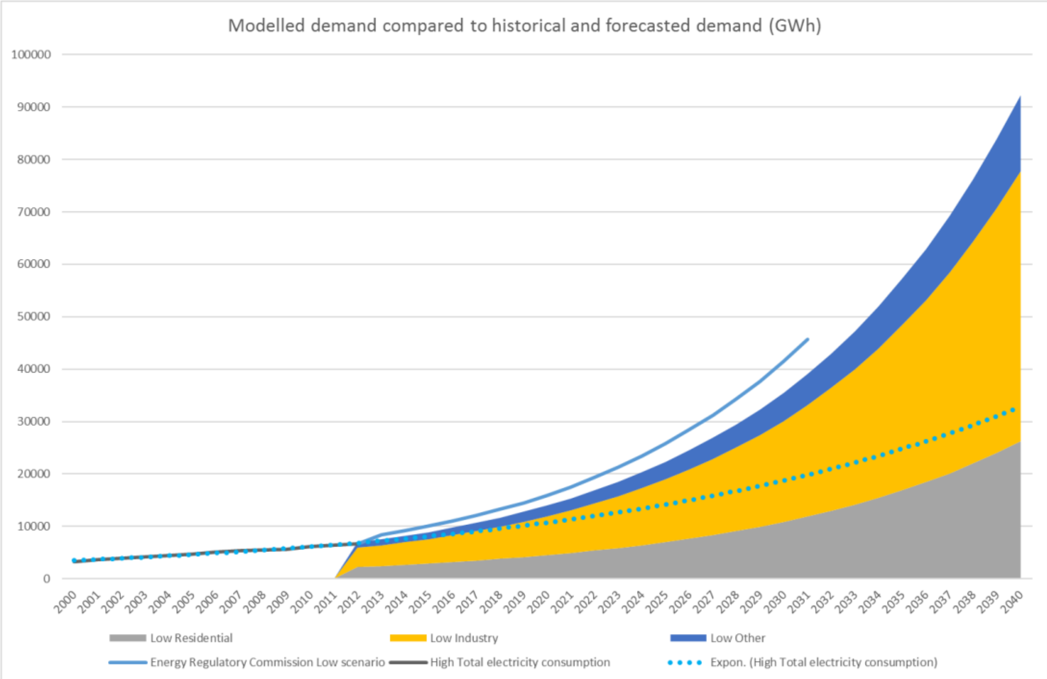

FIGURE 5. LOW DEMAND FOR KENYA COMPARED TO HISTORICAL AND FORECASTED (ENERGY REGULATORY COMMISSION, 2011) (INTERNATIONAL ENERGY AGENCY, 2013)

For the high demand the match is better comparing to the reference scenario from the Energy Regulatory Commission as seen in Figure 6 which follows the expected growth up until 2031. The annual growth for the high scenario amounts to 12.2% and comparing to the exponential trend line as seen in Figure 6 for 2000-2012 it is almost 6 times higher than the modelled demand in 2040.

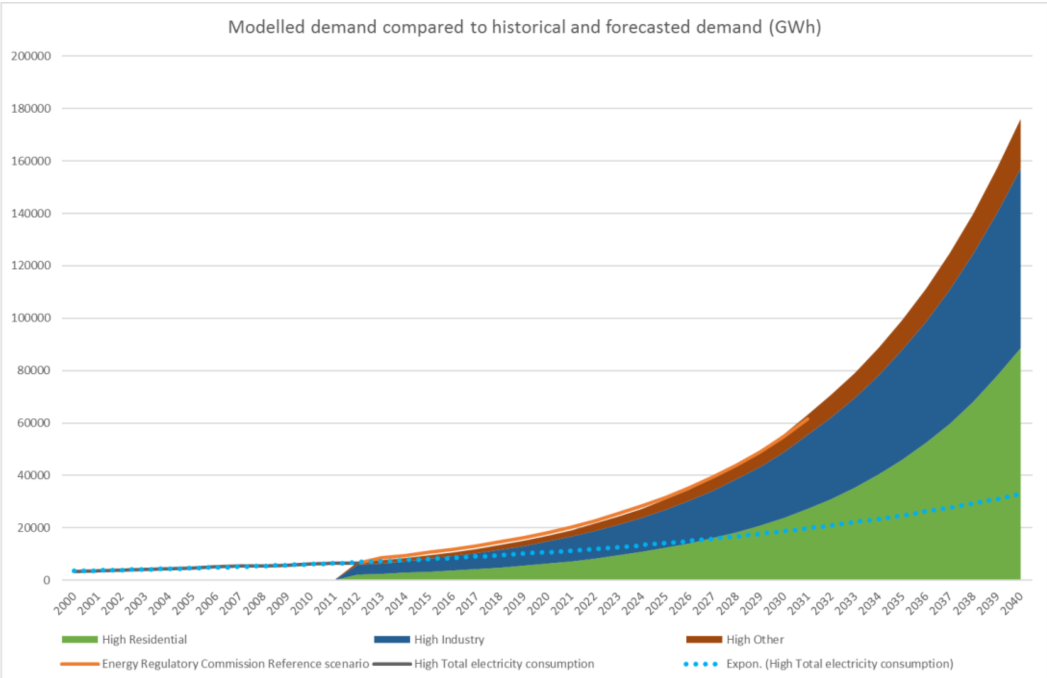

FIGURE 6. HIGH DEMAND FOR KENYA COMPARED TO HISTORICAL AND FORECASTED (ENERGY REGULATORY COMMISSION, 2011) (INTERNATIONAL ENERGY AGENCY, 2013)

3.3 Electrification model – ONSSET

For the ONSSET modelling following parameters and assumptions are used.

- For the residential electrification analysis, the base year is 2012 and projected until 2030 where the objective is 100% electrification in Kenya, in line with SDG Goal 7, universal electricity access.
- The "settlement" size which all GIS layers are related to is 2.5 km x 2.5 km (6.25 km^2) and are in total 92,867 settlements for Kenya. For the GIS layers used please see Appendix B.

For the costs related to the grid, micro grid and stand-alone solutions following values are used.

TABLE 7. COSTS FOR MICRO-GRID AND STAND-ALONE POWER

Parameter	*Capital cost $/kW*	*O&M $/kW*	*Fuel cost $/MWh*	*Capacity factor*	*Efficiency*
PV stand-alone	2566 (Ondraczek, 2014)	38.5 (1.5% of capital cost) (Ondraczek, 2014)	-	20%	-
Wind (capacity factor 20, 30, 40%)	2500 (IRENA, 2012)	50.0 (assumed 2% of capital cost)	-	20%, 30%, 40%	-
Diesel generator, Stand Alone	937.85 (ESMAP - World Bank, 2015)	93.4 (assumed 10% of capital cost)	172.8 (Ministry of Energy Kenya, 2010) (U.S. Energy Information Administration, 2016)	50%	28%
Diesel generator Micro grid	721.4 (ESMAP - World Bank, 2015)	72.1 (assumed 10% of capital cost)	172.8 (U.S. Energy Information Administration, 2016) (Ministry of Energy Kenya, 2010)	70%	33%
Mini grid PV (assumed same as stand-alone)	2566 (Ondraczek, 2014)	38.5 (1.5% of capital cost) (Ondraczek, 2014)	-	20%	-

Mini hydro	2902 (ESMAP - World Bank, 2015)	58 (assumed 2% of capital cost)	-	50%	-

For the first model the LCOE for grid is 0.125 $/kWh based on an 8% discount rate for 2013 electricity production as seen in Table 8.

TABLE 8. LCOE FOR GRID IN KENYA FOR FIRST MODEL (STEP 1 IN CLEWS APPROACH)

Power supply source	*LCOE USct/kWh (8% discount rate) (Ondraczek, 2014)*	*Production (GWh) 2013 (International Energy Agency, 2013)*	*Weighted cost*
Geothermal	6.9	2007	0.016
Wind	9.1	18	0.00018
Medium speed diesel	21.7	2726	0.065
Medium hydro	9.3	3945	0.041
Biofuels	0.1	179	0.002
LCOE GRID		**8875**	**0.125**

3.3.1 Planned transmission lines

The transmission lines for both existing and planned are of central importance for the ONSSET methodology as the distance from the transmission line combined with the electricity demand per settlement will impact how many will be connected to the grid.

For the first electrification analysis of how many that is connected to the grid a calibration towards the current grid was made based on two parameters: number of people and meters from the grid. To match the current electrification rate of urban (58.2%) and rural (6.7%) (World Bank, 2016) the distance from the current grid was set to 8400 m with a minimum population at 3400 per settlement. The distances and population density are probably slightly too high as current off-grid solutions are not included in the analysis.

The current transmission line modelled in ONSSET amounts to 2611 km in 2012 (GEOFABRIKK, 2016). Based on the map from Kenya Electricity Transmission Co Ltd. (KETRACO) the GeoReferencing tool in ArcMap was used to create a shape file, as seen in Figure 7, for planned transmission lines. The additional planned lines based on the GeoReferencing amounts to ~5000 km which in total is ~7600 km transmission lines which was modelled in ONSSET. There are plans by the government to expand the total transmission system by ~11000 km by 2033, where the initial ~5000 km should be implemented by 2018 (Energy Regulatory Commission, 2013). These maps for additional 6000 km were not available and thus is not included in the analysis.

To include the planned grid in Kenya (as seen in Figure 7) it was also assumed that the population living 5000 meters and with a minimum population of 1000 would be electrified in 2030. For the future planned grid electrification was chosen less lenient than the current electrification as mini-grid and stand-alone solutions are steadily increasing as cost efficient options.

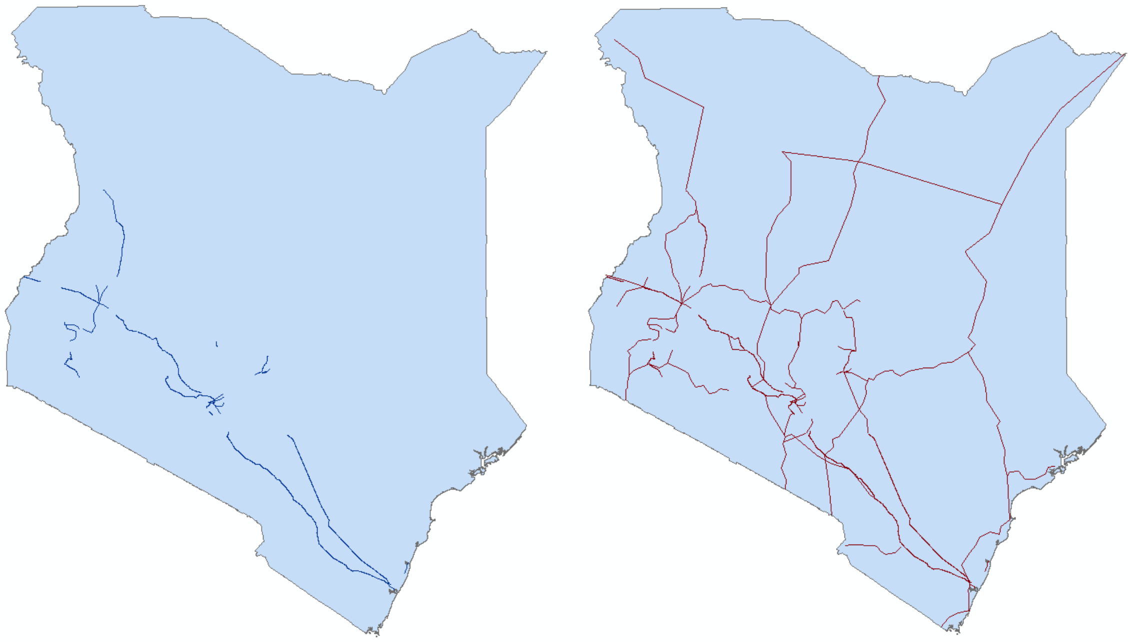

FIGURE 7. KENTRACO EXISTING (TO THE LEFT) AND PLANNED TRANSMISSION LINES (TO THE RIGHT) FOR 2018 (GEOFABRIKK, 2016) (KENYA ELECTRICITY TRANSMISSION COMPANY KENTRACO, 2016)

For the transmission and distribution losses it amounts to 18.2% (International Energy Agency, 2013) and the km price for High Voltage line in Kenya is US$ 92,823 (Energy Regulatory Commission, 2013).

As for the mining sites and power plants the planned transmission line was assumed to cover the expansion needed to these sites. As seen in Figure 8 the mining sites (seen in green) are located close to the planned grid except for two sites (one south west and the second south east).

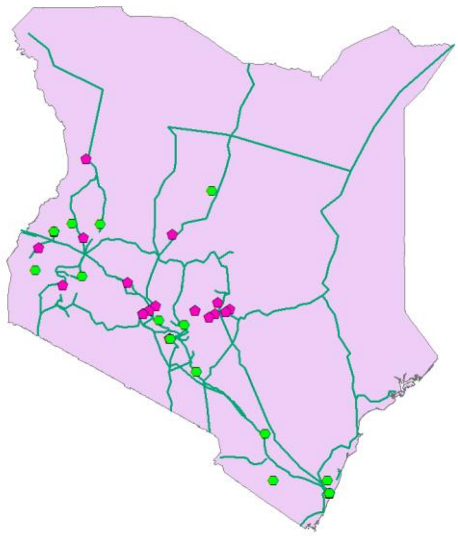

FIGURE 8. POWER PLANTS AND MINING SITES IN KENYA COMPARED TO PLANNED TRANSMISSION LINES (NATIONAL MINERALS INFORMATION CENTER OF THE USGS, 2014)

The wind potential and hydro potential was calculated in ArcMap as a dESA effort based on GIS-maps found in Annex B, Table B1.

3.4 Electricity grid model - OSeMOSYS

3.4.1 Basic settings

- The modelling framework is from 2012-2040 for OSeMOSYS to avoid any unwanted edge effect around 2030.
- 24 time periods per year, where the slices are based on 12 hours day interval and 12 hour night (as Kenya is situated on the equator) and actual days per month (January 31, February 28…), excluding leap year for February.
- Trade between neighbouring countries is not included as this is not part of the scope of the thesis.
- The demand modelled in OSeMOSYS is only the grid demand which does not reflect the total demand as ONSSET model covers the total residential demand.
- Feed-in-Tariffs will not be reflected in the OSeMOSYS model as they for the system will be represented as a cost which will be counterproductive in the optimization for renewable energy.
- The version used is OSeMOSYS_2015_08_27_short for all runs.

3.4.2 Specified demand curve

The load curve for a week in November 2013 shows that the variation between night and day varies between 800 MW night time and 1200 MW daytime with a peak load between 7-10 pm reaching 1400 MW.

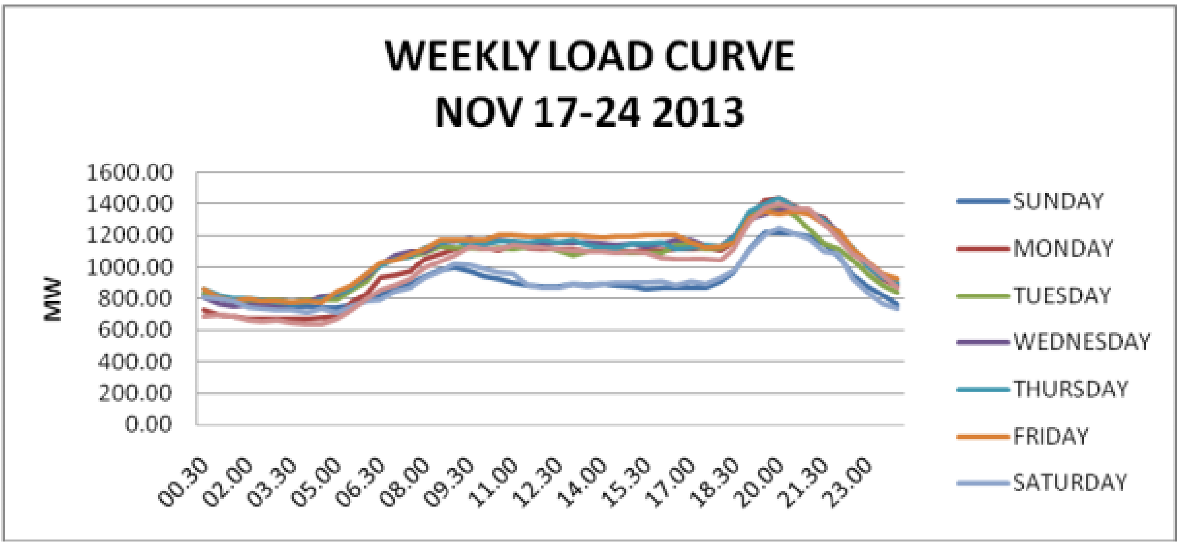

FIGURE 9. LOAD CURVE FOR WEEK IN NOVEMBER 2013 (ENERGY REGULATORY COMISSION, 2014)

The specified demand load will therefore be adjusted to 50% higher during the daytime compared to night time.

3.4.3 Technology performance and cost

For the transmission and distribution losses it is 18.2% (International Energy Agency, 2013), but the government has planned improvement to reach 15% losses by 2014, where most of the losses is in distribution to residential demand (Energy Regulatory Commission, 2011). The capital cost for the transmission lines installed capacity is based on the average cost of 17 projects planned to be completed between 2012-2014 with a cost of 112.76 M$USD/GW (Energy Regulatory Commission, 2012).

TABLE 9. TECHNOLOGIES EFFICIENCIES MODELLED

Technology	*Efficiency*
Coal Steam cycle	35% (International Energy Agency, 2010)
Medium speed diesel/Heavy Fuel oil combined cycle	45% (Burmeister & Wain Scandinavian Contractor A/S , 2016)
Geothermal	10% (International Energy Agency, 2013)
Transmission & distribution	94% & 87% (Energy Regulatory Commission, 2011)
CSP	15% (International Energy Agency, 2010)
PV	16% (International Energy Agency, 2014)
Nuclear Light water	36% (International Energy Agency, ETSAP, 2016)
Biomass, bagasse	33% (International Energy Agency, 2007)
Natural gas Combined cycle	55% (International Energy Agency, 2010)

TABLE 10. TECHNOLOGIES INVESTMENT COST, FIXED COST, VARIABLE COST AND TOTAL MAX CAPACITY

Technology	*Investment cost MUSD/GW, 6% discount rate during construction time*	*Fixed cost MUSD/GW*	*Variable cost MUSD/PJ*	*Total max capacity GW*
Geothermal (International Energy Agency, 2010)	Binary: 5049 Flash steam: 3787	Binary: 63 Flash Steam plant: 63	Binary: 6.9 Flash Steam plant: 2.5	Binary: 3.285 Flash steam: 6.715 (Energy Regulatory Commission, 2011)
Wind (International Energy Agency, ETSAP, 2016)	2650	50	5.55	See section 3.4.4

Heavy Fuel oil combined cycle/Medium speed diesel (Energy Regulatory Comission, 2014)	1678	62.5	2.50	-
Hydro river run off <10MW (Energy Regulatory Commission, 2011)	2902	2.05	1.24	0.5
Hydro dam <30MW (Energy Regulatory Commission, 2011)	3409	1.39	1.14	0.55
Hydro dam >30 MW (Energy Regulatory Commission, 2011)	3078	1.39	1.14	1.49
PV Utility (World Bank, International Finance Corporation, 2015) (International Energy Agency, 2014)	2120	4.2	0 (included in Fixed cost)	See section 3.4.4
Biomass CHP (Bagasse) (Energy Regulatory Comission, 2014)	2181	27.7	2.57	0.192 (Energy Regulatory Commission, 2011)
Natural gas Combined Cycle (Energy Regulatory Comission, 2014)	770	31	0.5	max 0.54 annually earliest 2018
Coal Single cycle	2903	69	1.28	Max 0.9 annually Earliest 2016
Nuclear Light water (International Energy Agency, ETSAP, 2016, p. Technology Brief E03)	6164	0 (Included in Variable cost)	4.44	Earliest date 2023 1.2 GW
Concentrated Solar Power, Solar tower with storage (International Energy Agency, ETSAP,	7420	0 (Included in Variable cost)	11.11	See section 3.4.4

2016, p. Technology Policy Brief E10)				
Transmission (Energy Regulatory Commission, 2012)	112	0	0	-
Distribution (Energy Regulatory Commission, 2012)	16	0	0	-

For the fuel cost the modelled costs are as seen in Figure 10 where the highest price is Diesel/Heavy fuel oil which follow the New Policies scenario from World Energy Outlook (2015) (International Energy Agency, 2015) and the cheapest fuel is uranium at UD$0.23/GJ. The Bagasse which is bio waste from the sugar industry is assumed to have no cost as the fuel would be waste otherwise.

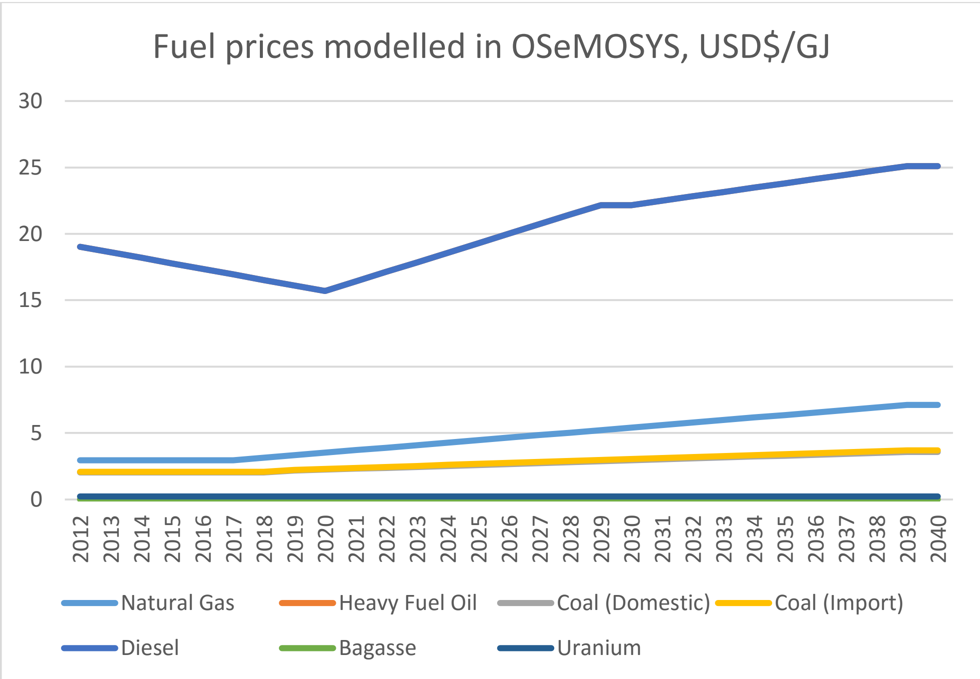

FIGURE 10. FUEL PRICES MODELLED IN OSEMOSYS

3.4.4 Renewable energy potential and capacity factors

The restrictions on the available energy in the wind is based on theoretical, technical, and geographical locations where conditions should be met with e.g. capacity factor higher than 20%, not protected area, distance from grid (Mentis, et al., 2015).

The annual Direct Normal Radiation (kWh/m^2/day) and Insolation Incident On A Horizontal Surface (kWh/m^2/day) is available from NASA on a 1 x 1-degree cell size average from 22-year Monthly & Annual Average (July 1983 - June 2005) (NASA, 2008) which together with the restrictions developed by (Sebastian Hermann, 2014) were considered available energy.

For CSP plants radiation under 1900 kWh/m^2/year is considered not suitable and therefore will be excluded (International Energy Agency, 2010). As the feasible settlements for PV and

CSP plants cannot be completely covered it is assumed that 1% of the feasible area can be used for solar power which equals 62,500 m^2 per settlement. For process steps please see Figure 11.

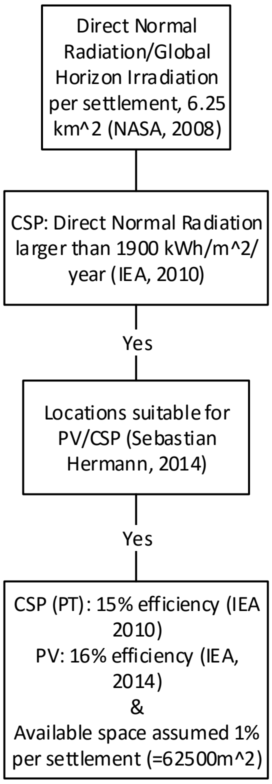

FIGURE 11. PROCESS FOR ASSESSING THE AVAILABLE ENERGY FOR CSP AND PV

The annual available wind and solar energy in Kenya is according to Table 11.

TABLE 11. SOLAR AND WIND ENERGY POTENTIAL IN KENYA

Renewable source	*Annual Energy available (PJ/year)*
CSP – Direct Normal Radiation	660 (based on process in Figure 11)
PV – Global Horizon Irradiation	3,981 (based on process in Figure 11)
Wind energy potential	2,330 (Dimitrios Mentis, 2015)

For the distribution of the energy the capacity factors for 92000 settlements in Kenya will be used:

TABLE 12. ENERGY POTENTIAL OF WIND PER CAPACITY FACTOR (DIMITRIOS MENTIS, 2015)

Capacity factor (%)	*Number of settlements*	*Energy per capacity factor (PJ)*
20-30	21058	1298.879
30-35	12414	765.708
35-40	4303	265.4134

In Equation 1 the method to distribute the average capacity factors based on the average wind speed is displayed. The method is a simplification to achieve the shape of each month.

EQUATION 1. MONTHLY WIND CAPACITY FACTOR CALCULATION

$$\boldsymbol{CF_{m,l} = \overline{CF}_{annual,l} \cdot \frac{\overline{WS}_{month,l}}{\overline{WS}_{year,l}}}$$

l = Capacity factor level 20-30, 30-35 and 35-40 (Dimitrios Mentis, 2015)

$CF_{m,l}$ = Monthly Capacity Factor for chosen l

$\overline{CF}_{annual,l}$ = Average Capacity factor for chosen settlements l

$\overline{WS}_{month,l}$ = Average Monthly Wind speed for settlement in chosen settlements l (NASA Global Modeling and Assimilation Office (GMAO) and GES DISC, 2016)

$\overline{WS}_{year,l}$ = Average Year Wind speed for chosen settlement l (NASA Global Modeling and Assimilation Office (GMAO) and GES DISC, 2016)

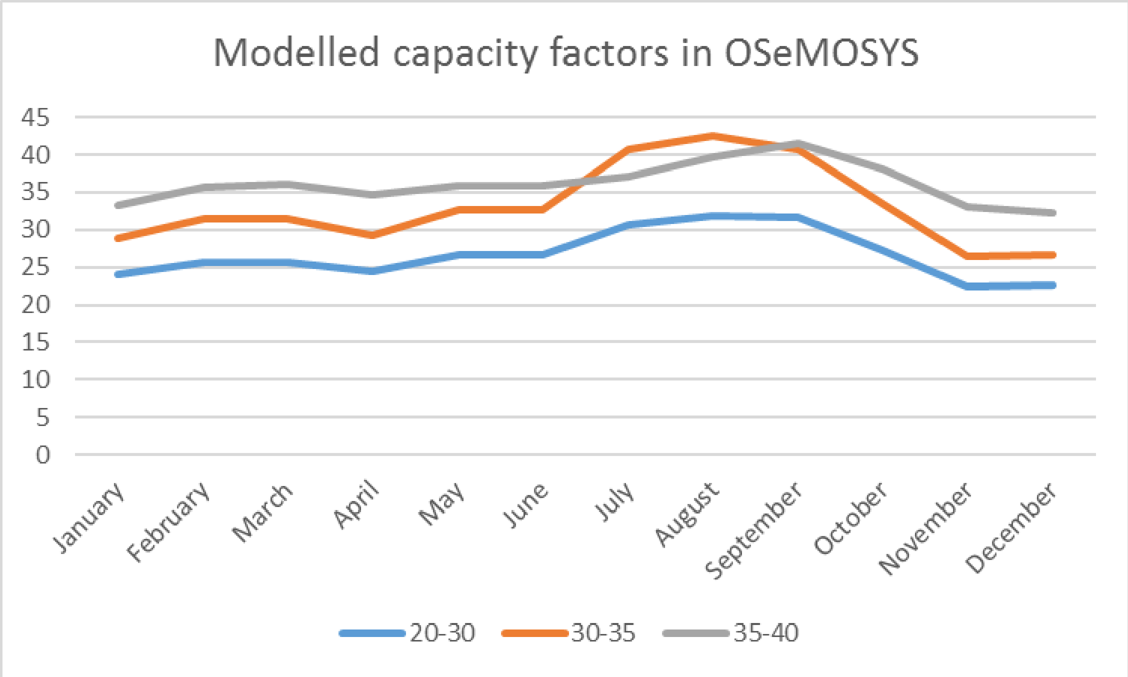

FIGURE 12. MODELLED MONTHLY CAPACITY FACTORS (%) FOR WIND IN OSEMOSYS

As seen in Figure 12 the wind speeds are highest during July-October and lower during the rest of the year.

Similarly, the Direct Normal Radiance and Insolation Incident on a Horizontal Surface monthly variation was applied for the PV and CSP capacity factors as seen in Equation 2.

EQUATION 2. MONTHLY DNR AND GHI CAPACITY FACTOR CALCULATION

$$CF_m = \overline{CF}_{PV,CSP} \cdot \frac{\overline{DNR/GHI}_{month}}{\overline{DNR/GHI}_{year}}$$

CF_m = Monthly Capacity Factor for PV and CSP

$\overline{CF}_{PV,CSP,}$ = Capacity factor 20% for PV and 40% for CSP

$\overline{DNR/GHI}_{month}$ = Average Monthly DNR/GHI (NASA, 2008)

$\overline{DNR/GHI}_{year}$ = Average Year DNR/GHI (NASA, 2008)

The modelled PV and CSP capacity factors in OSeMOSYS can be seen in Figure 13.

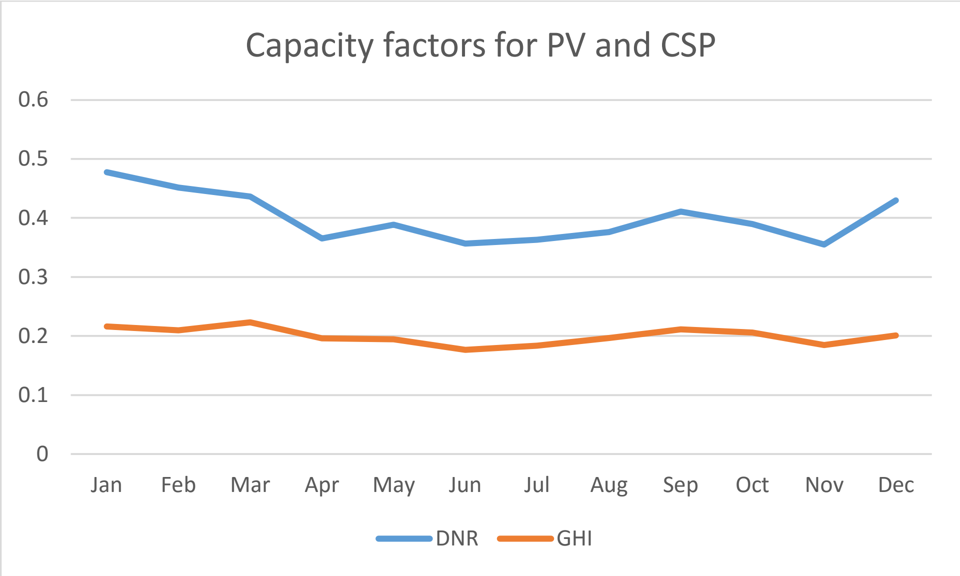

Figure 13. Capacity factor for PV (GHI) and CSP (DNR)

The capacity factors for hydro are based on the results from the WEAP modelling and was iterated to OSeMOSYS where the input Energy demand in WEAP was Capacity*8760h to see how much Energy the hydropower could meet in the modelled year 2012-2040. The average monthly value is displayed in Figure 14 where there are two power plants which does not exceed 10%, Gitaru and Low Grand Falls and one power plant (Mutonga) which exceed 90%. For these hydropower plants and also for all other hydropower plants outside the Tana catchment OSeMOSYS was modelled with the Kindaruma CF. The Kindaruma CF averages at 49% which is in line with (International Energy Agency, ETSAP, 2016, p. Technology Brief E06) which for large hydropower estimates 34-56% capacity factor.

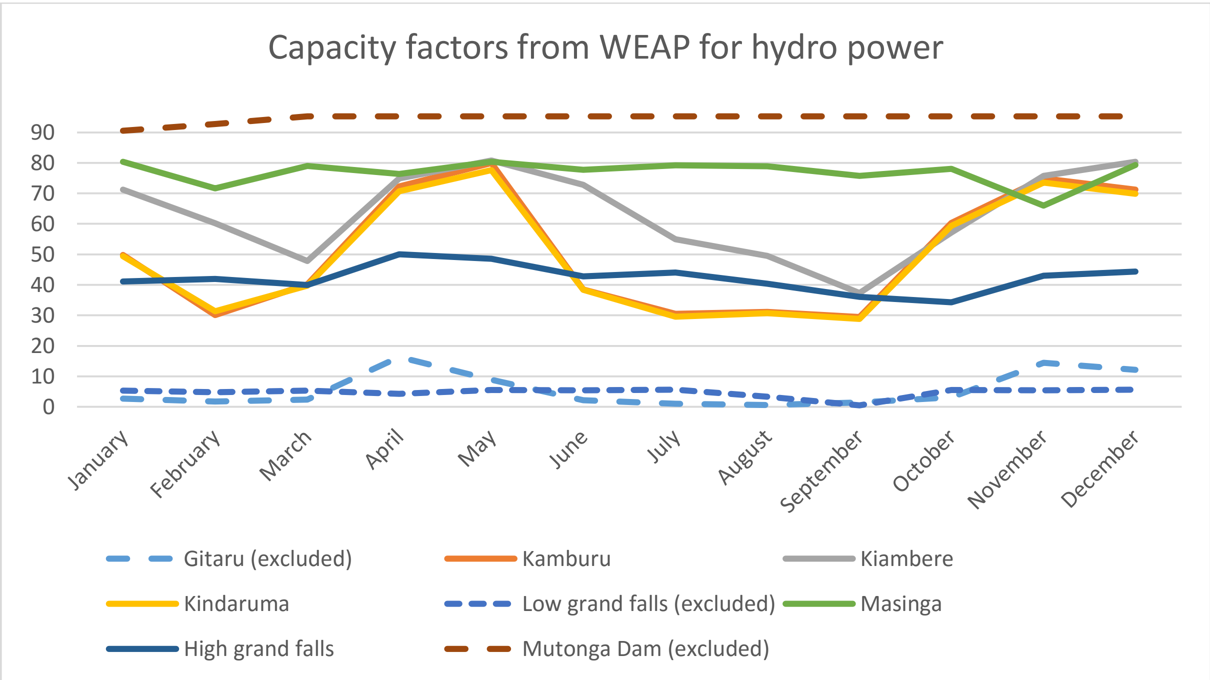

Figure 14. Capacity factors for hydropower modelled in WEAP

3.5 WEAP model

3.5.1 Basic parameter settings for Tana catchment

For the WEAP analysis only the Tana catchment will be analysed for three reasons: First the hydropower in the catchment supply 40% of the total power production and have more hydropower planned for the near future. Secondly the majority of the irrigation plans that the Ministry of water and irrigation have proposed are in the Tana catchment (Japan international cooperation agency, 2012) which is of interest for the CLEWs analysis. Thirdly there is a lack of data which does not motivate a more extensive analysis.

All subcatchments geographical boundaries and riversystem are developed in ArcMap where the sub catchments are developed in the Hydrology toolkit. For detailed list of GIS maps used for the WEAP model please see Appendix C. The method used for the catchements in WEAP is the "Rainfall Runoff" (simplified coefficient method), which does not consider the soil moisture.

The Minisitry of Water and Irrigation have developed a National water master plan 2030 (Japan international cooperation agency, 2012) where Kenya is divided into five major catchments. For this study the Tana catchment will only cover a sub-area of 89,000 km^2 of the total 126,026 km^2. In Table 13 the modelled sub-catchments in WEAP are described.

Table 13. Modelled sub catchments in WEAP

Catchment	*Sub-catchments*	*Rivers*	*Reservoirs*	*Gauges*	*Urban Demands*	*Rural Demands*	*Irrigation*
Tana catchment	Garissa	Tana river	-Masinga -Kamburu -Kindaruma -Kiambere -Gitaru -Mutonga (planned) -Low Grand Falls (planned) -High Grand Falls (planned)	-Garissa (The Global Runoff Data Centre 2016)	Garissa Urban -Household -Industry	Garissa Rural -Household -Livestock	Irrigation -G1 -G2 -G3 -G4 -G5 -G6 -G8 -G9 -G10
	Tana Estuary	Tana river		-Tana Estuary (Kitheka, et al., 2005)	Tana Urban -Household -Industry	Tana Rural -Household -Livestock	Irrigation -T3 -T7 -T8

The population per sub-catchment, as seen in Table 14, is calculated in ArcMap which is based on the same data as in the ONSSET model with same rural and urban growth.

TABLE 14. POPULATION PER CATCHMENT

Sub catchments	*Population 2012*	*Population 2030*	*Population 2040*	*Urban pop 2012*	*Urban pop 2030*	*Urban pop 2040*	*Rural pop 2012*	*Rural pop 2030*	*Rural pop 2040*	*Area km2*
Garissa	5,756,097	8,353,244	9,862,249	555,511	1,051,687	1,883,921	5,200,586	7,301,556	7,978,328	32,818
Tana estuary	1,166,306	1,675,289	1,926,564	15,926	32,265	47,760	1,150,379	1,643,024	1,878,804	56,247

For the household demand the following values were used for the Urban and Rural demand as seen in Table 15 which corresponds to the planned consumption in 2030 defined in the National Water Master plan 2030 as seen in Table 16 where on top of that there are large losses where the water loss amounts to 40% (Japan international cooperation agency, 2012).

TABLE 15. HOUSEHOLD WATER DEMAND

		2012	*2030*	*2040*
Urban household demand (L/p/d)	Improved water supply	75	75	92
	Unimproved water supply	60	60	60
	Percent with improved water supply	74%	100%	100%
Rural household demand (L/p/d),	Improved water supply	43	43	43
	Unimproved water supply	25	25	25
	Percent with improved water supply	55%	100%	100%

TABLE 16. PLANNED WATER DEMAND 2030 (JAPAN INTERNATIONAL COOPERATION AGENCY, 2012)

Item	Unit Water Consumption
1) Urban Water Supply (Nairobi/Mombasa and surrounding areas)	92 L/p/d
2) Urban Water Supply (Other area)	75 L/p/d
3) Large Scale Rural Water Supply	58 L/p/d
4) Small Scale Rural (Arid area)	25 L/p/d
5) Small Scale Rural (Others)	43 L/p/d

The Ministry of Water and Irrigation have plans to expand the irrigation in Kenya to increase the food security which is illustrated in Figure 15. The irrigation areas proposed are mapped where the major irrigation plans are in the Tana and Athi catchment in eastern Kenya. The irrigation areas in the Tana catchment were modelled in ArcMap with the GeoReferencing tool to model the irrigation needs in the sub-catchments in a more detailed way.

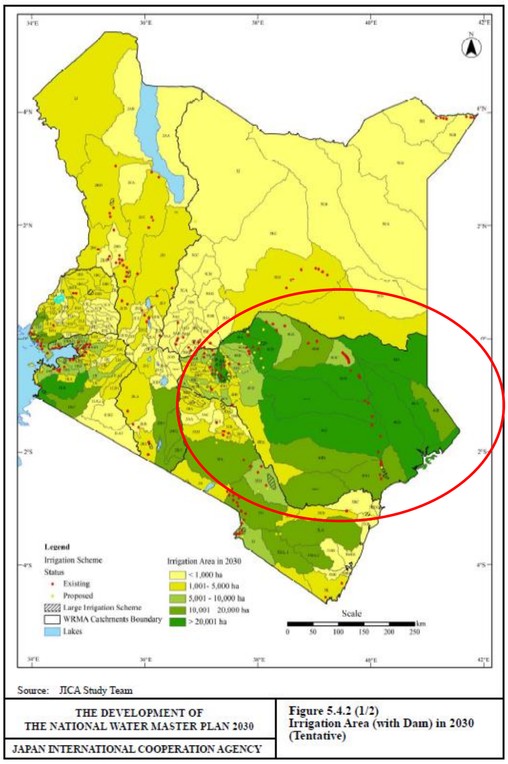

FIGURE 15. IRRIGATION PLANS FOR KENYA 2030 (JAPAN INTERNATIONAL COOPERATION AGENCY, 2012, PP. F-6)

3.5.2 Hydro power plans for Tana catchment

In the Tana catchment there are five reservoirs for hydropower generation: Masinga (40 MW), Kamuburu (94.2 MW), Gitaru (225 MW), Kindaruma (40 MW), and Kiambere (168 MW) with total installed capacity of 567 MW (Japan international cooperation agency, 2012). There are also plans to install two more power plants short term, Low Grand Falls 140 MW and Mutonga 90 MW in 2021 (Energy Regulatory Commission, 2013).

There is an alternative plan to develop a multi-purpose dam, High Grand falls dam, which would replace the Mutonga and Low Grand falls dam, with both hydropower, irrigation, water supply and flood control (Japan international cooperation agency, 2012).

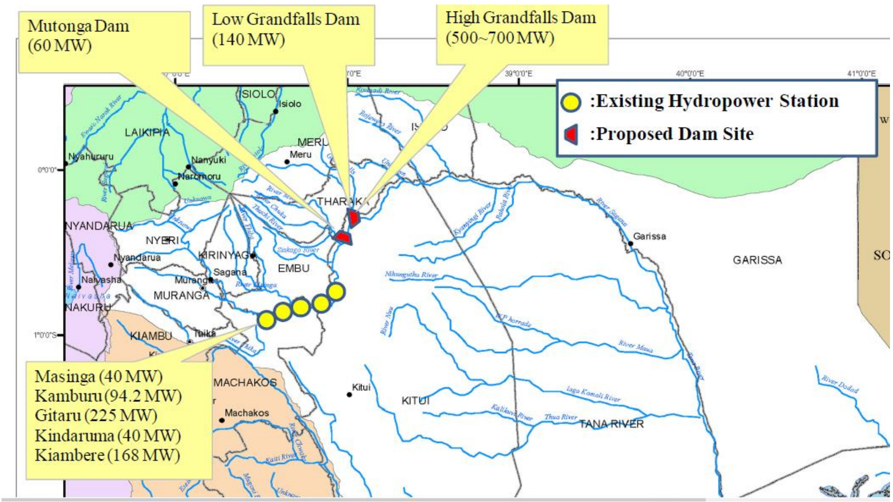

FIGURE 16. PROPOSED HYDROPOWER STATIONS IN TANA CATCHMENT AREA (JAPAN INTERNATIONAL COOPERATION AGENCY, 2012, PP. F-45)

From OSeMOSYS the energy demand was optimized based on capacity factors from WEAP. The energy demand from OSeMOSYS to WEAP is illustrated in Figure 17. For the Low demand the new hydro power stations is not preferred, but for the high demand both the Mutonga & Low Grand Falls and High Grand falls will be installed, but later than planned (2037 & 2038). As the hydropower plants already installed comes at a low cost both the high and low scenario will utilize the total available capacity in both scenarios.

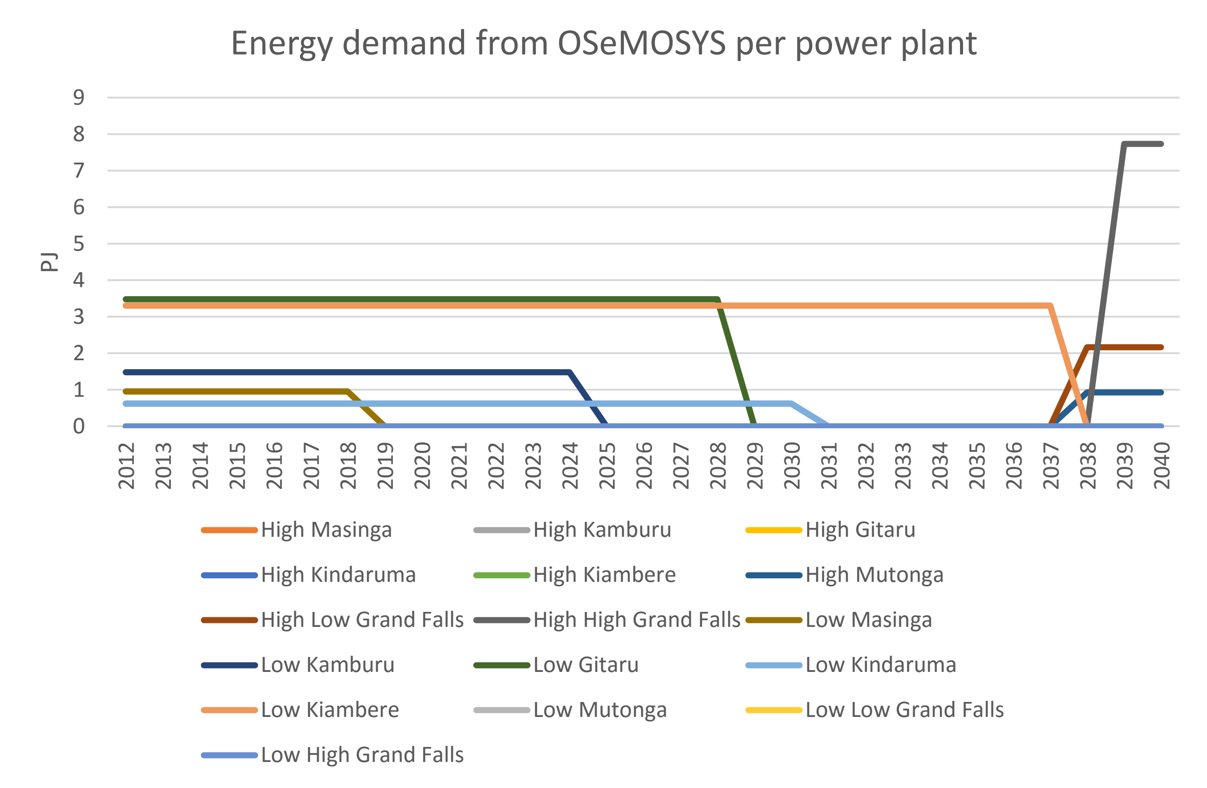

Figure 17. Annual Energy demand from OSeMOSYS to WEAP per hydro power plant (PJ)

3.5.3 Irrigation in Tana catchment

As Figure 15 showed the irrigation plans for Kenya are for large areas in the Tana catchment and in Figure 18 more detailed plans for irrigation is illustrated. For the modelled catchment the total area for irrigation in 2030 amounts to 424,674 ha, which is in line with the total irrigation plans for the area (Japan international cooperation agency, 2012).

Table 17. Irrigated area for each sub-catchment

Sub-catchment	*Irrigated area 2012 (ha)*	*Irrigated area 2030 (ha)*
G1	6,855	49,416
G2	8,224	59,998
G3	7,249	56,668
G4	1,027	7,499
G5	2,085	11,659
G6	1,052	7,685

G8	1,714	12,082
G9	6,169	45,000
G10	10000	10000
T3	16,803	134,155
T7	3,791	38,088
T8	312	2,325
Total	**56,379**	**425,674**

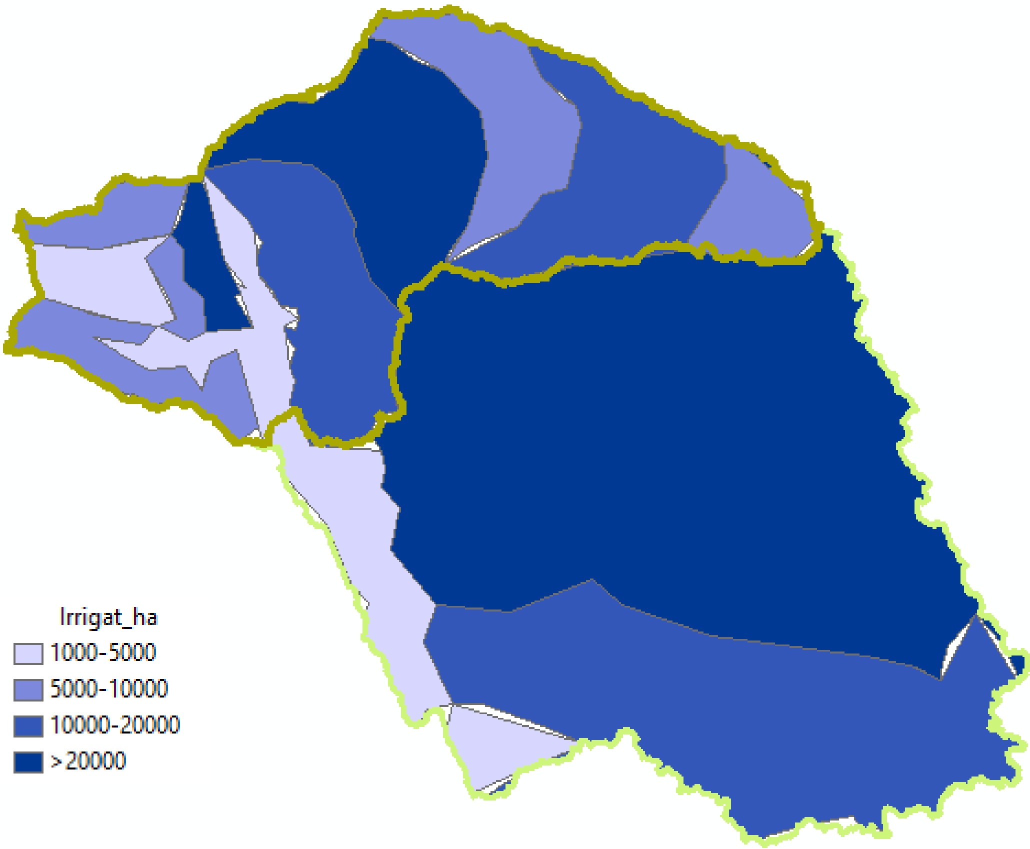

FIGURE 18. PLANNED IRRIGATION SCHEME FOR TANA CATCHMENT DEVELOPED IN ARCMAP FROM (JAPAN INTERNATIONAL COOPERATION AGENCY, 2012, PP. F-44)

Upstream the major crops are: banana, potato, beans and maize and in the outskirt of Mt. Kenya, tea and coffee are widely grown (Japan international cooperation agency, 2012).

The crops included in the analysis is based on the major crops in Kenya except for wheat as wheat is not planted in the region (FAO/IIASA, 2010) and the crops defined in the area by (Japan international cooperation agency, 2012) described in the previous section.

TABLE 18. CROPS INCLUDED IN THE ANALYSIS FOR TANA CATCHMENT

Product	*Assumed share of production in Tana catchment (%)*
Maize	50.3
Beans, dry	24.7
Sorghum	5.2
Cow peas, dry	5
Tea	4.4
Potatoes	3
Coffee, green	2.5
Bananas	1.35
Pigeon peas	3.3

3.5.4 Calibration of WEAP model

For the calibration in WEAP one way is to use flow measurements from stream gauges. For the stream gauge in Garissa the dataset was from 1934-1975 which for calibration purposes WEAP was modelled from 1934-1975, when only two of the hydropower plants were built (Kamburu 1974 & Kindaruma 1968). It was assumed that there was no irrigation needs for this period and that the evapotranspiration would increase in the rainy months according to Table 19.

TABLE 19. EFFECTIVE PRECIPITATION FOR GARISSA CALIBRATION

Month	*Jan*	*Feb*	*March*	*April*	*May*	*June*	*July*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Effective precipitation Garissa (%)	50	40	70	20	55	35	25	60	20	70	0	0

The reach before the stream gauge in Garissa follow the actual stream flow from 1934-1975 closely except for in November and December which is related to that the precipitation and evapotranspiration data (FAOClim-NET, 2016) is based on average values from 1982-1991. For the 2012-2040 model the effective precipitation is assumed to be the same as for 1934-1975 as no flow measurements were available for the model build for years after 1975 for Garissa. The same data from 1982-1991 for the evapotranspiration and precipitation is also assumed to be the same for 2012-2040 as more recent data on monthly basis was not available.

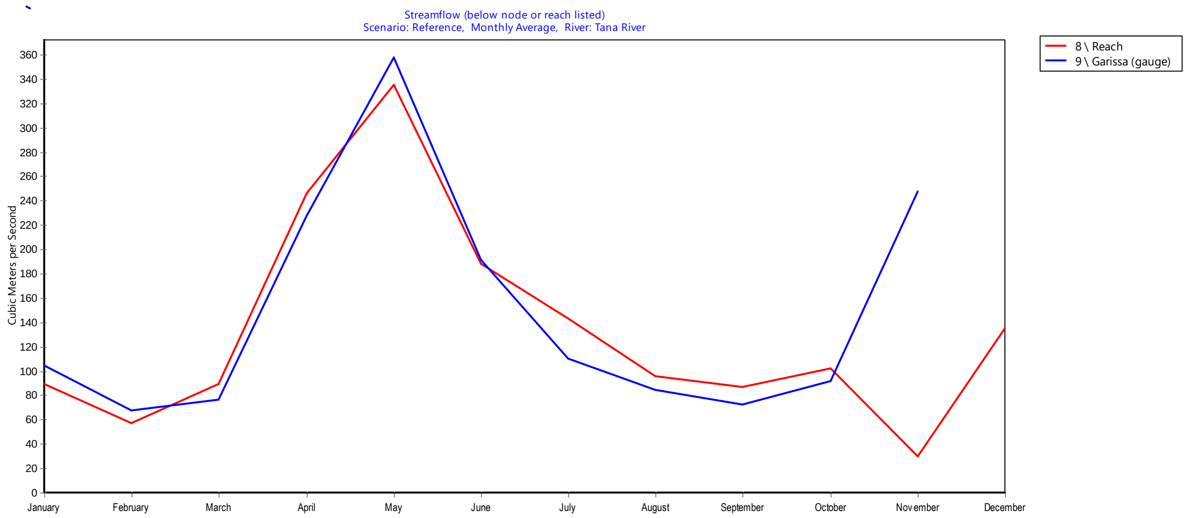

FIGURE 19. CALIBRATION OF STREAM GAUGE IN GARISSA

The same calibration is made for the Tana Estuary stream gauge which has data for 1957, 1959, 1961, 1962, 1982, 1983 and 2002. The same approach with population adjustment and hydropower expansion as for the previous calibration was made. As seen in Figure 20 the calibration for the Tana Estuary has a good match except for the rainy months April and November with effective precipitation as seen in Table 20. For these months the effective precipitation is 100%.

TABLE 20. EFFECTIVE PRECIPITATION FOR TANA ESTUARY CATCHMENT (%)

Month	*Jan*	*Feb*	*March*	*April*	*May*	*June*	*July*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Effective precipitation Tana Estuary (%)	80	80	90	100	75	0	0	20	40	90	100	90

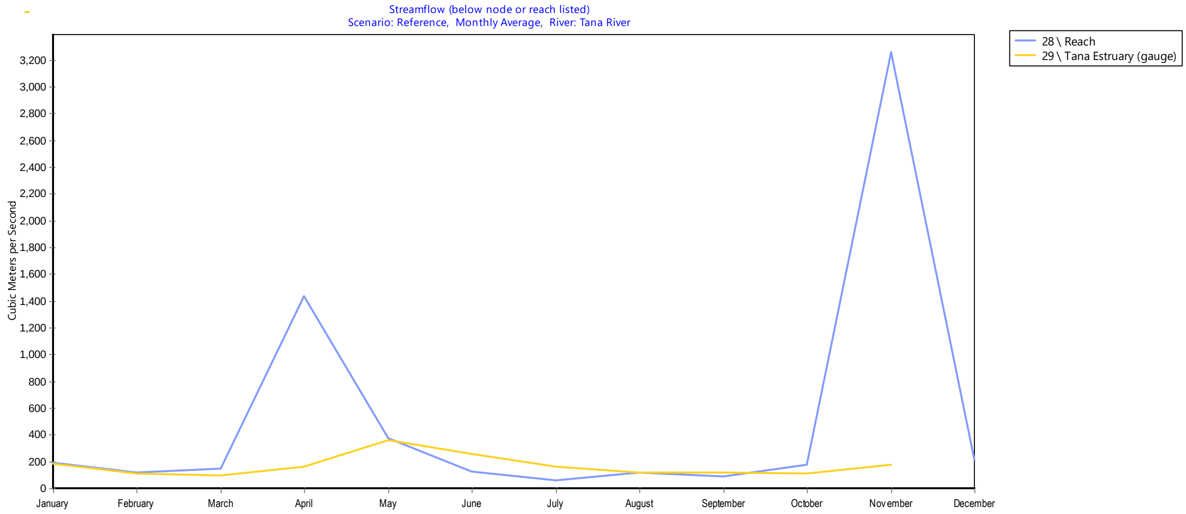

FIGURE 20. CALIBRATION OF TANA ESTUARY STREAM GAUGE

3.6 Methodology discussion

The methodology chosen for this master thesis is to support the overall objective which is how to achieve the climate, energy, water and food SDG/policy goals from a CLEWs perspective. To achieve this three models, which where is applicable, are interlinked with one another. From a scientific perspective the reliability and validity are questions that needs to be addressed to properly asses the outcome and conclusions from this thesis.

From a *reliability* perspective the tools used to model the data have clear input parameters defined for OSeMOSYS and WEAP which would, using the same version, produce the same result if repeated. For the ONSSET tool it is still under development, where this master thesis, outside of the research group, is the first to use it. Due to its early stages some of the algorithms could change over time which consequently could make it unreliable.

For the GeoReferencing that was made in ArcMap for the future transmission grid (ONSSET) and irrigation plans (WEAP) it will be difficult to repeat as this is based on drawing the GIS-map from a picture. The consequence of the GeoReferencing not being exactly the same has not a major impact as the transmission line is a line and will therefore not give a higher share of grid connections, but could be offset 1-2 km which would give electricity to another settlement. For the irrigation plans this is used for marking areas in WEAP and does not require exact match as long as the same number of areas are modelled.

From a *validity* perspective the sources used for the ONSSET and OSeMOSYS analysis are open source and widely used such as World bank database, IEA energy balances, IEA ETSAP, NASA GIS map, which can easily be accessed. Furthermore, for the specific data for Kenya, there are three major reports from the Energy Regulatory commission that are used, which are used for Kenya's long term planning and thus are by energy specialists in Kenya considered reasonable input parameters which would increase the validity.

For the WEAP model it is for the majority based on the National Water master plan 2030 from the Ministry of Water and Irrigation which describes the plans in line with Vision 2030. For the stream gauge measurement in Garissa it represents old data (1934-1975) which is difficult to calibrate towards as knowledge about how the catchment looked in 1934 is limited. As for the stream gauge in the Tana Estuary it is read from a chart which makes the reading not exact. To only use a few sources for a complete model makes the model stand on a weak ground, on the other hand the National water master plan is a complete water model for all of Kenya up until 2030 published from the Ministry of Water and Irrigation which sets the overall direction for Kenya.

As mentioned in the previous research there are positive effects of the trade which decreased the overall costs for the single country. To exclude trade from the OSeMOSYS model could inflate the demand for installed capacity and thus the costs in the model.

For the electrified settlements derived for this model it only considers the distance from grid and size of the settlement, and then is calibrated towards the urban and rural electrification rate. It would change the investments needed if the electrification would be more detailed mapped such as nightlight maps or GIS-layer with data for connected households. This is especially interesting for mini grid and stand-alone solutions as they are not included for the base year.

4. CLEWs modelling results

In this chapter the results from the ONSSET, OSeMOSYS and WEAP modelling is described for both the low and high demand scenarios, as well as changing the priority for water demand in WEAP.

4.1 Results from the Low electricity demand scenario

4.1.1 Electricity generation

For the grid electricity generation, the two major technologies which are the least cost for Kenya are geothermal flash steam power (49%) and natural gas combined cycle (42%) in 2040.

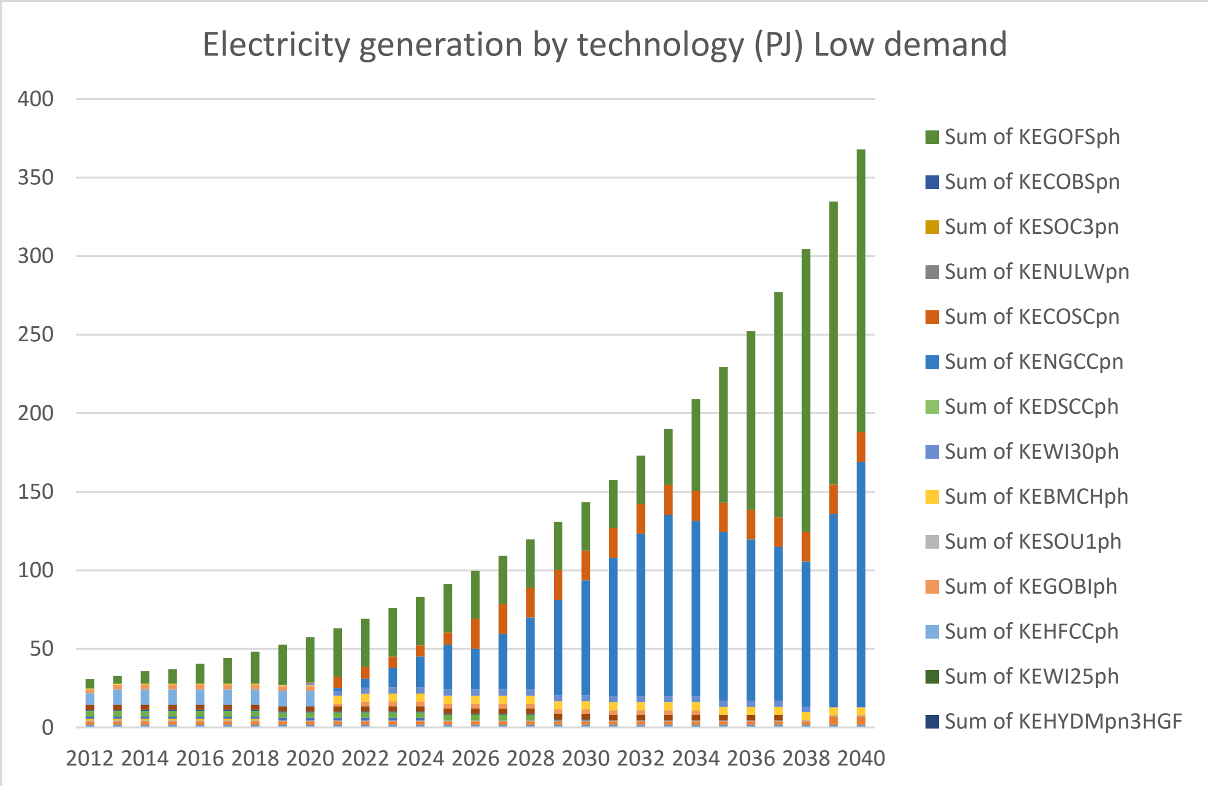

FIGURE 21. ELECTRICITY GENERATION FOR GRID DEMAND, LOW SCENARIO

From the Low demand scenario the optimization from OSeMOSYS gives a LCOE at 6.6 ct$/kWh which is iterated to ONSSET as LCOE for grid. The LCOE for the ONSSET off-grid analysis ranges between 0.105 $/kWh to 0.37 $/kWh.

For the residential electrification optimization, the low demand of 224 kWh/household for rural demand and 1800 kWh/household for urban displays a split by technologies with a high share of stand-alone solutions for the rural demand (72%) as seen in Figure 22.

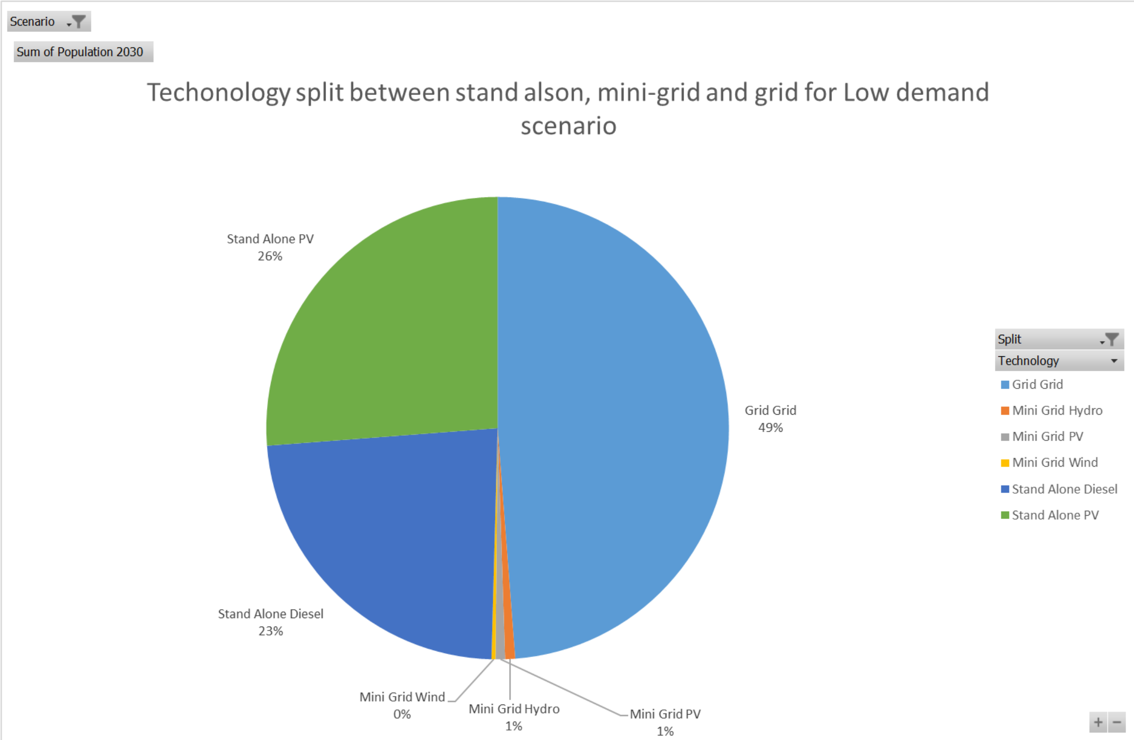

FIGURE 22. GRID/OFF GRID SHARE FOR LOW DEMAND SCENARIO 2030

The share of renewable from both the ONSSET and OSeMOSYS analysis develops towards from a fairly high share in 2012 (69%) to almost the opposite share in 2030 with 64% non-renewable and 36% renewable as seen in Figure 23. This is related to the optimization objective function where the least cost choice is favoured where natural gas and coal is cheaper than solar and wind technologies.

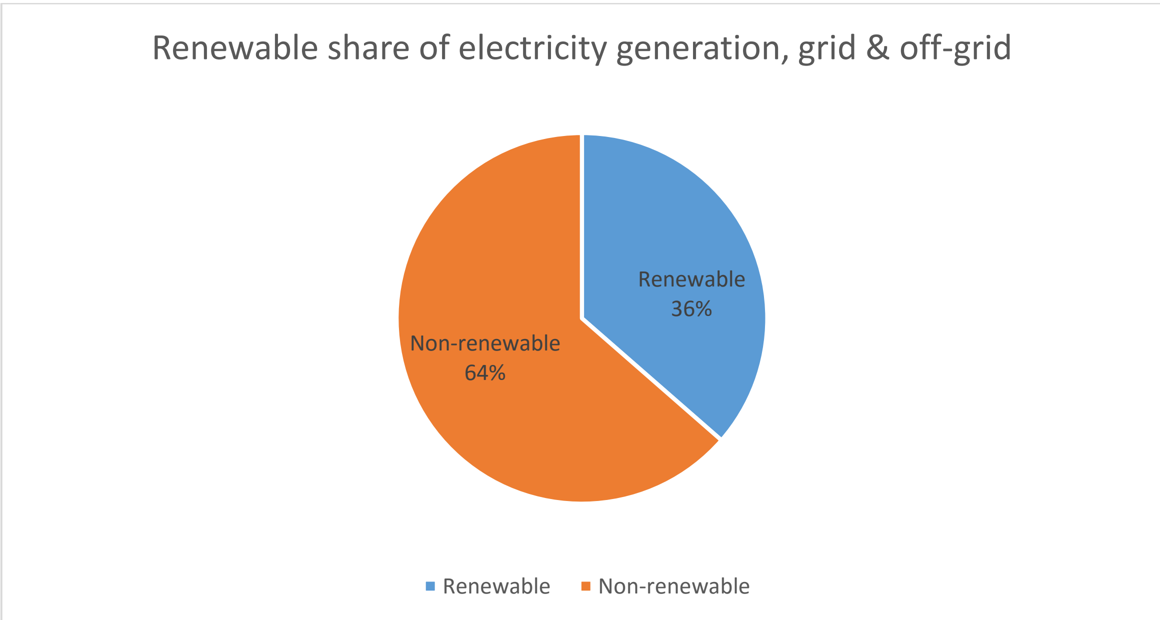

FIGURE 23.RENEWABLE SHARE IN LOW DEMAND SCENARIO FOR GRID AND OFF-GRID SOLUTIONS 2030

4.1.2 Costs

The discounted costs related to the low electrification scenario amounts to 61.5 billion USD, as seen in Table 21, with a high share for transmission costs which represents 38% of the total discounted cost from 2012-2040 including the planned grid by KENTRACO of 5,666 km.

TABLE 21. TOTAL DISCOUNTED (6%) COST FOR LOW SCENARIO (MUSD)

		MUSD
HV planned transmission incl. bays and sub stations (Energy Regulatory Commission, 2013)	5,666 km	2,100
LV/HV connections <50km (ONSSET)	15,447,533 people	19,989
Transmission (OSeMOSYS)	12.85 GW	1,499
Mini Grid (ONSSET)	1,075,946 people	212.63
Stand Alone (ONSSET)	32,518,787 people	2,107
Power plants (OSeMOSYS)	15.78 GW	35,537
Total cost (MUS$D)		**61,482**

4.1.3 CO2eq emissions

The CO2eq emissions which are related to the grid electricity production (where NOX have a warming potential of 298) amounts to 9.5 million tonnes CO2eq in 2040 which is an increase of 1700% from 2012 relating to the high natural gas and coal production. This is less than the BAU scenario developed in the National Climate Change Action Plan for Kenya which is estimated to 18.4 MtCO2eq at 5.4 MtCO2eq in 2030.

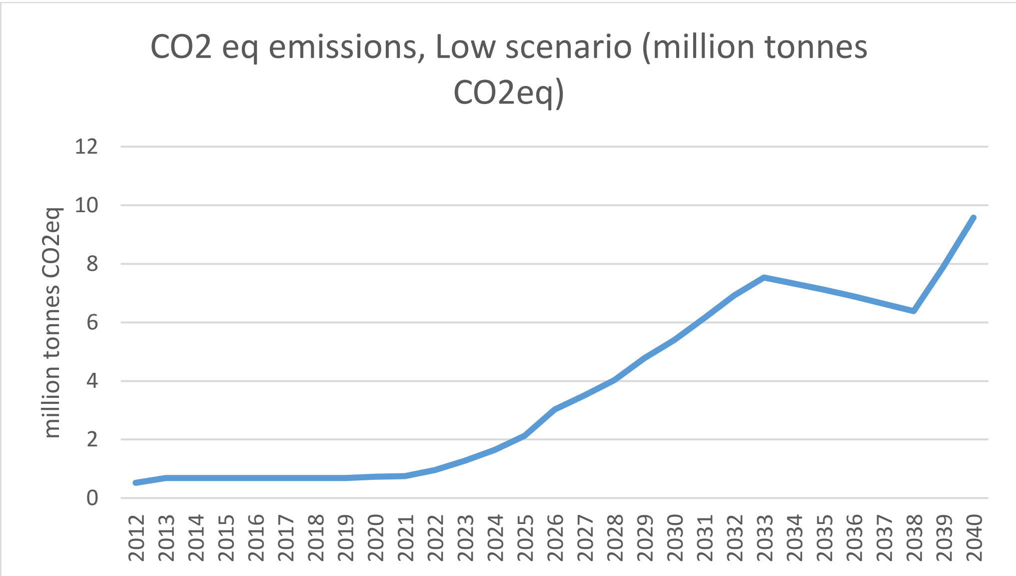

FIGURE 24. CO2EQ EMISSIONS FROM GRID ELECTRICITY GENERATION (MILLION TONNES CO2EQ)

4.2 Results from the High electricity demand scenario

4.2.1 Electricity generation

For the OSeMOSYS grid optimization similar results as seen for the Low demand with a high share of natural gas (45%) and geothermal (30%) where geothermal natural resources are fully exploited. As seen in 2039 nuclear power will also come into play, as well as new large hydro power.

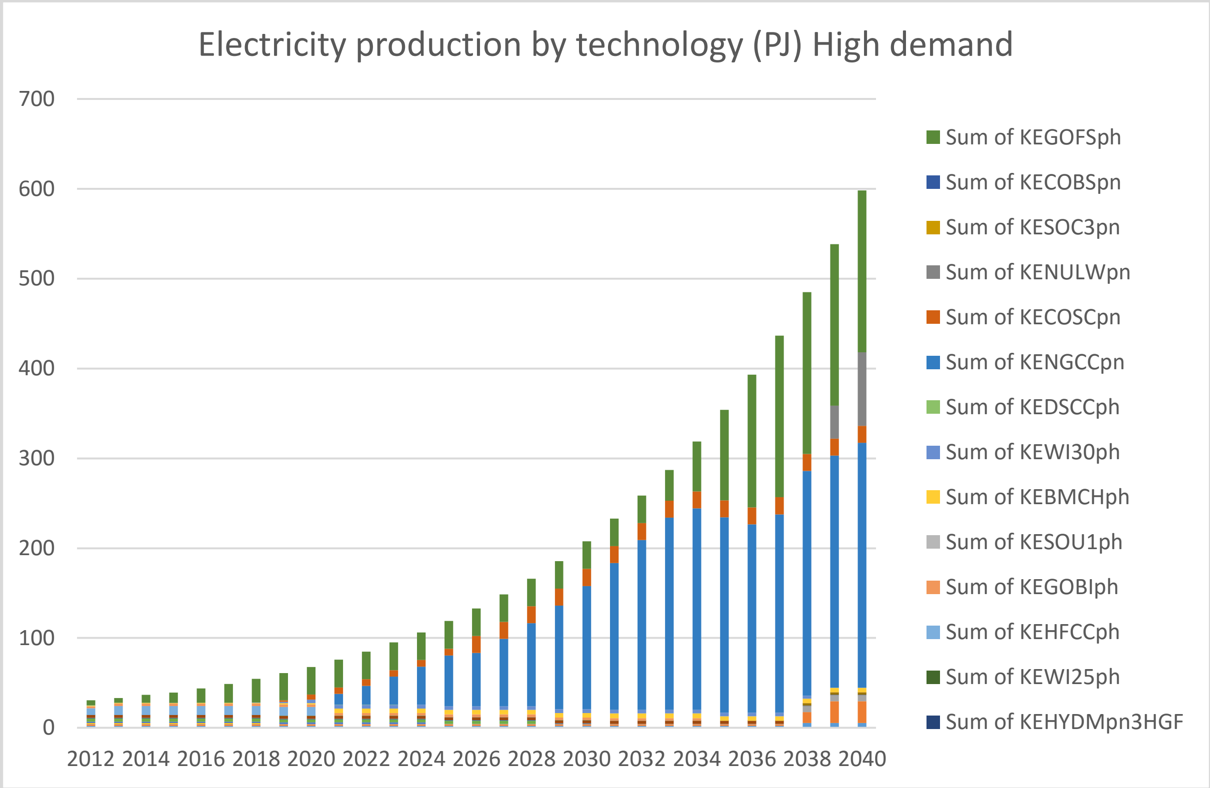

FIGURE 25. ELECTRICITY GENERATION FOR GRID DEMAND, HIGH DEMAND SCENARIO

From the High demand scenario, the optimization from OSeMOSYS gives a LCOE at 6.6 ct$/kWh which is iterated to ONSSET as LCOE for grid. The LCOE for the off-grid solutions ranges between 0.092 $/kWh to 0.37 $/kWh.

The optimal solution for the residential electricity demand with 1800 kWh/household for rural and 2195 kWh/household for urban has a much higher share of grid connections and mini-grid solutions compared to the low scenario as seen in Figure 26.

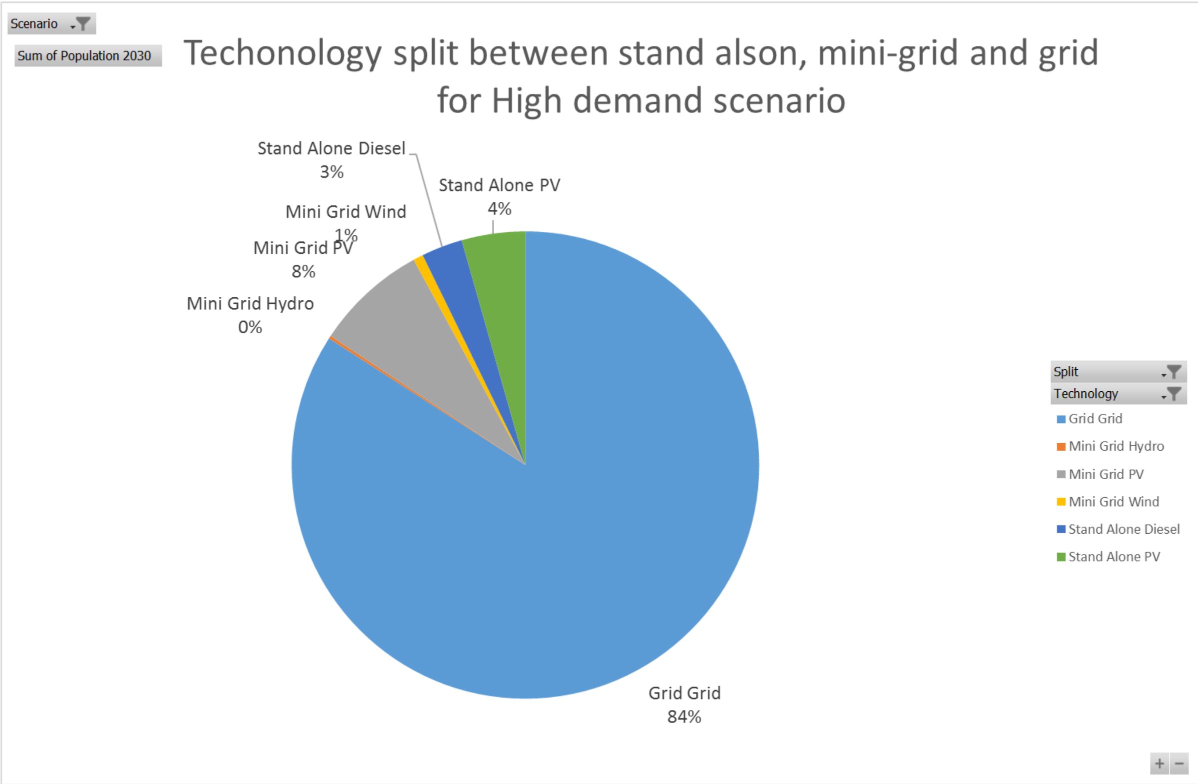

FIGURE 26. SHARE OF GRID/OFF-GRID SOLUTIONS FOR HIGH DEMAND SCENARIO 2030

For the electricity generation the renewable share for both grid and off-grid solutions amounts to only 28% where natural gas and coal plays a major role in the large non-renewable share. As the OSeMOSYS model aims to optimize the least cost scenario wind and solar is not favoured over coal and natural gas.

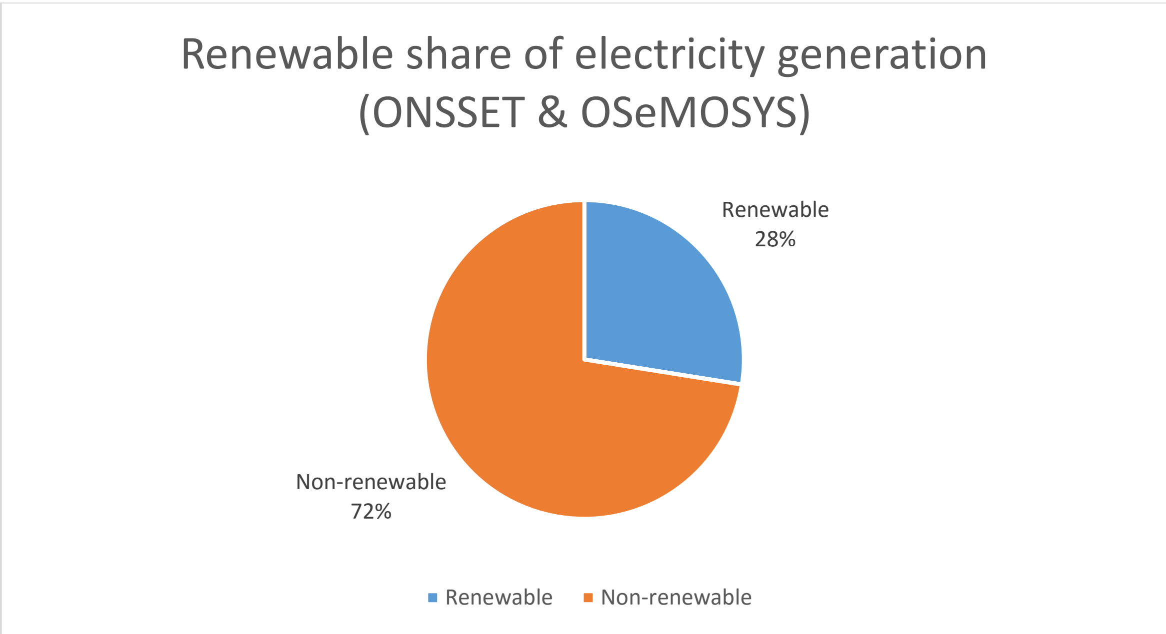

FIGURE 27. RENEWABLE SHARE FOR ELECTRICITY PRODUCTION FOR BOTH GRID & OFF GRID, HIGH SCENARIO 2030

4.2.2 Costs

For the high energy demand scenario, the costs for both the ONSSET and OSeMOSYS model amounts to 106.7 billion USD where the transmission costs represent 34% of the costs.

TABLE 22. TOTAL DISCOUNTED COST FOR HIGH DEMAND SCENARIO

		MUSD
HV planned transmission incl bays and sub stations	5666 km	2,100
LV/HV connections <50km (ONSSET)	38,624,265 people	32,618
Transmission (OSeMOSYS)	21.61 GW	2,437
Mini Grid (ONSSET)	5,665,639 people	844
Stand Alone (ONSSET)	4,752,361 people	2,558
Power plants (OSeMOSYS)	26 GW	66,149
Total cost (MUSD)		**106,706**

4.2.3 CO2eq emissions

The CO2eq emissions which are related to the grid electricity production (where NOX have a warming potential of 298) amounts to 15.4 million tonnes CO2eq in 2040 which is an increase of 2833% from 2012 relating to the high natural gas and coal production. It is still below the BAU estimate from National Climate Change Action Plan of 18.4 MtCO2eq by 2030 at 8.7 MtCO2eq.

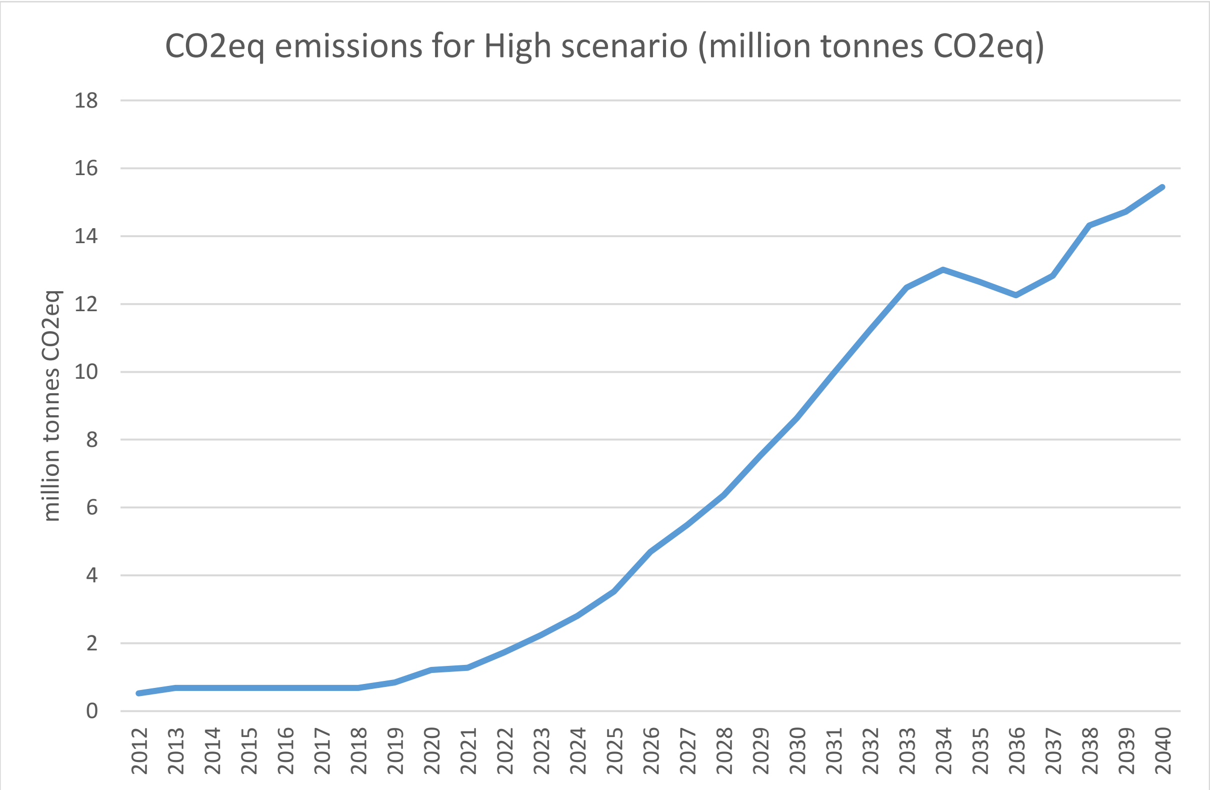

FIGURE 28. CO2EQ EMISSIONS FOR HIGH SCENARIO (MILLION TONNES CO2EQ)

4.3 WEAP modelling results

The modelling area from WEAP is as seen in Figure 29 where there are two main catchments which represents the domestic, livestock and industry demand (as seen in red dots in the schematic). The irrigation is represented by 11 catchments (seen as green dots) to see how the irrigation withdrawal following the river affects the total water demand. The electricity demand for the Tana catchment does not change during the period of 2012-2038 for the low and high demand and therefore, as the year of interest is 2030, the results are presented together in this chapter. As the High grand falls hydropower is installed in 2038 the effect for the CLEWs analysis is small and is therefore not further analysed.

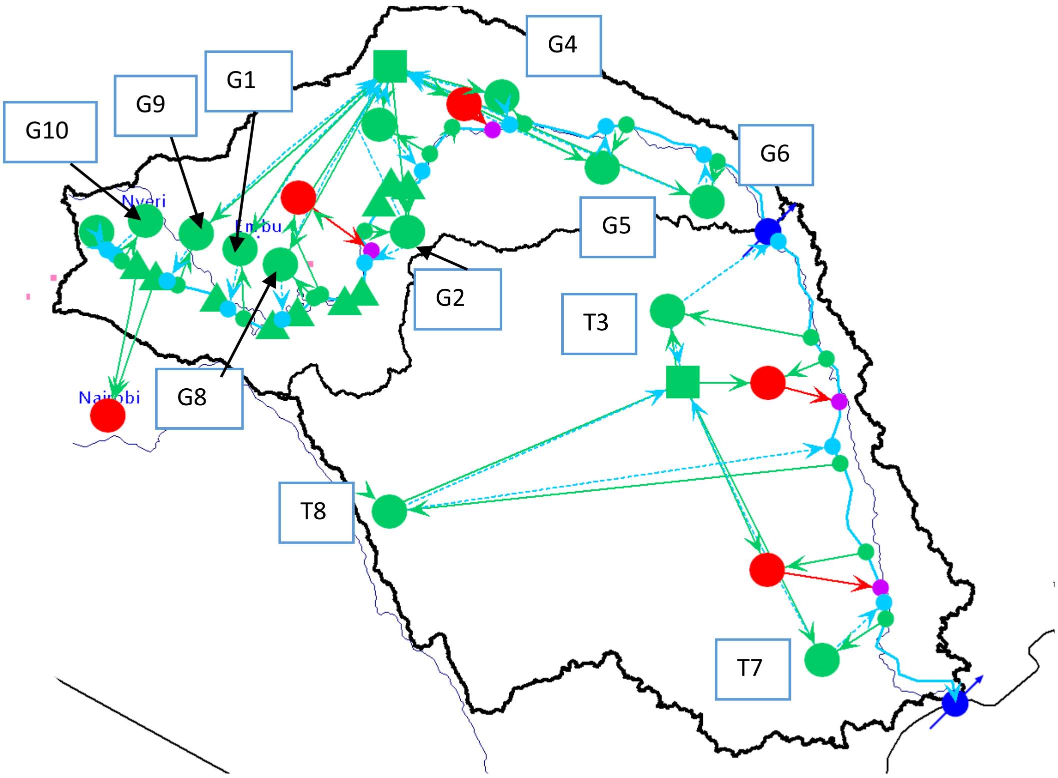

FIGURE 29. WEAP SCHEMATIC OF THE TANA CATCHMENT

The irrigation demand is based on the Single crop coefficient (K_c) values for the crops that is modelled and they will affect the water demand for the different months. As seen in Figure 30 the major water demand is in the months of May to September when most of the growing of the crops will occur.

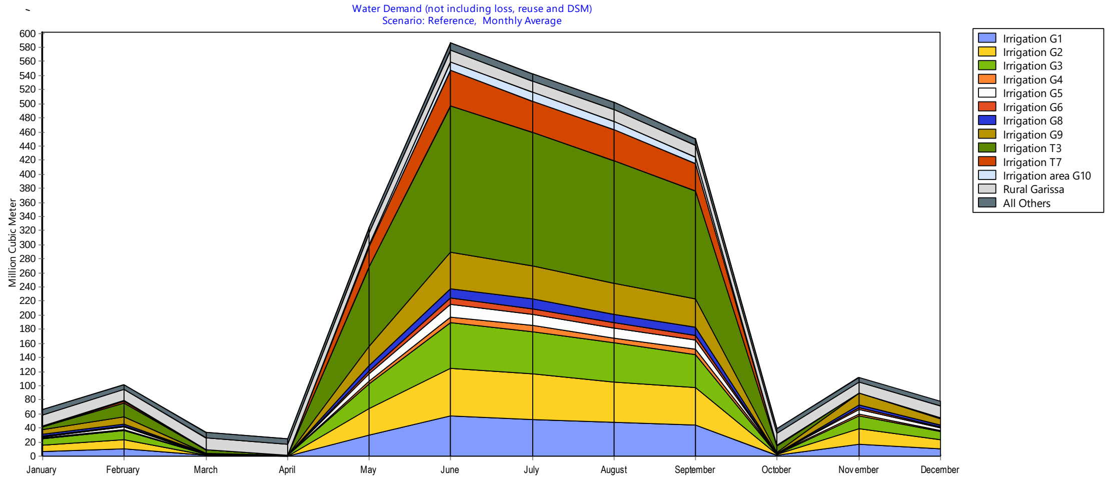

FIGURE 30. AVERAGE MONTHLY WATER DEMAND 2012-2040, WEAP

The total water demand, as seen in Figure 31, amounts to 3805 MCM in 2030 where 91% of the demand is from the planned irrigation scheme and 5.7% is from Rural demand in the Garissa catchment.

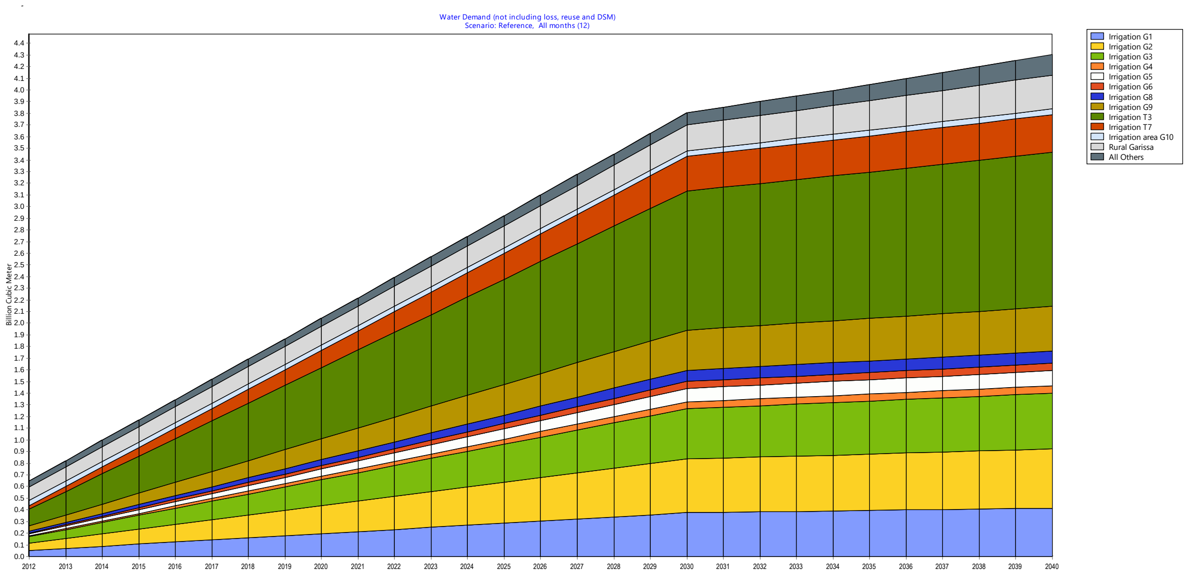

FIGURE 31. TOTAL WATER DEMAND FOR MODELLING PERIOD 2012-2040

The modelled water demand was modelled initially with all demands set as priority 1 to see if there is any unmet demand based on the irrigation plans, population growth and hydropower expansion in the Tana catchment. Due to the high evapotranspiration in the dry months the results have a high volatility pattern which could be mitigated by including soil moisture in the analysis.

4.3.1 Demand priority all set to 1

When modelling all of the demand with priority 1 the unmet demand in 2030 is in the upstream areas. For the Urban demand in the Garissa catchment which is withdrawn upstream in the river, the runoff from the catchments are still quite low. During the dry months the coverage towards the demand is 44% where the other demands which is situated further down streams have 100% demand coverage. This is related to the high evapotranspiration and low precipitation in the dry months together with the early withdrawal from the river which up to that point have a smaller catchment area than further down.

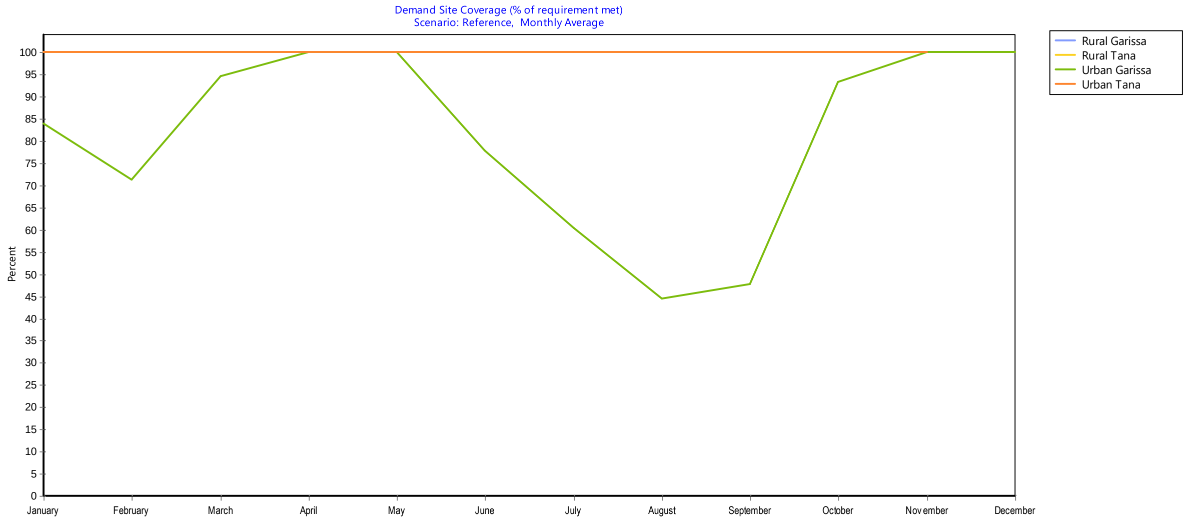

FIGURE 32. DEMAND COVERAGE FOR URBAN/RURAL DEMAND IN 2012-2040

For the irrigation demand the results are similar in the early upstream irrigation areas the seasonal variety shows as low as 21% coverage of the demand for the dry months. The only irrigation areas affected are upstream in the Garissa sub-catchment (G1, G2, G10, G8 and G9) where the remaining irrigation demand is met to 100%.

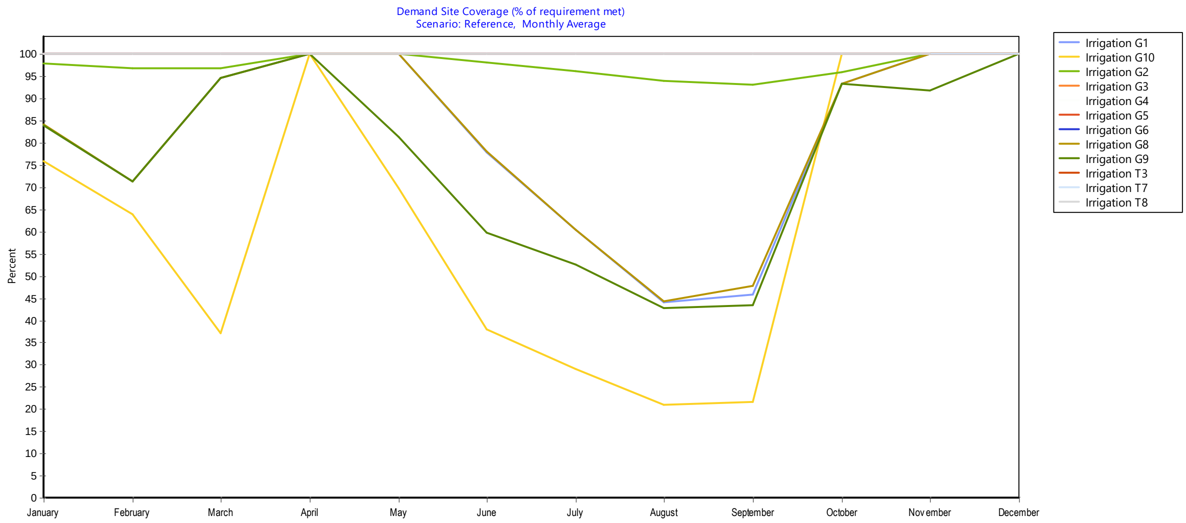

FIGURE 33. WATER DEMAND COVERAGE FOR ALL IRRIGATION AREAS 2012-2040

For the hydropower plants they are situated upstream in the Tana river as seen in Figure 34 where the Mutonga, Low grand falls and High grand falls hydropower are planned power plants.

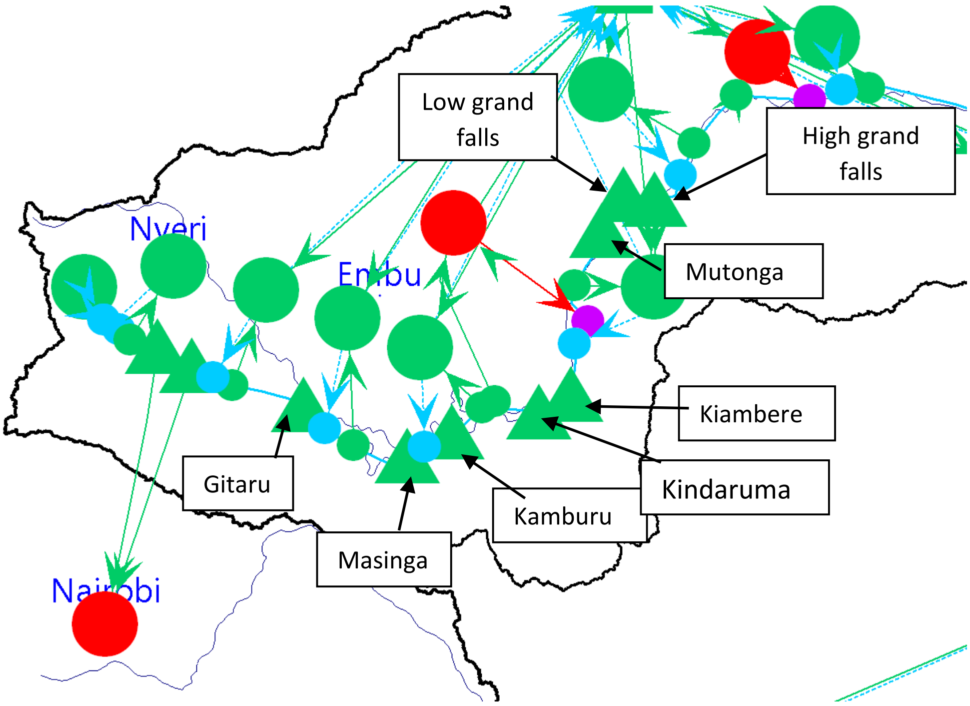

FIGURE 34. SCHEMATIC OVER HYDROPOWER PLANTS MODELLED IN WEAP

For the coverage of the hydropower demand the coverage is low even with the capacity factors from WEAP which constraints the OSeMOSYS electricity generation. Two power plants, Gitaru and Low grand falls, show the same pattern as when modelling the capacity factors and is assumed to be incorrect as the Gitaru power plants is generating 820 GWh in 2010 (Cameron, et al., 2012) where in the WEAP model it generates only 205 GWh (2012).

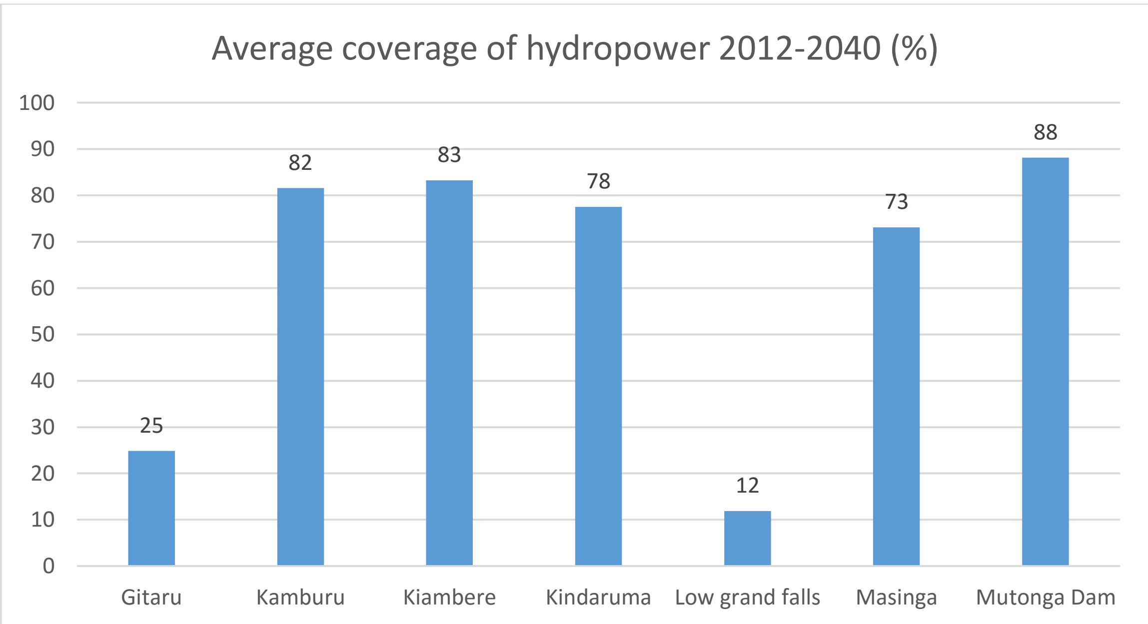

FIGURE 35. HYDROPOWER GENERATION COVERAGE 2012-2040

4.3.2 Demand priority for Urban/Rural demand

If the demand for the urban/rural demand would have a higher priority than the irrigation and hydropower generation the demand would be met for 100% of the rural and urban demand but the impact for the irrigation areas upstream in Garissa (G1, G2, G9, G10 and G8) would be high as Figure 36 shows. For September the monthly average for the modelled years 2012-2040 has as low as 5% coverage for the upstream catchment G10 and for G8, G9 and G1 the lowest coverage is 15%.

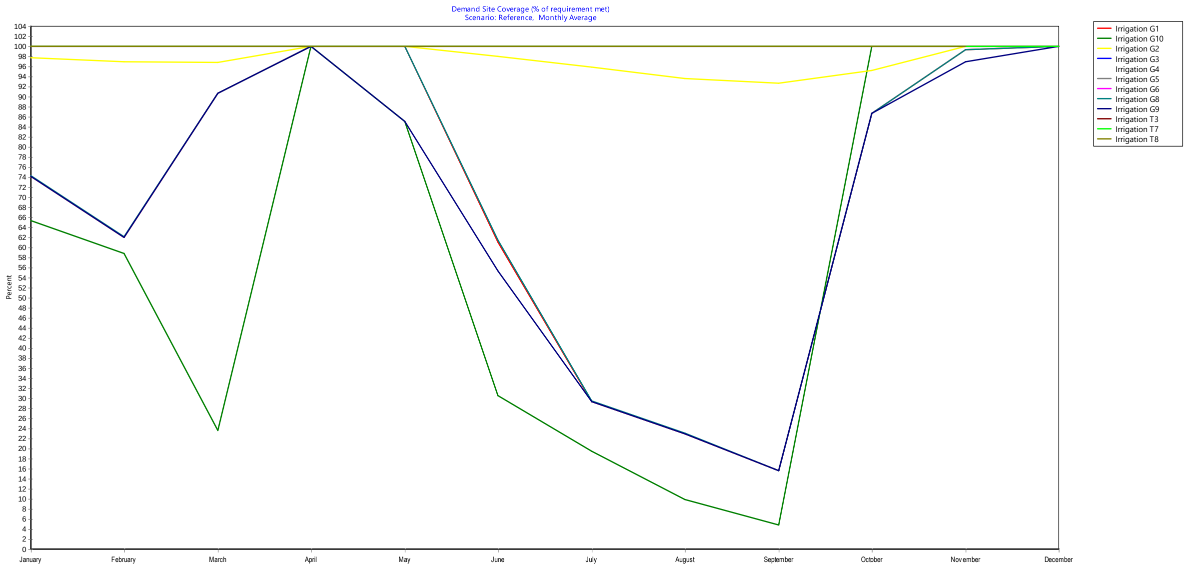

FIGURE 36. MONTHLY AVERAGE COVERAGE OF IRRIGATION WATER DEMAND 2012-2040

The hydropower production will increase for the power plants which are situated downstream as the irrigation also have a lower priority and thus the runoff will increase. The power plants situated prior to the withdrawal from the Urban water demand in Garissa (Masinga, Gitaru, Kamburu) have decreased coverage compared to when all demand has 1st priority.

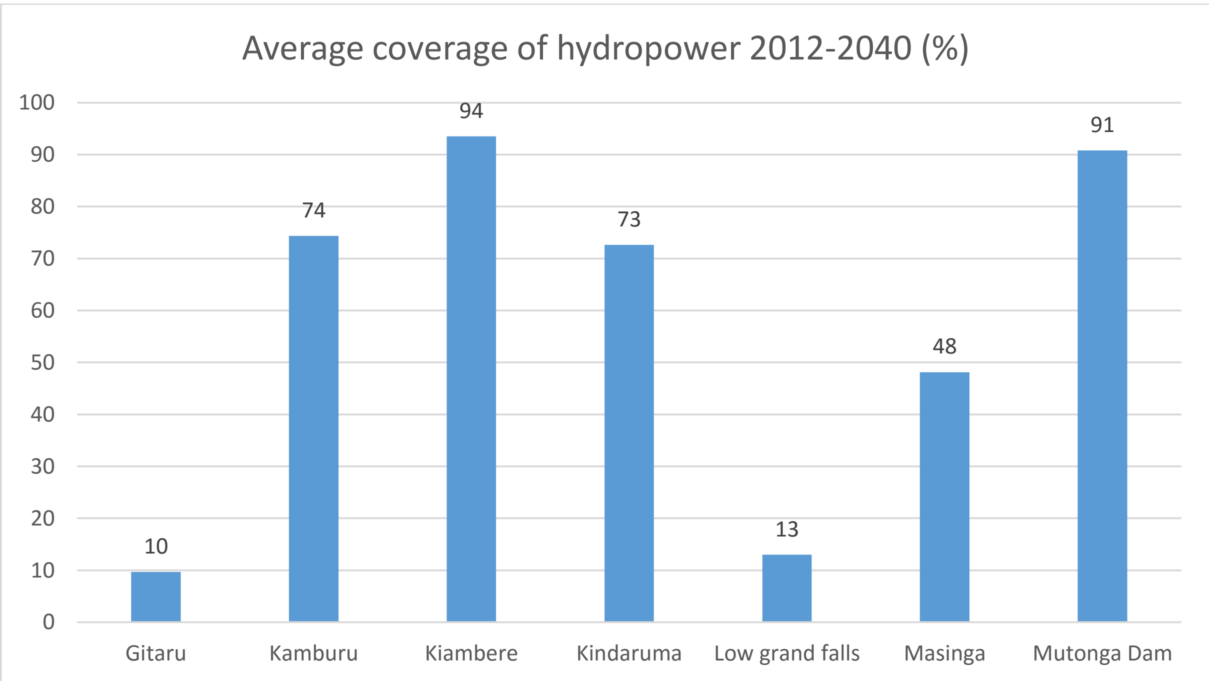

FIGURE 37. HYDROPOWER COVERAGE WITH RURAL/URBAN DEMAND PRIORITY

4.3.3 Irrigation demand set as first priority

If instead prioritizing the irrigation the demand for irrigation is still not met for the upstream areas G1, G8, G9, G10 but the coverage is higher at 44% for September as seen in Figure 38.

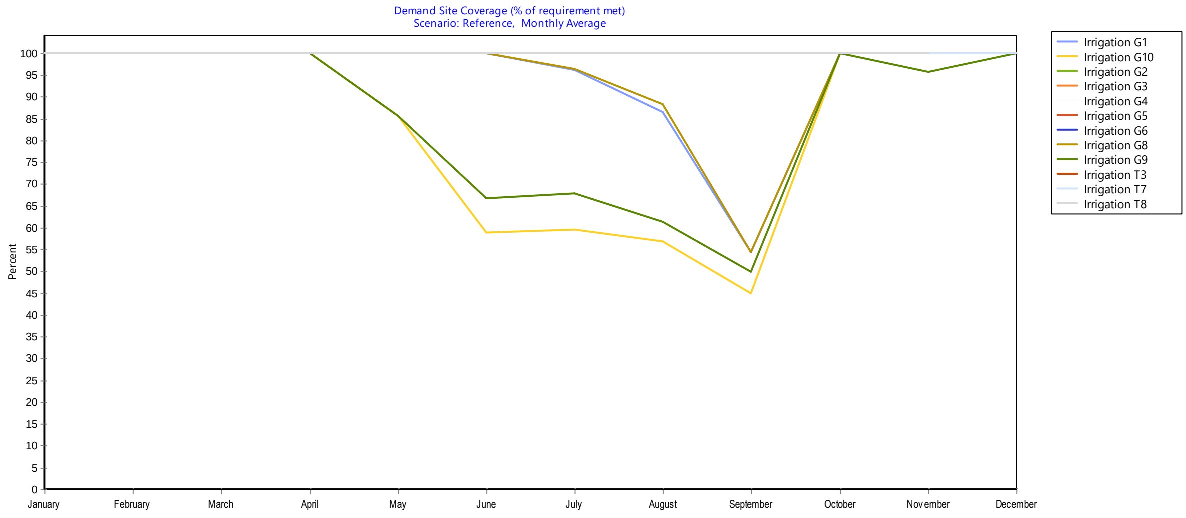

FIGURE 38. IRRIGATION WATER DEMAND COVERAGE WHEN IRRIGATION HAS HIGHEST PRIORITY

The consequences of prioritizing irrigation before the urban and rural demand will affect the urban demand in the Garissa catchment very hard where in September only 7% of the demand will be covered as seen in Figure 39.

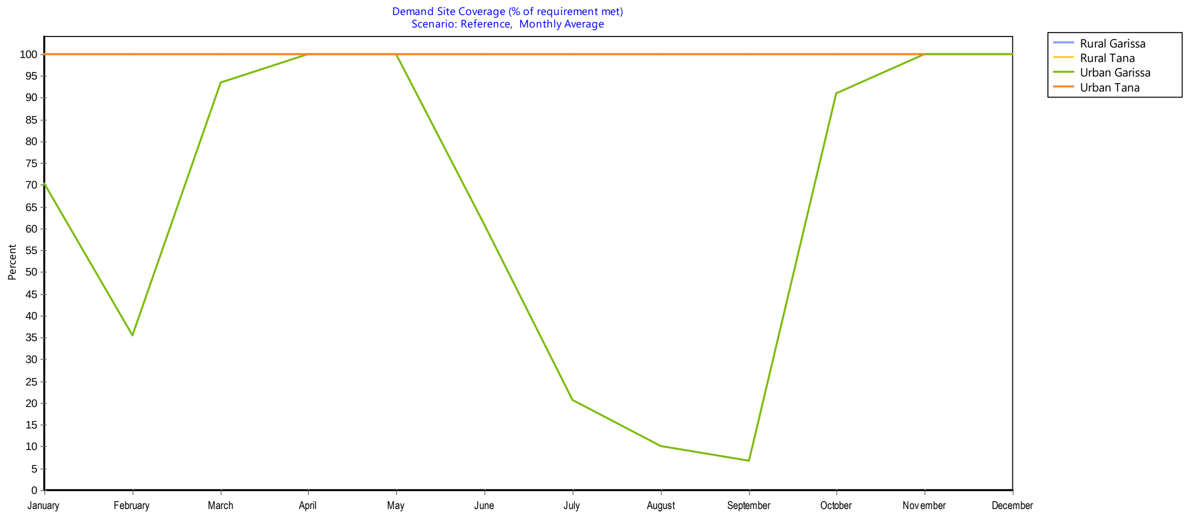

FIGURE 39. URBAN/RURAL DEMAND COVERAGE WHEN IRRIGATION IS PRIORITIZED

For the hydropower production the coverage for the upstream area is affected similar to when the Urban/Rural demand have priority but with less power generation as the irrigation demand is much higher than the Rural/Urban demand.

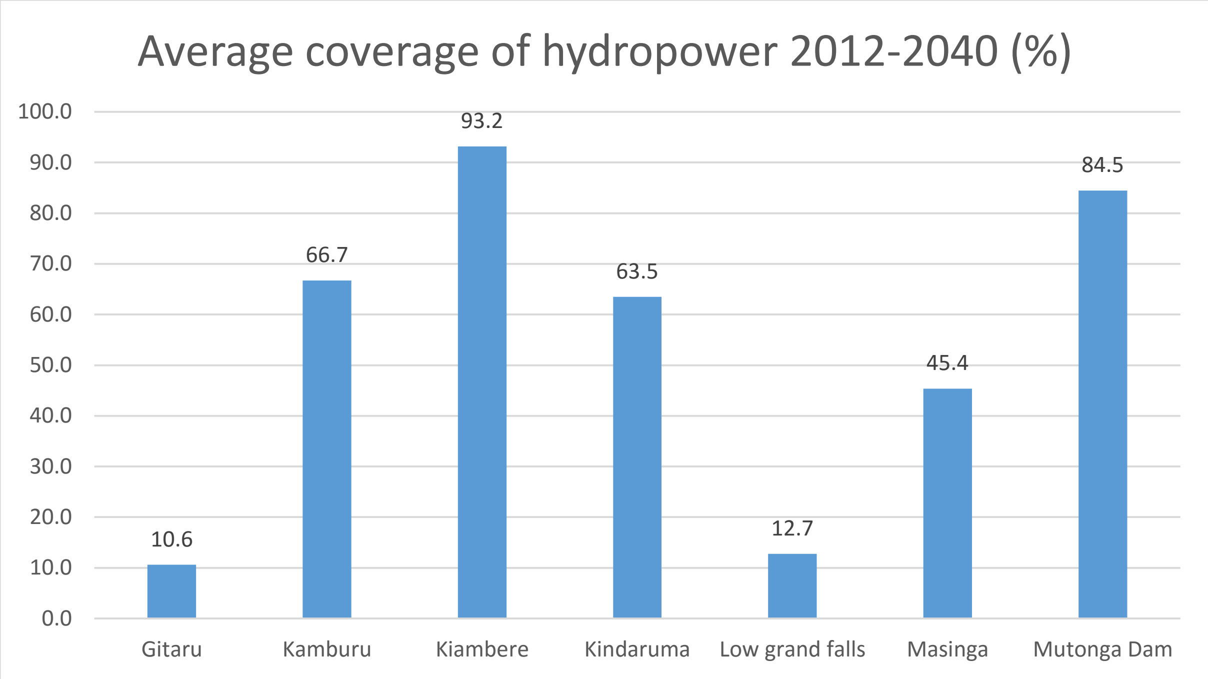

FIGURE 40. HYDROPOWER GENERATION COVERAGE WHEN IRRIGATION HAVE PRIORITY

4.4 Sensitivity analysis

For the discount rate for the optimization in OSeMOSYS and LCOE for grid in ONSSET a sensitivity analysis is performed to assess the modelled settings and see how much they would change if a different setting would have been chosen.

4.4.1 Discount rate for OSeMOSYS

The discount rate for the OSeMOSYS modelling was set to 6%, but the discount rate affects the investments, and as seen in Figure 41 an increased discount rate will favour power production with a low capital cost such as natural gas and coal. The CO2 emissions with the higher discount cost will decrease from 179 MtCO2 to 144 MtCO2 over the total modelling period.

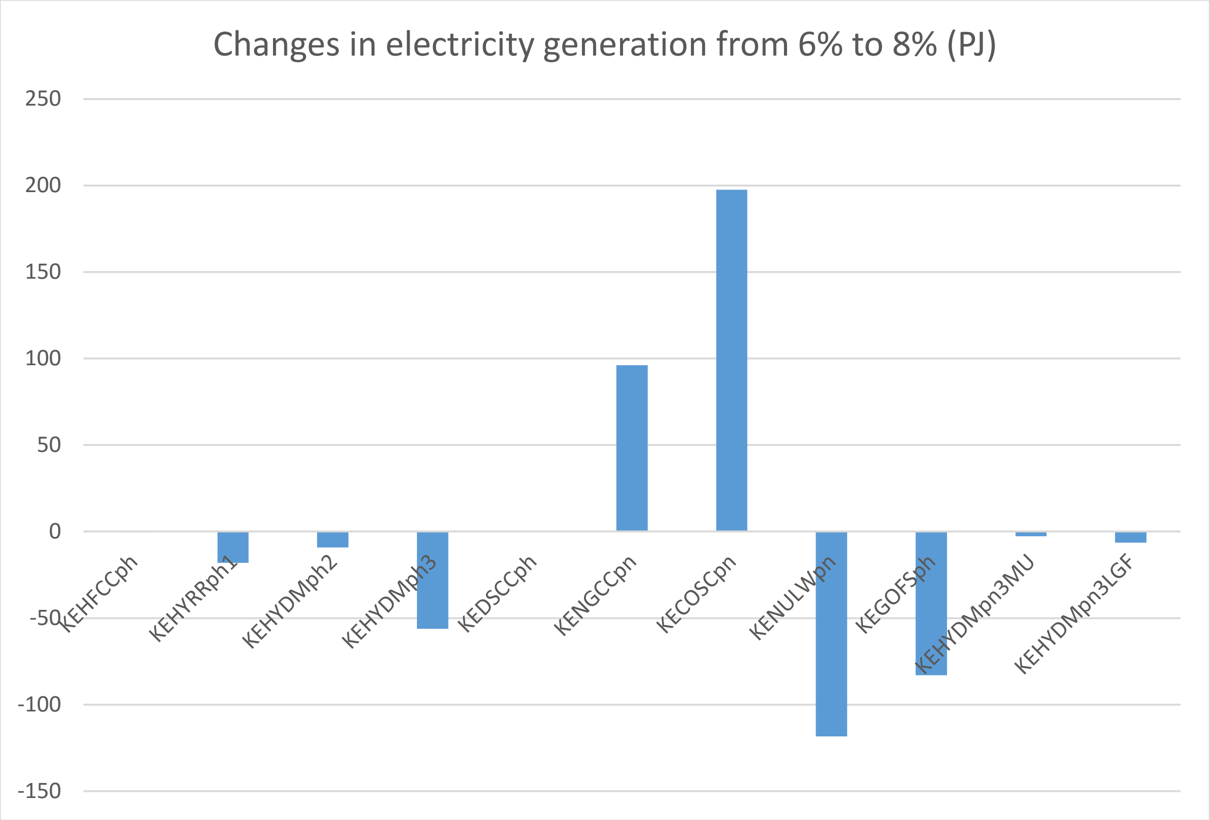

FIGURE 41. CHANGES IN ELECTRICITY GENERATION WHEN CHANGING FROM 6% TO 8% FOR HIGH DEMAND

When decreasing the discount rate from 6% to 4% the electricity generation will favour technologies with a high capital cost which in this case shifts to nuclear, geothermal and hydropower as seen in Figure 42.

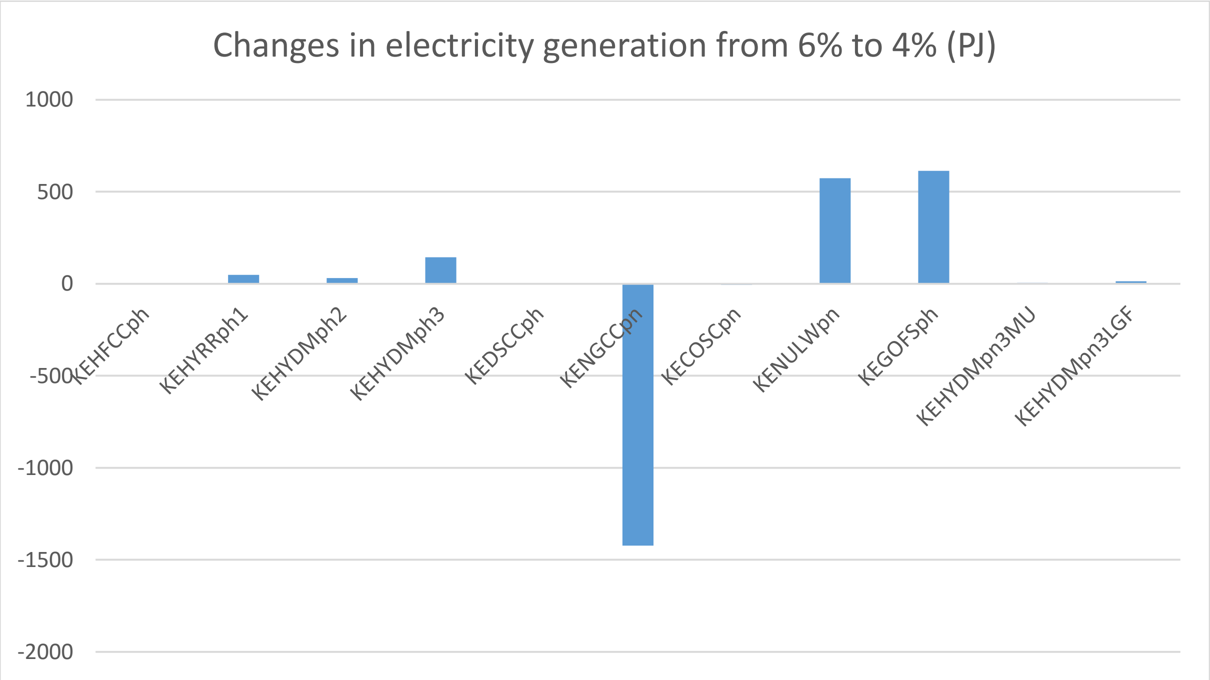

FIGURE 42. CHANGES IN ELECTRICITY GENERATION WHEN CHANGING FROM 6% TO 4% FOR HIGH DEMAND

4.4.2 LCOE for grid in ONSSET

The LCOE for the grid affects the share of settlements that will get connected to the grid in the optimization. As seen in Figure 43 the changes in technology for the high demand scenario (with a demand of 1800/kWh for rural households and 2195/kWh for urban household) from a high LCOE of 12.5 $ct/kWh to 9.4 $ct/kWh. The total grid connections are increased by 7.87 million people in favour of Mini-grid solutions PV, Wind and Hydro.

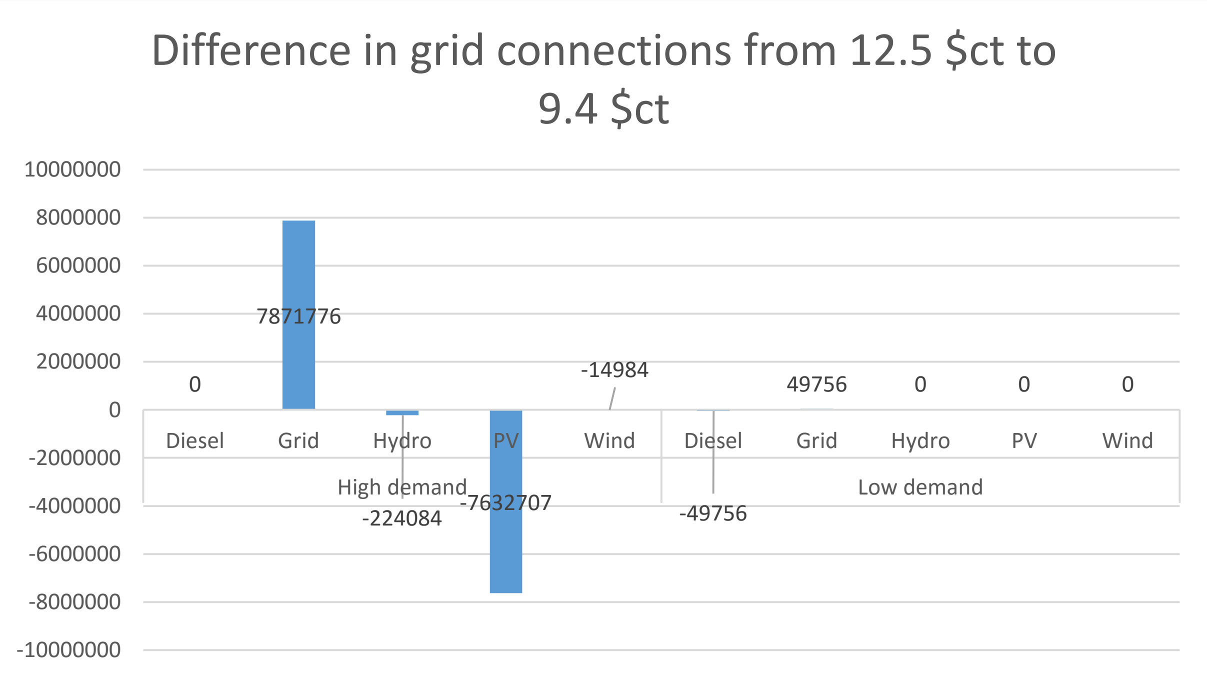

FIGURE 43. CHANGES IN TECHNOLOGY WHEN DECREASING THE LCOE FOR GRID FROM 12.5 $CT/KWH TO 9.4 $CT/KWH FOR HIGH AND LOW ELECTRICITY DEMAND

The changes in the low demand is not as sensitive for the LCOE for grid. As seen in Figure 43 a small change will occur in the urban settlements from stand-alone Diesel to Grid when the LCOE for grid is decreased. The diesel stand-alone solution is favoured when the travel time from large cities is small, which also is one of the conditions for the grid extension.

4.5 Sustainable development goals - indicators

In this chapter the results from different scenarios impact on the SDG indicators will be described.

From the results aforementioned the indicators described in the introduction two of the indicators (7.1.1. percentage of population with access to electricity and 6.1.1 percentage of population using safe managed drinking water services) are covered in the results (for water only for the Tana catchment) as well as the CO2 emissions from the electricity production and renewable energy share in electricity production. For the two remaining indicators (2.1.1 prevalence of undernourishment and 7.2.1 renewable energy share in the total final energy consumption) the results from the modelling is indicative, but does not cover the complete picture.

For the Percentage of population with access to electricity the SDG of universal access by 2030 is achieved with different consumption levels of high and low demand. The renewable share for electricity production will decrease with both scenarios to 36% and 28%. For the percent of population with access to improved water in the Tana catchment this is dependent on if all water demand will have the same priority where 99% of the population would have access, but if the rural/urban demand have the highest priority the coverage is 100% of the modelled demand.

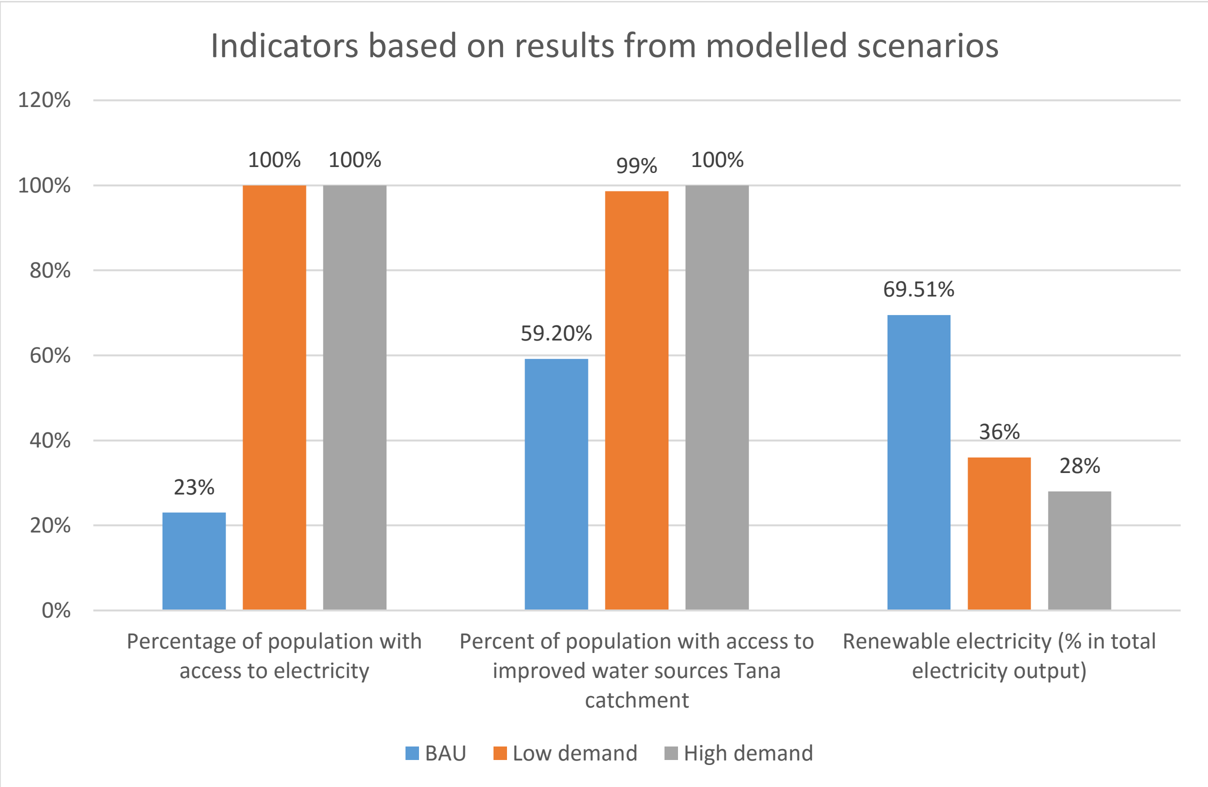

FIGURE 44. SDG INDICATORS BASED ON MODELLING RESULTS (2030)

For the CO2eq emissions the BAU scenario defined in the National Climate Change Action at 18.4 MtCO2eq both scenarios have less emissions than projected from the electricity production as seen in Figure 45.

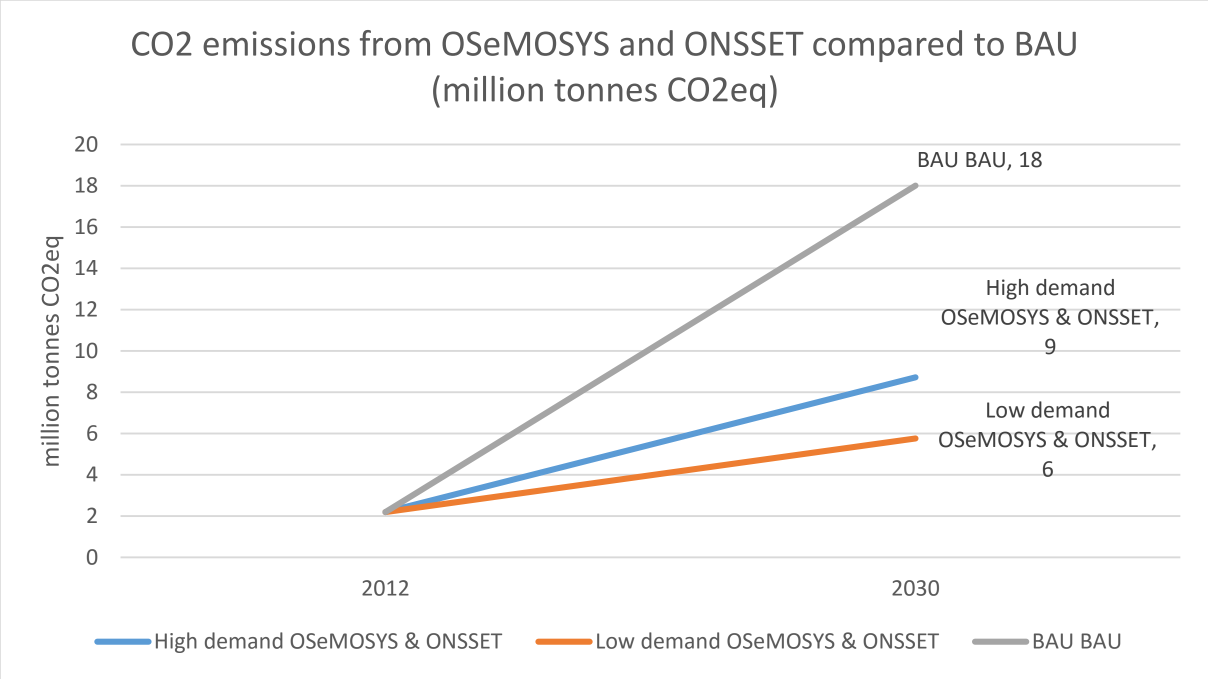

FIGURE 45. CO2EQ EMISSIONS PER SCENARIO COMPARED TO BAU

5. Discussion and conclusion

From the modelling results for both the high and low demand scenario the goals of achieving universal electricity access and improved water for all (for the Tana catchment) by 2030 are achieved if this goal is prioritized. The CO_2 emissions from the electricity production are well below the projected BAU for 2030 which was in the INDC for COP21 declared to further reduce by 30% by 2030. This goal includes LU-LUCF which accounts for 75% of the emission and considering that 55% of the population relies on primary biofuels in 2012 this demand will shift towards electricity instead for the majority of the energy demand.

The renewable total final electricity consumption was in 2012 77% where 55% was from primary solid biofuels and looking at the results from the electricity modelling the renewable share decreases to 36% and 28%. Based on the assumption that the demand for solid biofuels will decrease as the electricity access will increase the renewable share of TFEC will most likely decrease.

As for the land-use analysis the analysis has been focusing on agricultural demand where major irrigation plans have been analysed. Based on the analysis of (Mwangi, et al., 2016) for the Mara river the major effects on water discharge changes are not from climate change but from land-use changes from the Mau Forest, which is one of the five water towers, converted to agricultural land-use. It is not conclusive that this is the case for the Tana catchment but similar to the Mara river the Tana catchment origins from one of the other five water towers in Kenya, Mount Kenya, which is important to control the water flows and drought management (Akotsi, et al., 2006). Thus the agricultural demand for the catchment instead of climate changes is most likely be the major factor for streamflow changes.

The irrigation demands for the upstream parts of the river are not met in any of the scenarios which can be explained by the small catchment area where the runoff is yet to be accumulated. If the demand from rural and urban demands are prioritized the irrigation demand will not be met in the early upstream flows for G1, G10, G9 and G8 which in total represents 25% of the planned irrigated area (107,488 ha) as the demand in September is in the middle of the growth season for many of the crops. The location of the withdrawal is of importance and it is possible that the demand could be withdrawn further downstream and transported but this was not considered in the modelling.

From the SDG indicators the prevalence of undernourishment in Kenya for 2012 was 22% which is based on 28% irrigated crops. Based in the analysis for the Tana catchment the irrigated area amounts to ~56,000 ha. Considering that the irrigated areas in the early upstream area would not be feasible to irrigate the increase of feasible areas would increase from 56,000 to 318,000 the increase is 468% 2012 to 2030. The population increase over the same period is 54% for Kenya which could imply that the food availability would be more stable even for drought years but to estimate the prevalence of undernourishment is not possible from the modelling results for 2030.

For the costs related to increase of access to electricity in Kenya the transmission costs accounted for 34% respectively 38% of the total cost. Based on the share of the costs for transmission the GIS analysis for the expansions of the planned grid as well as cost effective settlements to connect to the grid increases the granularity of the analysis. For the optimization of the grid in OSeMOSYS the cost is based on installed GW which can be misleading as the number of km is of importance for the transmission cost.

As part of the limitations of the OSeMOSYS model feed-in tariffs are not included. Kenya has feed in tariffs for wind, biomass, small hydro, geothermal, biogas and solar energy which range between 6-20ct/kWh (Ministry of Energy Kenya, 2010). As the least cost optimization for both scenarios did not install utility solar PV or CSP and did not utilize the full wind potential the feed-in tariffs could shift the investments towards aforementioned technologies.

Looking at the African ONSSET model available on (UNDESA, KTH dESA, 2016) there are some significant differences in the analysis. First the LCOE for grid in Africa model is set to 0.05 $/kWh, secondly the settlement size is 100 km^2 and the planned grid was not as extensive as in the analysis conducted in this thesis. Furthermore, other costs related to Kenya, such as PV cost, was lower which will be favoured in the optimization. The investment cost for all of Kenya to reach 696 kWh/household amounts to US$10.12 billion and 1800 kWh/household amounts to US$23.06 billion.

Comparing the results to the results in this thesis the LCOE for grid was 0.066 $/kWh, settlement size was 6.5 km^2 and the extensive planned grid was included. The cost for 812 kWh/household amounts to US$22.34 billion and for 1777 kWh/household the investment cost amounts to US$36.02 billion which comparing the results are higher for both scenarios. As the results showed the high demand scenario lead to many grid connections which in this analysis is 1.6 ct/kWh higher than in the Africa model analysis. Furthermore, the connection to the grid, which represents the majority of the costs, is set to 92,823 USD/km for HV-line.

To conclude; the pressure points from the CLEWs modelling appears in the water modelling where the irrigation plans for the upstream areas conflict with hydropower production and water demand for household, livestock and industry. For the electricity access there are feasible solutions for two levels of demand, which in both cases are within the INDC commitment for 2015. The irrigation plans are of importance to increase the food security which could be a trade off, but this is not concluded in the analysis.

6. Recommended future research areas

As this thesis was conducted under a constrained timeline there are some areas which would be of interest to further investigate. First the WEAP model was based on a few source which some were quite old. This together with that the soil moisture was not included in the analysis can give a deeper understanding of the catchment modelled. Also there are other catchment areas such as the Athi catchment where Nairobi is situated, South and North Victoria Lake catchment where there is a high density of population which would be of interest to model to get a more complete picture.

As aforementioned Kenya is part of East African Power Pool and trade can reduce the investment costs needed for the grid (Taliotis, et al., 2016) and thus this could further reduce the investments needed for Kenya.

In the analysis there are no climate changes factors which can impact the water availability which could be of importance to further investigate.

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Appendix A. SDG data

TABLE A1. SUSTAINABLE DEVELOPMENT GOALS, ADOPTED SEPTEMBER 2015 (United Nations General assembly 2015)

Sustainable Development Goals
Goal 1. End poverty in all its forms everywhere
Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture
Goal 3. Ensure healthy lives and promote well-being for all at all ages
Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
Goal 5. Achieve gender equality and empower all women and girls
Goal 6. Ensure availability and sustainable management of water and sanitation for all
Goal 7 Ensure access to affordable, reliable, sustainable and modern energy for all
Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
Goal 10. Reduce inequality within and among countries
Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable
Goal 12. Ensure sustainable consumption and production patterns
Goal 13. Take urgent action to combat climate change and its impacts*
Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development
Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
Goal 17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

Appendix B. ONNSET data

TABLE B1. GIS-LAYERS FOR ONSSET ANALYSIS

GIS-layer	*Description*	*Source*
Administrative boundary	Administrative boundary for Kenya, shape file	(DIVA-GIS, 2016)
Population data	Population data for Kenya, Raster file 100 m grid cells	(WorldPop, 2016)
Transmission lines data	Transmission lines 2015, shape file	(GEOFABRIKK, 2016)
Travel time to major cities	Travel time to major cities in Kenya, shape file	(Joint Research Center EU, 2016), further developed by team at dESA.
Solar Global Horizon Radiation	1-degree resolution based on monthly averages of 22-years data (July 1983 - June 2005).	(NASA, 2008)
Digital Elevation Map – DEM	Spatial Resolution 0.00083 degrees	(CGIAR-CSI, 2016)
Run-off data	Runoff data – GSCD, Spatial Resolution: 0.125 degrees	(GSCD - Global Streamflow Characteristics Dataset, 2016)
Wind data	0.5x0.667 degrees spatial resolution	(EarthData - NASA, 2016)
River network	River network, shapefile	(HydroSHEDS - WWF, 2016)
Mining sites	Mining sites in Kenya, shape file	(National Minerals Information Center of the USGS, 2014)

Appendix C. WEAP data

Table C1. Dam size and height modelled in WEAP (Food and Agriculture Organization of the United Nations (FAO). , 2016)

Name of dam	River	Sub-basin	Completed /operational since	Dam height (m)	Reservoir capacity (million m3)
Kindaruma	Tana	Tana	1968	24	16
Kamburu	Tana	Tana	1974	56	150
Gitaru	Tana	Tana	1978	30	20
Masinga	Tana	Tana	1980	70	1560
Kiambere	Tana	Tana	1987	112	585

Table C2. GIS layers for WEAP modelling

GIS layer	*Description*	*Source*
DEM file	Digital elevation map	(NASA, 2016)
Irrigation map	Own development from National water master plan 2030	(Japan international cooperation agency, 2012)
Population settlements	Developed based on World pop data to 6.25 m^2 settlements	(WorldPop, 2016)
Administrative boundary	Boundary for Kenya	(DIVA-GIS, 2016)
Power plants	Locations for power plants in Kenya	(African development bank, 2016)
River system	Developed from DEM file with Hydrology tool in ArcMap	DEM-file