KTH Industrial Engineering and Management

Kenya meeting the electricity demand of 2030

An assessment of how *Kenya Vision 2030* and climate change impact the optimal electricity generation mix

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Bachelor of Science Thesis
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ROYAL INSTITUTE
OF TECHNOLOGY

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The International Relations Office at KTH the Royal Institute of Technology, Stockholm, Sweden, administers the MFS Programme within engineering and applied natural sciences.

Erika Svensson
Programme Officer
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ABSTRACT

Kenya's electricity sector faces extensive development as the country strives to achieve the goal of universal access to electricity by 2020 and the national blueprint *Kenya Vision 2030*. With a history of overestimating the future electricity demand, it is important to make investment decisions based on realistic demand prognoses. In this study, we evaluate a cost-optimal energy mix for electricity generation in 2030 for scenarios following business-as-usual (BAU) and *Kenya Vision 2030* demand forecasts, using the spatial electrification tool OnSSET and the energy system modelling tool OSeMOSYS. Kenya is vulnerable to climate change and faces the challenge of frequent droughts, making water management a national priority. This study considers the nexus of Climate, Land, Energy and Water (CLEW). We look at how a climate change scenario, following a worst-case development according to Representative Concentration Pathway (RCP) 8.5, can affect the hydrology of the Tana River and thereby the electricity generation from its hydro power plants. Results show that the share of grid connected households increase with a higher demand forecast, that the investment cost of meeting the electricity demand of *Kenya Vision 2030* is 106 % higher than the investment cost at BAU demand and that extreme climate change reduces the electricity generation of hydropower, leading up to that 2 % of electricity production must be supplied by other (non-hydro) sources in 2030. A conclusion drawn from this study is that the demand estimation has a central role for the investments in electricity technologies and is suggested to be based on trends of Kenya's actual growth rather than visionary goals. Another conclusion is that a scenario of climate change impacts the future usage of hydropower, making the nexus to other natural resources important to include in the development of the electricity system.

SAMMANFATTNING

Kenyas elsektor står inför omfattande utveckling när landet strävar efter att ge hela befolkningen tillgång till elektricitet och att uppfylla de nationella utvecklingsmålen enligt *Kenya Vision 2030*. Då elbehovet tidigare överskattats är det viktigt att investeringsbeslut grundas på realistiska efterfrågeprognoser. I den här studien utvärderas en kostnadsoptimal energimix för elgenerering år 2030 i scenarion som följer prognostiserade elbehov enligt business-as-usual (BAU) och *Kenya Vision 2030*, med hjälp av modelleringsverktygen OnSSET och OSeMOSYS. Kenya är utsatt för klimatförändringar och har problem med återkommande torka, därför är vattenplanering högt prioriterad i landet. Den här studien tar hänsyn till hur Klimat, Land, Energi och Vatten (CLEW) påverkar varandra. Vi tittar på hur ett extremt klimatförändringsscenario som följer Representative Concentration Pathway (RCP) 8.5 kan påverka hydrologin i floden Tana och därmed elgenereringen från dess vattenkraftverk. Resultaten visar att andelen elnätsanslutna hushåll bör bli större vid ett högre elbehov, att investeringskostnaden för att möta elbehovet enligt *Kenya Vision 2030* är 106 % högre än investeringskostnaden i ett BAU-scenario och att extrema klimatförändringar kan göra att elgenereringen från vattenkraft minskar, vilket gör att 2 % av elgenereringen måste ersättas av andra energikällor år 2030. En av slutsatserna i studien är att efterfrågeprognosen har en central roll för investeringar som görs i elsystemet och bör baseras på utvecklingstrender snarare än visionära mål. En annan slutsats är att klimatförändring påverkar den framtida produktionen från vattenkraft, vilket gör att kopplingen till andra naturresurser är viktig att inkludera i utvecklingen av elsystemet.

ACKNOWLEDGEMENT

We would like to acknowledge the following people for their help, advice and encouragement in the work with this Bachelor's Thesis:

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ABBREVIATIONS

BAU	Business-as-usual
CLEW	Climate, Land-use, Energy and Water
CO_2	Carbon dioxide
GHG	Greenhouse gases
HPP	Hydro Power Plant
LCOE	Levelized Cost Of Electricity
OnSSET	Open Source Spatial Electrification Tool
OSeMOSYS	Open Source Energy Modelling System
PGTMP	Power Generation and Transmission Master Plan
PP	Power Plant
PV	Photovoltaic
RCP	Representative Concentration Pathway
SDGs	Sustainable Development Goals
TEMBA	The Electricity Model Base for Africa
WEAP	Water Evaluation And Planning system

LIST OF UNITS

GW	Gigawatt (10^9 W)
GWh	Gigawatt-hour (10^6 kWh)
hh	Household
kWh	Kilowatt-hour
kWh/hh/year	Kilowatt-hour per household per year
$MtCO_2eq$	Million tonnes of CO_2-equivalents
MW	Megawatt (10^6 W)
USD	US Dollars

1. INTRODUCTION

1.1 BACKGROUND

Energy poverty is declared to be one of the main problems that sub-Saharan Africa is facing. In 2014, more than 620 million people in sub-Saharan Africa didn't have access to electricity in their homes (International Energy Agency 2014). "To ensure access to affordable, reliable, sustainable and modern energy for all" is the 7th (UNDESA 2016) of The Sustainable Development Goals (SDGs), agreed upon by world leaders in 2015 as a part of *The 2030 Agenda* – a global action plan for people, planet and prosperity (United Nations 2016). The Government of Kenya has declared the target to reach universal access to electricity by 2020 (The Government of Kenya 2007). In 2015, the percentage of electrified households was 46 % (Power Africa 2016), compared to 23 % in 2012 (The World Bank 2012). The rate of new grid connections is high, partly thanks to the rural electrification programme "The Last Mile Connectivity Project" (African Development Bank Group 2017), carried out by The African Development Bank, The Government of Kenya and The World Bank to supply households with electricity from on- and off-grid electricity solutions (Ministry of Energy 2016).

Increasing access to energy has positive effects on other SDGs since it is closely linked to economic and social development (UNDESA 2016). Achieving the goal of universal access to electricity is crucial to carry out Kenya's long-term national planning strategy, *Kenya Vision 2030*, containing ambitious goals for economic, social and political development. The main vision is to transform Kenya into "a newly industrializing middle-income country providing a high-quality life to all its citizens by the year 2030" (The Government of Kenya 2007). Kenya's population is estimated to increase from 46 million to 65.4 million in the years 2015-2030 (The World Bank Group 2017a) and the electricity consumption is forecasted to increase with 315 % during that period in case *Kenya Vision 2030* and universal access to electricity are achieved (International Energy Agency 2017). This implies that Kenya's electricity sector must develop to meet a much higher demand and there are several flagship projects for electricity generation planned (Ministry of Energy and Petroleum 2016).

Historically, hydropower has been the most used source for electricity generation in Kenya (IEA 2017). Today, the reliability of hydropower is questioned (Wahome 2013) as periods of droughts have affected the output of hydropower plants (HPPs) the last years (Ministry of Environment and Natural Resources 2016). Climate change impacts the patterns of rainfall and temperature, causing periods of floods and droughts (Ministry of Environment and Mineral Resources 2013). Kenya has a high vulnerability to these fluctuations in water availability since it destroys livelihoods and causes hunger (Kenya National Bureau of Statistics 2014), disease and even death (National Drought Management Authority 2013). Access to clean drinking water (SDG6) and security in food supplies (SDG2) cannot be endangered when expanding the energy system. Water can't be replaced when it comes to drinking and irrigation. Meanwhile, Kenya has a good potential to use energy from wind and sun as well as geothermal energy located in the Rift Valley (Energy Regulatory Commission 2012) for future electricity generation to replace hydropower if that is necessary.

In this study the Climate, Land-use, Energy and Water strategies (CLEWs) framework has been applied to model the nexus of these natural resources in Kenya (Figure 1). The idea behind CLEWs is that the natural resources of land, energy and water are highly integrated and that the exploitation of them contributes to climate change, meanwhile they are all highly vulnerable to it. The interlinkages between those systems must be considered to develop consistent strategies and ensure an efficient resource management (Bazilian et al. 2011; Howells et al. 2013).

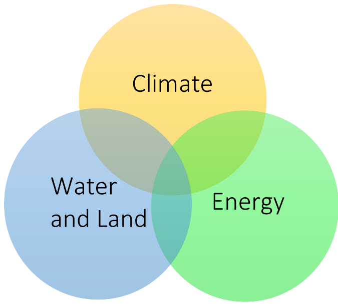

FIGURE 1 – THE CLEWS FRAMEWORK

As a part of our work with this Bachelor's thesis, we have conducted a field study in Nairobi. We met professionals in Kenya's energy sector[1] to ask for their opinions on the main challenges for Kenya's electricity generation. Some of them expressed concern about the risk of overestimating the future demand, since previous demand forecasts for Kenya has regularly been too optimistic (Ministry of Energy and Petroleum 2016). Kenya has the goal to sustain a yearly GDP growth of 10 % (The Government of Kenya 2007) to achieve *Kenya Vision 2030*. There is a risk of overestimating the need of capacity investments if demand-prognoses are based on a correlation with the 10 % GDP growth (Power Africa), since this is a very ambitious goal compared to earlier GDP growth in Kenya (varying in the range 0.2 % to 8.4 % in the period 2001-2014 (The World Bank Group 2014)). The World Bank projects the GDP growth in Kenya to be 5.8 % in 2018 and 6.1 % in 2019 (The World Bank Group and Kenya Economic Roundtable 2017).

1.2 OBJECTIVE

The objective of this study is to investigate how the choice of demand estimation for 2030 and the climate change affects the energy mix for electricity generation in Kenya.

1.3 RESEARCH QUESTIONS

1. How does the size of electricity demand forecasted for *Kenya Vision 2030* change the optimal split of household electrification solutions based on spatial electrification analysis, compared to a BAU demand?
2. How does the size of electricity demand forecasted for *Kenya Vision 2030* change the cost-optimal energy mix for on-grid electricity generation compared to a BAU demand?
3. What impact will climate change according to RCP 8.5[2] have on the electricity generation from hydropower in Tana River by 2030 and what are the effects on the on-grid electricity generation mix?

1.4 STUDY BOUNDARIES

- Kenya's electricity system is modelled. No electricity trade with neighbouring countries has been included.
- This study investigates a simplification of reality where only households are given the possibility to get electricity from off-grid solutions.
- The optimization in this study runs from year 2015 till year 2030.
- The impacts of climate change have only been modelled for the HPPs in the Tana river basin.

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[1] The professionals that we have talked to about the development of Kenya's electricity generation is:
Maria Stridsman - Swedish Embassy in Nairobi
Boniface Kinyanjui – Chief Engineer, Generation Planning at Kenya Power and Lightning Company
David Mwangi – Senior Energy Consultant
Charles Muchunku – Independent Renewable Energy Consultant

[2] RCP is short for Representative Concentration Pathway. The scenario RCP 8.5 is a worst-case scenario of climate change where the concentration of greenhouse gases don't stagnate within the 21th Century (Riahi, Grübler, and Nakicenovic 2007).

2. METHODOLOGY

An electricity demand for development in accordance with *Kenya Vision 2030* (**Vision**) was compared to a lower demand based on development following historical growth, referred to as **BAU**. Two extremes of climate change scenarios, RCP 2.6 (van Vuuren et al. 2007) and RCP 8.5 (Riahi, Grübler, and Nakicenovic 2007), were applied to the scenario with **Vision**-demand.

Three modelling softwares were used to investigate what mix of electricity generation sources Kenya should aim to have in 2030, taking into account the nexus of Climate, Land, Energy and Water (Howells et al. 2013; Bazilian et al. 2011) (Figure 2). Energy was modelled in the Open Source Spatial Electrification Tool (OnSSET) (Mentis et al. 2015) and in The Open Source Energy Modeling System (OSeMOSYS) (Howells et al. 2011). Water and Land-use were modelled in the Water Evaluation and Planning tool (WEAP) (Sieber 2017), using an existing model of the Tana catchment (Moksnes and Howells 2016). To include Climate in the nexus assessment, this model was extended with RCP-specific precipitation and evapotranspiration data to see how climate change affects the hydrology in the Tana river, and thereby the capacity factors of its hydropower plants in 2015-2030.

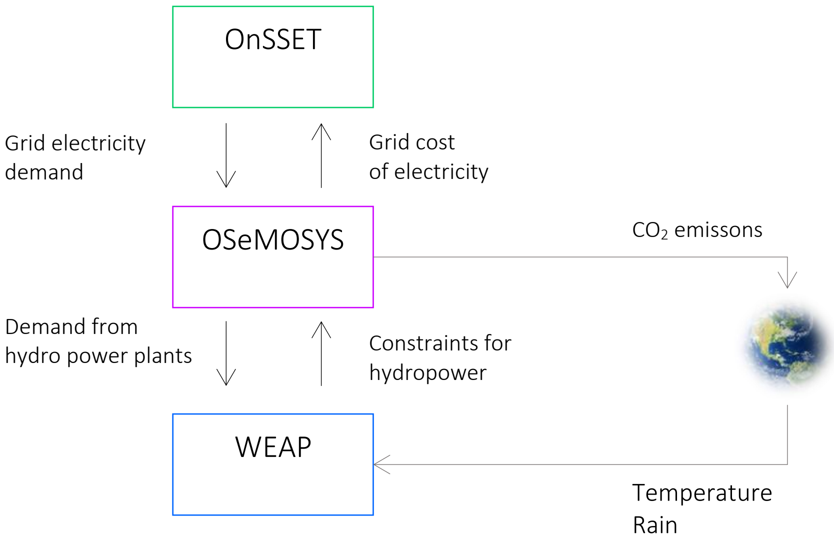

FIGURE 2 – INTERLINKAGE OF THE MODELS

2.1 SCENARIOS

If *Kenya Vision 2030* is achieved, the national electricity demand is expected to increase rapidly, starting at 7655 GWh in 2015 (IEA 2017). In *the Power Generation and Transmission Master Plan* (*PGTMP)* a similar Vision-scenario is investigated and they project a demand of 39 260 GWh in 2030 (Ministry of Energy and Petroleum 2016). That demand prognosis is used in the **Vision** scenario. The average electricity consumption per household and year was set according to Tier 3 (695 kWh/hh/year) following Nerini et al. (Nerini et al. 2016). This level of electricity consumption is enough to power a washing machine, computer and lights – a set of household appliances that can be argued necessary to provide all citizens ”a high-quality life” (Rosling 2010), which Kenya aims to achieve by 2030 (The Government of Kenya 2007). A **BAU** scenario with a lower level of national electricity demand was created to put the **Vision** scenario in a context. The electricity demand in **BAU** was set to 27 366 GWh (collected from the reference-scenario in *PGTMP*) (Ministry of Energy and Petroleum 2016), following historical trends of growth in Kenya. The household electricity consumption was set to 484 kWh/hh/year, assuming that residential electricity demand in **BAU** represents the same share of the total national electricity demand as in **Vision.** Both scenarios are based on that universal access to electricity is achieved in Kenya before 2030.

To understand the impact of climate change, two different scenarios of future climate were studied. The smallest possible climate change was used as a reference with a projected peak of global emissions of greenhouse gases (GHGs) before year 2020, following the Representative Concentration Pathways 2.6 (van Vuuren et al. 2007). RCP 2.6 implies an increase of global mean temperature limited to two degrees Celsius (Symon 2013) and is in line with trends of flat emissions of greenhouse gases the past years (International Energy Agency 2016). This scenario was compared to a scenario of extreme climate change with climate data from RCP 8.5 where the concentration of GHGs is not expected to stagnate within the 21th Century (Riahi, Grübler, and Nakicenovic 2007).

The demand levels were combined with climate predictions into three research scenarios: **Vision**, **Vision – Climate Change** and **BAU**. Their characteristics are presented in Table 1.

TABLE 1 – DEFINITION OF SCENARIOS: VISION, VISION – CLIMATE CHANGE AND BAU

SCENARIO:	VISION	VISION - CLIMATE CHANGE	BAU
NATIONAL ELECTRICITY DEMAND 2030	*Vision demand 39 260 GWh*	*Vision demand 39 260 GWh*	*BAU demand 27 366 GWh*
HOUSEHOLD ELECTRICITY CONSUMPTION 2030	*695 kWh*	*695 kWh*	*484 kWh*
CLIMATE SCENARIO	*RCP 2.6*	*RCP 8.5*	*RCP 2.6*

2.2 CALIBRATION OF MODELS

2.2.1 ONSSET

The Open Source Spatial Electrification Tool (OnSSET) is developed by KTH Royal Institute of Technology in collaboration with UNDESA as a part of reaching the goal of universal access to electricity globally (Mentis et al. 2015). It calculates an optimal split of on-grid, mini grid and standalone electrification solutions for unelectrified households to reach a target level of electricity consumption, comparing the Levelized Cost Of Electricity (LCOE) (Nerini et al. 2016). OnSSET takes local characteristics such as population density, distance to transmission lines and available energy sources into account, and investments are made in a single timestep over the whole modelling period.

The cost optimization tool OnSSET (Mentis et al. 2015) was used to calculate the split of household electrification technologies and the electricity demand on the national grid in the scenarios of **Vision** and **BAU** demand. The household electrification technologies included in this optimization were: national grid; mini grids of diesel, hydro, solar photovoltaic (PV) and wind; standalone diesel and solar PV. The modelling period in OnSSET was 2015-2030. At the start of this period, 46 % of the households had access to on-grid electricity (USAID 2017), and by 2030, universal access shall be achieved according to SDG7 (UNDESA 2016). In 2015-2030 the population will grow from 46.1 million to 65.4 million (The World Bank Group 2017a), the urban ratio increase from 25.6 % to 32.97 % (The World Bank Group 2017b) and the number of people per household is 4.4 (Michael Bauer Research 2015). For the national grid a capacity investment cost of 1935 USD/kW (KTH-dESA 2017), an existing grid-cost ratio of 0.1 (KTH-dESA 2017), a base-to-peak ratio of 0.38 (KPLC 2016) and losses at an average of 14.75 % (KPLC 2017) were used. An initial grid price of 0.052 USD/kWh was assumed before calculating scenario-specific grid price from OSeMOSYS. The diesel price used was 0.760928 USD/liter, calculated as an average over the modelling period (Ministry of Energy and Petroleum 2016). The capital costs for the off-grid electrification technologies used are presented in Appendix 1.

2.2.2 OSeMOSYS

The Open Source Energy Modelling System (OSeMOSYS) is a tool for long-run energy planning (Howells et al. 2011). It is a flexible multi-year tool that calculates the lowest net present cost of an energy system to meet a specified demand within given constraints. The open source basis of the tool makes it accessible to students, business analysts, government specialists and developing country energy researches which aims to create a better understanding of energy modelling in the developing countries (Howells et al. 2011).

OSeMOSYS was used to optimize the energy mix for the national grid to meet Kenya's 2030 electricity demand in the different scenarios. Kenya-specific data from The Electricity Model Base for Africa (Taliotis et al. 2016) was used as a foundation for sets and parameters in OSeMOSYS. The cost optimization was made with a discount rate of 5 %. The modelling period was set to start in 2015, for the possibility to use historical data to calibrate the base year, and end in 2040 to avoid unwanted edge effect around 2030. The model was divided into 36 Timeslices. The days were divided into three Timeslices (see Figure 3) to capture the fluctuations in electricity demand and the hours of sunshine. Over the year the 12 calendar months were used as Timeslices, to capture the variations in capacity factors of wind (extracted using the Renewable Ninja Tool) (see Appendix 4.4) (Staffell and Pfenninger 2016; Pfenninger and Staffell 2016) and hydropower modelled in WEAP.

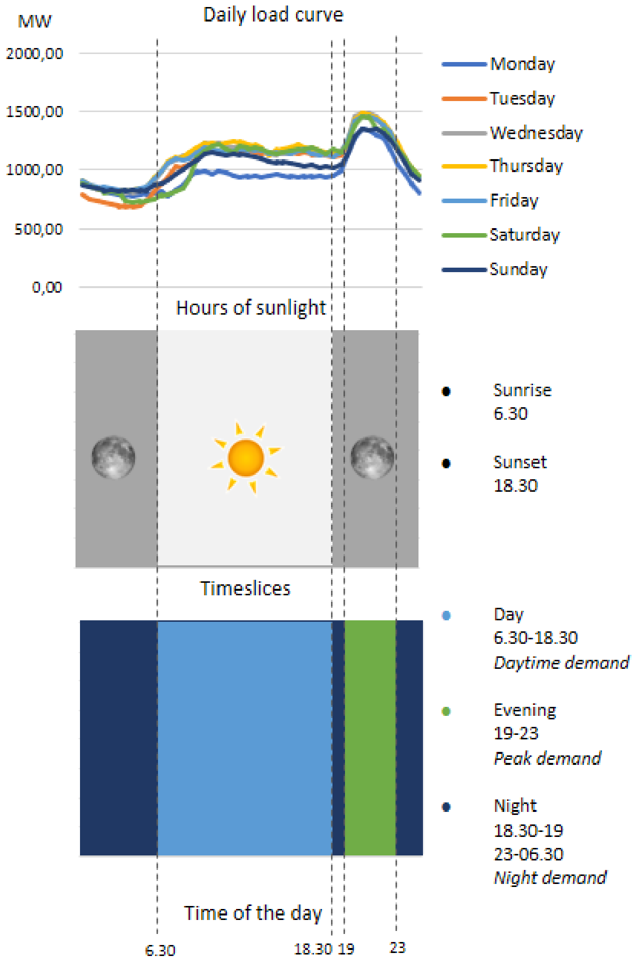

FIGURE 3 – THE OSEMOSYS TIMESLICES

The existing HPPs Masinga, Gitaru, Kiambere, Kamburu and Kindaruma and the future HPP candidate High Grand Falls were modelled separately in OSeMOSYS with all their associated parameters, since these technologies were modelled in WEAP. Nuclear has been included as a technology since it is a candidate for future generation expansion, introduced earliest in 2028 (Ministry of Energy and Petroleum 2016). A representation of technologies who produce, use & convert, and transfer energy carriers is found in the Reference Energy System (Figure 4). The ResidualCapacity was set in accordance with statistics from the Energy Regulation Commission (Energy Regulatory Commission 2015). TotalMinAnnualCapacityInvestment represents actual investments in power plants for the years 2016-2020, presented in *PGTMP* (Ministry of Energy and Petroleum 2016), since these projects has reached financial closure at the date of this report. TotalAnnualMaxCapacityInvestment has been set to 100 MW for all technologies in the years 2018-2020, except for geothermal power plant since capacity of 318.5 MW is planned in 2019 (Ministry of Energy and Petroleum 2016), to disable OSeMOSYS from investing in large projects that are not scheduled in reality. Other techno-economic parameters such as costs associated with investment and operation, availability factors, capacity factors, efficiency and lifetime of technologies were collected from various sources (see Appendix 4).

All costs associated with transmission and distribution technologies were set to zero since they are modelled in OnSSET, not to be accounted for twice. The grid electricity losses were set to 17.5 % in 2015 and assumed to decrease towards KPLC's goal of 12 % losses in 2030 (KPLC 2017). ReserveMargin was assumed to increase from 1 % in 2015 to 18 % in 2030, even though this reserve margin does not correctly reflect the reality of 2015. This assumption was made due to lack of data of the actual reserve margin in 2015 and to reflect a situation of frequent power cuts. Kenya has the intention to limit its total CO_2-emissions 30 % below a business as usual scenario of 143 $MtCO_2eq$ per year by 2030 (Ministry of Environment and Natural Resorces 2015). Based on emission data from earlier years, the electricity generation accounts for approximately 22% of the total emissions (IndexMundi 2017). With the assumption that this emission ratio stays constant and all sectors stay 30 % below their business as usual projection, the upper limit for CO_2 emissions was set to 22 $MtCO_2eq$ for 2015-2030. After 2030 they could increase at the same rate as the electricity demand, since this is beyond Kenya's long-term plans.

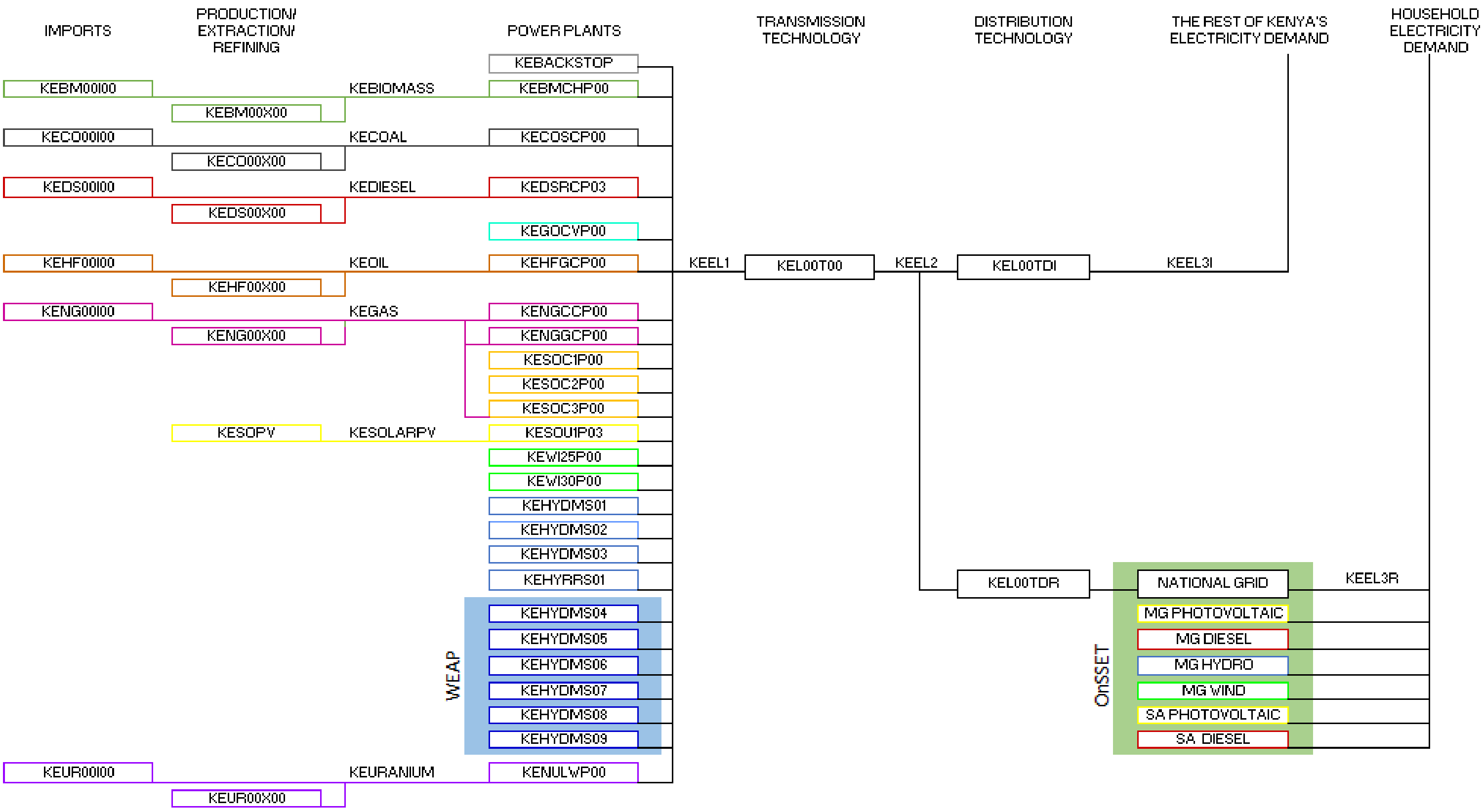

FIGURE 4 – REFERENCE ENERGY SYSTEM

LISTS OF ENERGY CARRIERS AND TECHNOLOGIES ARE PRESENTED IN APPENDIX 2 AND APPENDIX 3

2.2.3 WEAP

WEAP (Water Evaluation And Planning) is a software for integrated water resources planning, developed by Stockholm Environmental Institute. It operates on the principle of a water balance and can be applied to simulate a broad range of natural and engineered components in different kinds of water systems, for example a river basin, over a given period. A WEAP-model can be customized to meet the requirements of the analysis and data availability of the system (Sieber 2017).

WEAP was used to simulate the future potential of hydropower in the climate scenarios. An existing WEAP model from *UN Sustainable development goals from a Climate Land Energy and Water perspective for Kenya* by Moksnes (2016) was used and extended with data for climate change. The model represents the Tana basin, supplying major irrigation sites with water (Moksnes and Howells 2016) and containing 599 MW of Kenya’s 820 MW installed hydropower capacity (Energy Regulatory Commission 2015). The Tana basin is interesting for a CLEWs analysis since it is a system that uses Water for agriculture (Land-use) and hydropower (Energy).

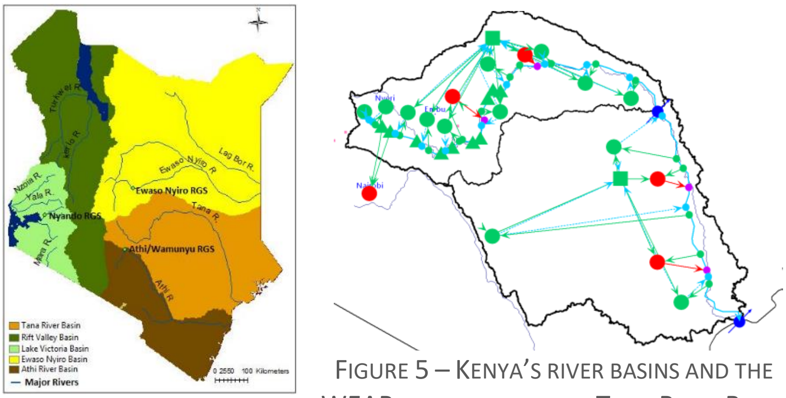

FIGURE 5 – KENYA’S RIVER BASINS AND THE WEAP SCHEMATIC OF THE TANA RIVER BASIN (MOKSNES AND HOWELLS, 2016)

The Moksnes-model was adjusted to simulate the hydrology in the river in the scenarios of climate change (RCP 2.6 and RCP 8.5), using a simplified method. The focus was to update the climate scenario-specific parameters that have most impact on the hydrology of the river - monthly precipitation and monthly evapotranspiration for all irrigation sites of the basin. Precipitation-data was extracted for the climate scenarios and used as input without adjustments, see Figure 6. Data for variations in relative humidity and mean, max & min temperatures were extracted and recalculated into monthly evapotranspiration data, see Figure 6, using the ETo Calculator version 3.2 (Food and Agriculture Organization of the United Nations 2017) developed by the Food and Agriculture Organization of the United Nations. All climate data was extracted monthly over the modelling period 2012-2040 from the CMIP5 multi model ensemble supplied by World Climate Research Programme's Working Group on Coupled Modelling (Taylor, Stouffer, and Meehl 2012), available at KNMI Climate Explorer (The Royal Netherlands Meteorological Institute (KNMI) 2017). Data was extracted for the coordinates 35-40 E, 2.5-0 S which represents the area of the Tana basin. The hydropower priority was set to 99 (lowest possible) for all reservoirs in the model since we aimed to reflect a situation where clean water for the cities and for irrigation in the agriculture areas isn’t endangered. Due to lack of data the model was not recalibrated after changing values for evapotranspiration and precipitation in this work.

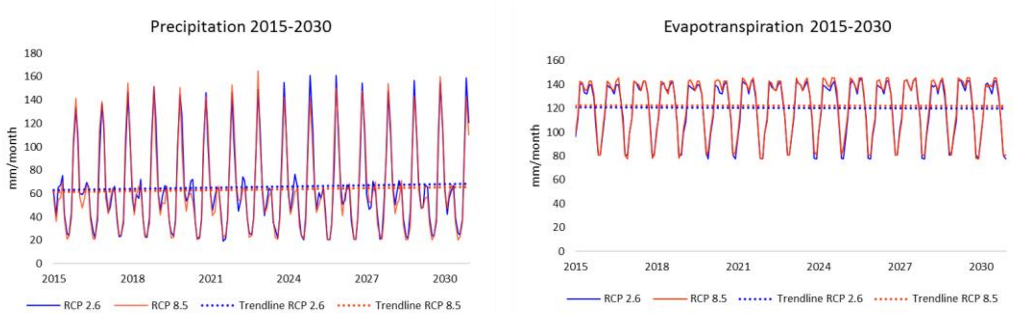

FIGURE 6 – PRECIPITATION AND EVAPOTRANSPIRATION DATA FOR RCP 2.6 AND RCP 8.5

2.3 MODELLING PROCESS

Following process was carried out when extracting results for the three scenarios:

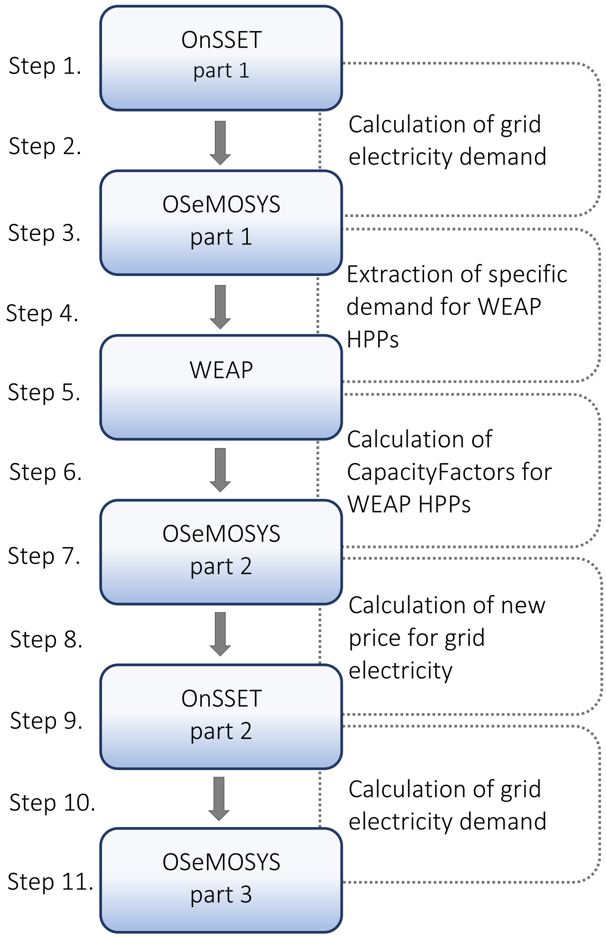

FIGURE 7 – THE MODELLING PROCESS

1. An OnSSET optimization was performed using the value 0.052 USD/kWh as an initial price for grid electricity. This resulted in a first on- vs off-grid electrification split.
2. The demand parameters for OSeMOSYS (SpecifiedAnnualDemand) were calculated (see Appendix 6.1). A constant growth-rate was assumed for the demand from 2015 to 2030, continuing throughout the modelling period. SpecifiedAnnualDemand parameters were imported to OSeMOSYS.
3. A first optimization in OSeMOSYS (part 1) was performed with CapacityFactors for the HPPs modelled in WEAP set to 100 %. This resulted in a cost optimal generation from these HPPs, as if they were not restricted by variations in Capacity Factors within the years.
4. The OSeMOSYS-result ProductionByTechnology was extracted and used as Demand-input for the HPPs in WEAP.
5. The WEAP model predicted how the water availability allowed the power plants to meet the demand during each month of the modelling period.
6. From the results of Hydropower Generation in WEAP, the CapacityFactors for the HPPs were calculated (see Appendix 6.3).
7. The WEAP-CapacityFactors were inputted to OSeMOSYS for Masinga, Kindaruma, Kiambere and Kamburu HPPs. Noticing that the results for Gitaru HPP were not realistic, the CapacityFactors for Kiambere were used since its installed capacity is of similar size[3]. The categoric HPP-technologies in OSeMOSYS were given CapacityFactors of Kiambere (Large) and Kamburu (Medium) since we wanted to represent the variation in hydrology for all of Kenya's HPPs. After these adjustments, OSeMOSYS calculated a new cost-optimization.
8. With the results from OSeMOSYS part 2, a new grid price was calculated (see Appendix 6.2).
9. The new price of grid electricity was used as input in OnSSET part 2, resulting in an updated version of the optimal split of on- and off-grid household electrification solutions.
10. The SpecifiedAnnualDemand for residential and industrial on-grid electricity was calculated (see Appendix 6.1).
11. With the new SpecifiedAnnualDemand, the final results were extracted in OSeMOSYS part 3.

[3] Gitaru HPP has a capacity of 225 MW and Kiambere 168 MW (Energy Regulatory Commission 2015).

3. RESULTS

3.1 SPLIT OF HOUSEHOLD ELECTRIFICATION SOLUTIONS

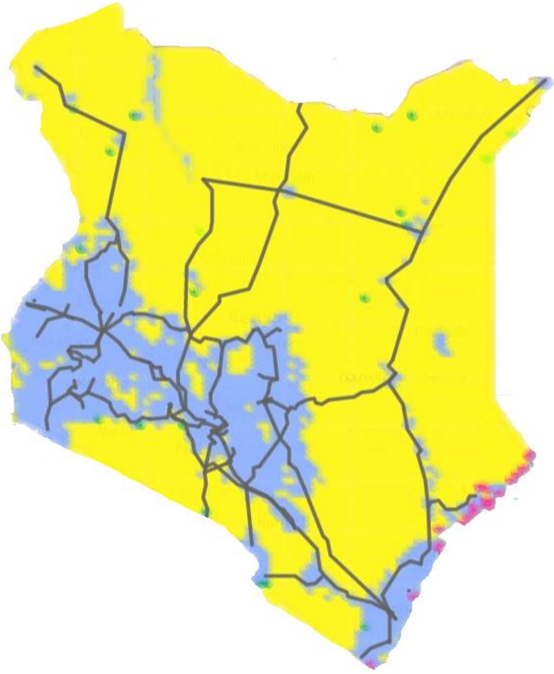

FIGURE 8 – ONSSET MAP WITH THE OPTIMAL SPLIT OF HOUSEHOLD ELECTRICITY SOLUTIONS IN THE VISION-SCENARIO

TABLE 2 – COMPARISON OF THE COST OPTIMAL SPLIT OF ELECTRICITY SOLUTIONS IN VISION AND BAU SCENARIOS

Scenario:	**Vision**	**BAU**
National grid	*93,18%*	*90,37%*
Standalone diesel	*0,009%*	*0,014%*
Standalone PV	*6,53%*	*9,57%*
Mini grid diesel	*0%*	*0%*
Mini grid PV	*0%*	*0%*
Mini grid wind	*0,11%*	*0%*
Mini grid hydro	*0,17%*	*0,05%*

The least cost split of electrification solutions shows that the areas where Kenya's major cities are located should be connected to the national grid, while rural areas with a lower population density should be electrified with off-grid solutions. The comparison of the split of electrification solutions in the **Vision** and **BAU** scenarios shows that the higher household consumption in **Vision** results in a larger share of the population connected to the national grid. The most common off-grid solution at both demand levels is standalone photovoltaic. At the **BAU** demand, only a little hydro and no wind is installed as mini grid technologies. When the demand increases to the **Vision**-level, mini grid hydro increases its share and mini grid wind is introduced. Even though they support more people with electricity, these technologies are not as visual on the map as standalone diesel. This can be explained partly by the fact that there needs to be a larger population in a settlement for a mini grid to be more cost-effective than a standalone. The use of diesel as a source of electricity is slightly lower in **Vision**, reflecting the situation of a low investment cost but a high variable cost (diesel fuel) that makes diesel a less suitable alternative at high consumption levels.

3.2 OPTIMAL ENERGY MIX FOR ELECTRICITY GENERATION TO THE NATIONAL GRID IF *KENYA VISION 2030* IS ACHIEVED

The results of the OSeMOSYS optimization is presented in Figure 9 and Figure 10. Capacity installations follow TotalMinAnnualCapacityInvestment (see 2.2.2 OSeMOSYS) during the first five years and the only deviations from the plans are small increases in hydropower, geothermal and wind. We notice a switch in the capacity installations around 2023. After this year, no additional capacity of hydro, wind and coal is installed. Instead solar PV (2022) and natural gas (2024) are introduced to the energy mix and increase in capacity throughout the modelling period. No oil is installed during the modelling period and its residual capacity is phased out and replaced with other fossil fuel candidates. The optimization suggests that electricity demand shall be covered without installation of nuclear.

A comparison of the installed capacity in the scenarios **Vision** and **BAU** shows that solar PV, natural gas, geothermal, coal and diesel are expanded to meet the higher demand. Diesel and geothermal increase their shares in the mix substantially (with 6.7 % respectively 3.9 %), which results in that the shares of especially hydro and wind decrease. The total discounted investment cost for the capacity installed in **Vision** is 38400 Million USD which is 106 % higher than **BAU**.

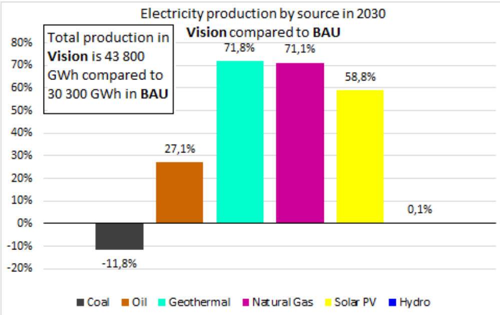

FIGURE 9 – ELECTRICITY PRODUCTION BY SOURCE IN 2030 IN VISION COMPARED TO BAU

Geothermal is the main source of electricity in the production mix suggested for **Vision**, followed by hydro and solar PVs. The production mix is dominated by CO_2-neutral sources as electricity from fossil fuels has a low contribution to the mix (only 5 %). If looking at the graphs of installed capacity and electricity generation it is noticeable that 2.30 GW of diesel capacity is installed in 2030, but it does not contribute to the production at all – this indicates that diesel is installed as reserve capacity.

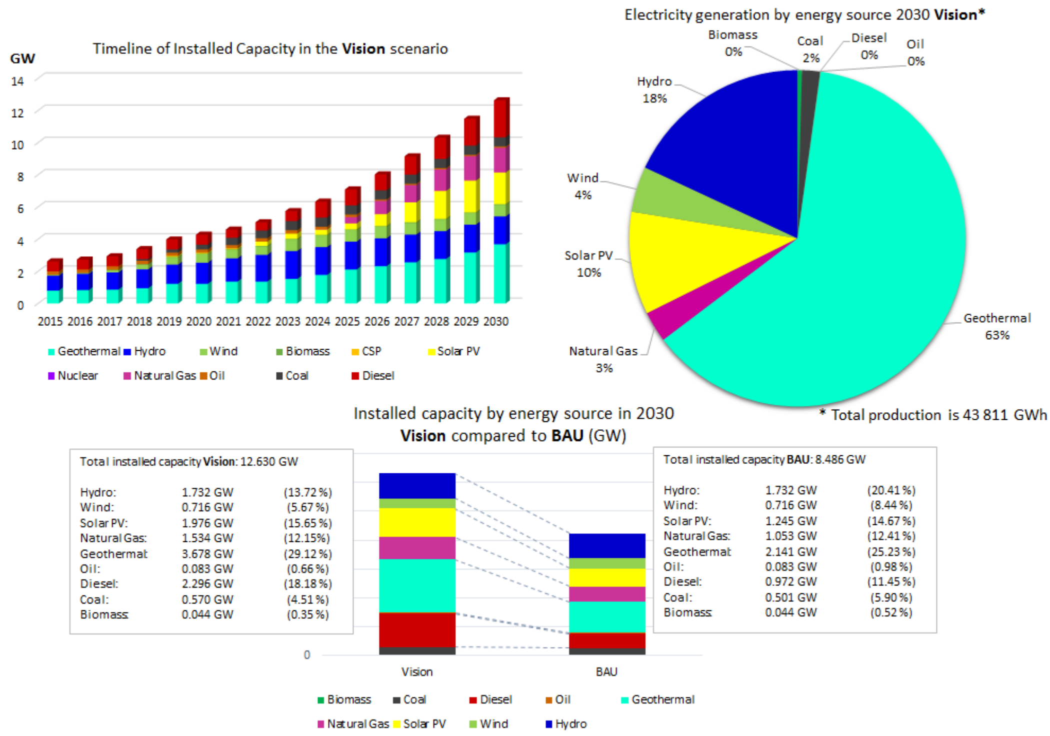

FIGURE 10 – OSEMOSYS RESULTS FOR VISION
TIMELINE OF INSTALLED CAPACITY, ELECTRICITY GENERATION BY ENERGY SOURCE AND COMPARISON TO BAU

3.3 IMPACTS ON HYDROPOWER ELECTRICITY GENERATION IN 2030 IF CLIMATE FOLLOWS REPRESENTATIVE CONCENTRATION PATHWAY 8.5

Figure 12 shows how the capacity factors vary over the year, with a peak in December-January, after a period of rain in October-November, and a common low in August-October following a dryer period in June-September (see Appendix 5). The capacity factor curves in **Vision - Climate Change** show bigger fluctuations within the year and lower averages, compared to **Vision.** This applies to all four HPPs modelled.

The HPPs generate less electricity in the **Vision - Climate Change** scenario compared to **Vision**, because of the lower capacity factors. The total reduction in electricity production from the HPPs (including the HPPs that were not modelled in WEAP (2.3 Modelling process, step 6)) is 198 GWh in 2030. Figure 11 shows how the energy mix is affected by this reduction of hydropower electricity generation. Following this change, the electricity production from geothermal energy decreases, resulting in a total generation cut of 350 GWh from these two sources combined. It is mainly covered by solar PV, but natural gas and coal increase in production as well.

To summarize the changes in the electricity generation mix for the **Vision - Climate Change** scenario compared to the **Vision** scenario: biomass and wind remain unchanged; coal, natural gas and solar PV increase (to 1.78 %, 3.09 % and 10.50 %) while hydro, oil and geothermal decrease (to 17.6 %, 0.02 % and 62.2 %). The additional capacity investment cost to fill the on-grid demand is 182 MUSD in **Vision - Climate Change** compared to **Vision**.

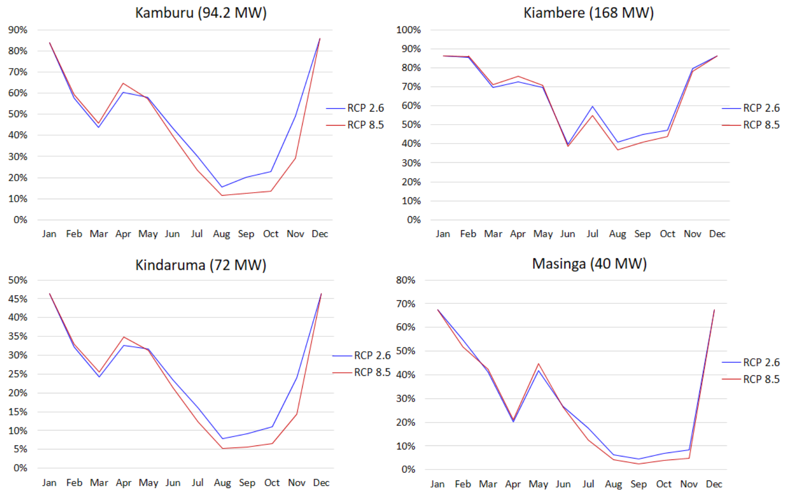

FIGURE 12 – THE CAPACITY FACTORS FOR KAMBURU, KIAMBERE, KINDARUMA AND MASINGA HPPS IN 2030 IN RCP 2.6 AND RCP 8.5

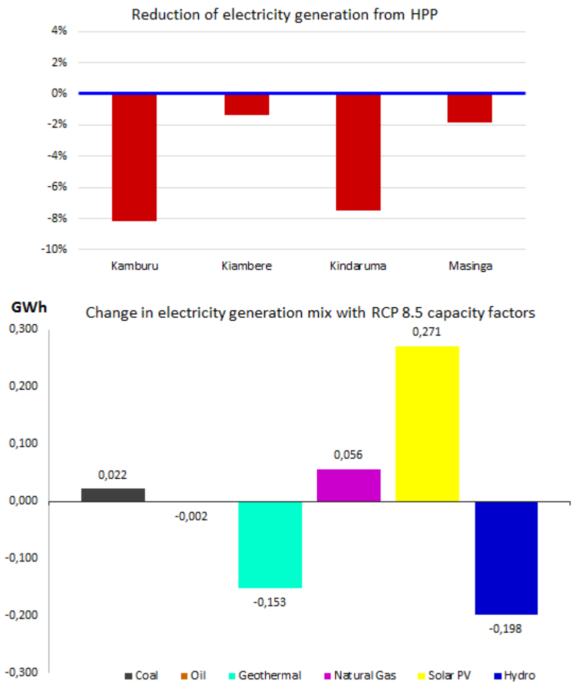

FIGURE 11 – REDUCTION OF ELECTRICITY PRODUCTION BY HPP AND THE EFFECTS ON THE TOTAL ENERGY MIX AT VISION-DEMAND

4. DISCUSSION

The cost optimization suggests that 93.2 % of the population should be connected to the national grid in 2030 in **Vision**. When comparing **Vision** to **BAU,** we see that a higher household electricity demand increases the share of households connected to the national grid. This is also suggested by Nerini et al. (Nerini et al. 2016), explaining that the high capital cost of grid connection becomes more economic on a cost per kilowatt basis at higher demand and high population density. To electrify Kenya in the most financially effective way by 2030, the forecast of future household electricity consumption – on which investment decisions are made – will play an important role.

The earlier mentioned Last Mile Connectivity project was initiated as one step towards reaching the national goal of universal access to electricity by 2020 (African Development Bank Group 2017), by connecting new consumers to the national grid and thereby enabling them to use electricity. Initially, these households will use low-Tier. In an assessment of universal access to electricity in Kenya by 2020, Power Africa (Power Africa 2016) estimates that 70-80 % should be connected to the national grid at a consumption level of Tier-1 and Tier-2. This indicated that off-grid solutions are better suited for low-electricity demand, while a higher demand makes connection to the grid more cost-effective. The investment horizon plays an important role, since the short-term national goal of universal access to electricity by 2020 (low-Tier) and the longer-term *Kenya Vision 2030*, to give Kenya's citizens a high-quality life (indicating at least Tier-3), will suggest different cost-optimal splits of electrification technologies. If both goals are to be achieved, the best solution might be for rural households to gain access to electricity by 2020 with off-grid solutions. In the long-run this early gained access will contribute to reaching higher Tiers and thereby justify the investment of connecting additional households to the national grid.

As discussed in the previous section, the size of the demand plays an important role in cost-optimizations of the electricity system. In OSeMOSYS, a higher demand gives a multiplier effect on the size of installed capacity needed to meet peak demand and reserve margin. Our results show that size of demand corresponding to **BAU** requires 8.48 GW of installed capacity, while demand corresponding to **Vision** requires a 48.8 % higher capacity at 12.6 GW. At the same time, the total discounted investment cost is 106 % higher in **Vision** than **BAU**, indicating a leverage effect on the investment costs required to install the bigger capacity. This result can be explained by that the least-cost power plants are utilized to meet **BAU** demand and when the demand increases in **Vision** more cost intensive technologies are installed. Even if our results have many uncertainties (for example in economic input data, reserve capacity and maximum limits for possible installations) this quantifies how an overestimation of the demand can potentially lead to additional costs of installing excess capacity. That can happen in Kenya since projects for electricity generation are scheduled to meet the demand of *Kenya Vision 2030* (Ministry of Energy and Petroleum 2016), while it is not definite that the vision will be achieved. One of the flagship projects in *PGTMP* is Lamu Coal PP (1000 MW), planned to be built in 2021-2023 in the coastal region near Kenya's second largest city Mombasa (Ministry of Energy and Petroleum 2016). In our optimization, a total installed capacity of 570 MW coal is suggested in 2030 in **Vision**, indicating that the Lamu Coal PP might not be cost optimal at that size. Many of the people in Kenya's energy sector that we have met for discussions have indicated that there is an imbalance in Kenya caused by that demand and production are located in different areas. This leads us to one of the limitations of the OSeMOSYS optimization: it does not include a spatial analysis which would be important to consider, especially as fuel prices differ within the country and the losses in transmission are high.

Comparing the results of **Vision - Climate Change** to **Vision** gives an insight to the possible restrictions on the use of hydropower, caused by climate change according to RCP 8.5. The capacity factors in

Vision - Climate change show more variability and lower average values for all HPPs that were modelled, resulting in a reduced electricity generation from the same size of installed capacity of HPPs. An installation of 0.08 GW additional capacity of solar PV, coal and natural gas is needed to cover the production loss. This indicates that the availability of water for the HHPs changes the optimal electricity generation investments and needs to be considered when planning for future power plants. It is hard to come up with a more extended analysis for how climate change will impact the use of hydropower in Kenya, since the results presented in this study are based on the short modelling period of 15 years and does only investigate the most extreme of the climate change RCPs. The WEAP-modelling was furthermore built on the assumptions that it would be possible to prioritize water for cities and irrigation higher than water to the HPPs. This prioritization has had an impact of the results in each scenario, although it might not be fully realistic.

5. CONCLUSIONS

This study shows that the estimations of future electricity demand play a central role when making investment decisions for electrification technologies and when planning a cost optimal electricity generation mix for the national grid. It is suggested that the forecasted demand-level is based on the trends of Kenya's actual growth rather than visionary goals. The study shows that climate change will impact the reliance of hydropower which proves the importance to understand the connection of climate, land, energy and water when developing an electricity system that meets Kenya's future demand.

6. RECOMMENDATIONS FOR FUTURE WORK

- Trade with neighbouring countries should be included to not over-estimate the need of electricity generation in Kenya, since cross-border electricity connections can lead to less long-term investments and fuel costs in Africa (Pappis 2016).
- The on-grid optimization could be improved by including a spatial analysis since that would capture the distances of transmission and make sure that the electricity generation and demand are balanced over the map.
- Since geothermal, coal, natural gas and oil depend on water availability (Kęsicki et al. 2016) they should be included in the climate change analysis to get a complete picture of the effects on the energy system. The modelling period of climate change scenarios should be extended to reflect the slow changes and long-term effects.
- Since Kenya's economic development is highly dependent on climate sensitive sectors (Ministry of Environment and Mineral Resources 2013) and the future demand has correlations with GDP-growth (Power Africa 2016), it would be interesting to include research about how extreme weather caused by climate change affects GDP and the electricity demand.
- Since we have concluded that the forecasted electricity demand is important for the investment decisions, we suggest an extensive demand-analysis to be included in future work. It should take the correlation of social development with electricity demand growth, traditions that may impact electricity consumption and energy efficiency improvements into consideration.

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APPENDIX 1 – CAPITAL COST FOR ONSSET OFF-GRID TECHNOLOGIES

TECHNOLOGY	CAPITAL COST
MINI GRID DIESEL	*721 USD/kW*
MINI GRID HYDRO	*5000 USD/kW*
MINI GRID SOLAR PHOTOVOLTAIC	*4300 USD/kW*
MINI GRID WIND	*2500 USD/kW*
STANDALONE DIESEL	*938 USD/kW*
STANDALONE SOLAR PHOTOVOLTAIC	*5500 USD/kW*

Source: KTH-dESA

APPENDIX 2 – ENERGY CARRIERS IN THE REFERENCE ENERGY SYSTEM

Energy carriers	
KEBIOMASS	Biomass
KECOAL	Coal
KEDIESEL	Diesel
KEEL1	Electricity from power plants
KEEL2	Electricity after transmission
KEEL3I	The rest of Kenya's electricity demand
KEEL3R	Kenya residential electricity demand
KEOIL	Oil
KEGAS	Natural Gas
KESOLARPV	Solar PV potential
KEURANIUM	Uranium

APPENDIX 3 – TECHNOLOGIES IN THE REFERENCE ENERGY SYSTEM

Technologies		
	KEBACKSTOP	Backstop technology
	KEBM00I00	Biomass import
	KEBM00X00	Biomass extraction/production/refining
	KEBMCHP00	Biomass cogeneration heat & power plant
	KECO00I00	Coal import
	KECO00X00	Coal extraction/production/refining
	KECOSCP00	Coal power plant
	KEDS00I00	Diesel import
	KEDS00X00	Diesel extraction/production/refining
	KEDSRCP03	Diesel power plants (Utility)
	KEEL00T00	Transmission technology
	KEEL00TDI	Distribution technology (to rest of Kenya's demand)
	KEEL00TDR	Distribution technology (to residential demand)
	KEGOVP00	Geothermal power plant
	KEHF00I00	Oil import
	KEHF00X00	Oil extraction technology
	KEHFGCP00	Oil fired gas turbine OIL SCGT
	KEHYDMS01	Hydro Power Plant (Dam) Small
	KEHYDMS02	Hydro Power Plant (Dam) Medium
	KEHYDMS03	Hydro Power Plant (Dam) Large

	KEHYDMS04	Gitaru Hydro Power Plant (Dam) Large
	KEHYDMS05	Masinga Hydro Power Plant (Dam) Medium
	KEHYDMS06	Kamburu Hydro Power Plant (Dam) Medium
	KEHYDMS07	Kindaruma Hydro Power Plant (Dam) Medium
	KEHYDMS08	Kiambere Hydro Power Plant (Dam) Large
	KEHYDMS09	High Grand Falls Hydro Power Plant (Dam) Large
	KEHYDRRS01	Hydro Power Plant (Run-of-River)
	KENG00I00	Natural Gas imported
	KENG00X00	Natural Gas extraction technology
	KENGCCP00	Natural Gas power plant (Combined Cycle)
	KENGGCP00	Natural Gas power plant (Single Cycle)
	KENULWP00	Nuclear power plant
	KESOC1P00	CSP (Without storage)
	KESOC2P00	CSP (With storage)
	KESOC3P00	CSP (With gas firing)
	KESOPV	Solar potential
	KESOU1P3	Solar Photovoltaic (Utility)
	KEUR00I00	Uranium import
	KEUR00X00	Uranium extraction/production/refining
	KEWI25P00	Wind (Offshore, 17% Capacity Factor)
	KEWI30P00	Wind (Onshore, 43% Capacity Factor)
	MG DIESEL	Mini Grid Diesel
	MG HYDRO	Mini Grid Hydro

	MG PHOTOVOLTIC	Mini Grid Photovoltaic
	MG WIND	Mini Grid Wind
	NATIONAL GRID	National Grid
	SA DIESEL	Standalone Diesel
	SA PHOTOVOLTIC	Standalone Photovoltaic

APPENDIX 4 – DATA COLLECTION OSEMOSYS MODEL

APPENDIX 4.1 – TIMESLICES OSEMOSYS

TIMESLICE	SHARE OF YEAR
JAND	0.0425
JANE	0.0142
JANN	0.0283
FEBD	0.0384
FEBE	0.0128
FEBN	0.0256
MARD	0.0425
MARE	0.0142
MARN	0.0283
APRD	0.0411
APRE	0.0137
APRN	0.0274
MAYD	0.0425
MAYE	0.0142
MAYN	0.0283
JUND	0.0411
JUNE	0.0137
JUNN	0.0274
JULD	0.0425
JULE	0.0142
JULN	0.0283
AUGD	0.0425
AUDE	0.0142
AUGN	0.0283
SEPD	0.0411
SEPE	0.0137
SEPN	0.0274
OCTD	0.0425
OCTE	0.0142
OCTN	0.0283
NOVD	0.0411
NOVE	0.0137
NOVN	0.0274
DECD	0.0425
DECE	0.0142
DECN	0.0283

APPENDIX 4.2 – TECHNOLOGY COSTS

	CAPITAL COST (MUSD/GW)		FIXED COST (MUSD/GW)		VARIABLE COST (MUSD/PJ)	
	2015	**2030**	**2015**	**2030**	**2015**	**2030**
KEBACKSTOP	9999	9999	9999	9999	9999	9999
KEBM00I00	0	0	0	0	1.5	1.5
KEBM00X00	0	0	0	0	1.5	1.5
KEBMCHP00	5094.98099	4836.855152	57.66588012	54.95856183	0.7977776741	0.7603233231
KECO00I00	0	0	0	0	3.14	5.185
KECO00X00	0	0	0	0	2.81	4.85
KECOSCP00	2528.253	2528.253	26.74815973	26.74815973	1.160944433	1.160944433
KEDS00I00	0	0	0	0	13.7	27.375
KEDS00X00	0	0	0	0	13.7	27.375
KEDSRCP03	780.57	780.57	8	8	0.5555555556	0.5555555556
KEEL00T00	0	0	0	0	0	0
KEEL00TDI	0	0	0	0	0	0
KEEL00TDR	0	0	0	0	0	0
KEGOCVP00	5894.593096	5462.089624	48.625	45.33333333	0	0
KEHF00I00	0	0	0	0	7.935	15.9
KEHF00X00	0	0	0	0	7.935	15.9
KEHFGCP00	1488.375	1488.375	0	0	4.166666667	4.166666667
KENG00I00	0	0	0	0	12.32	15.6
KENG00X00	0	0	0	0	7.2	10.2
KENGCCP00	1181.935125	1181.935125	1.323058618	1.323058618	0.6595155211	0.6595155211
KENGGCP00	780.57	780.57	8.328946435	8.328946435	0.5576278211	0.5576278211
KESOC1P00	5189.039185	3558.528283	179.90625	125.0833333	0	0
KESOC2P00	6654.65323	3878.753357	54.06503532	41.7775273	0.6007226145	0.4641947472
KESOC3P00	1590.57675	1590.57675	0	0	4.555555556	4.555555556
KESOPV	0	0	0	0	0	0
KESOU1P03	1517.748327	1085.822567	24.25	22.33333333	0	0
KEWI25P00	2126.168903	1922.652502	76.1	75.339	0	0
KEWI30P00	2126.168903	1922.652502	76.1	75.339	0	0
KEHYDMS01	3000	3000	27	27	0.13988889	0.13988889
KEHYDMS02	3933.2	3933.2	17.5	17.5	0.13988889	0.13988889
KEHYDMS03	3325.533	3325.533	27.58274	27.58274	0.13988889	0.13988889
KEHYRRS01	3430	3430	27.4	27.4	0.13988889	0.13988889
KEHYDMS04	-	-	27.4	27.4	0.13988889	0.13988889
KEHYDMS05	-	-	27.4	27.4	0.13988889	0.13988889
KEHYDMS06	-	-	27.4	27.4	0.13988889	0.13988889
KEHYDMS07	-	-	27.4	27.4	0.13988889	0.13988889
KEHYDMS08	-	-	27.4	27.4	0.13988889	0.13988889
KEHYDMS09	3708	3708	16	16	0.13888889	0.13888889
KENULWP00	8068	8068	7.5	7.5	2.77777778	2.77777778
KEUR00I00	0	0	0	0	2.8	2.8
KEUR00X00	0	0	0	0	2.8	2.8

SOURCE: (PAPPIS 2016; MINISTRY OF ENERGY AND PETROLEUM 2016)

APPENDIX 4.3 – TECHNOLOGY PERFORMANCE

	INPUT ACTIVITY RATIO	OUTPUT ACTIVITY RATIO	AVAILABILITY FACTOR	CAPACITY FACTOR	OPERATIONAL LIFE (YEARS)
KEBACKSTOP		1	1		1
KEBM00I00		1	1		35
KEBM00X00		1	1		35
KEBMCHP00	2.631578	1	0.93	0.53	30
KECO00I00		1	1		35
KECO00X00		1	0		35
KECOSCP00	2.7027	1	0.94	0.85	40
KEDS00I00		1	1		30
KEDS00X00		1	1		30
KEDSRCP03	2.85714	1	0.9	0.9	25
KEEL00T00	1	0.959	1		60
KEEL00TDI	1	0.8603	1		60
KEEL00TDR	1	0.8603	1		60
KEGOCVP00		1	0.914	0.93	25
KEHF00I00		1	1		25
KEHF00X00		1	1		25
KEHFGCP00	2.85714	1	0.9	0.9	25
KENG00I00		1	1		100
KENG00X00		1	1		30
KENGCCP00	2.083333	1	0.93	0.935	30
KENGGCP00	3.33	1	0.93	0.935	25
KESOC1P00		1	1	0.7 / 0 / 0 *	25
KESOC2P00		1	1	0.71 / 0.55 / 0.55 *	25
KESOC3P00	1.886792	1	0.93	0.92	25
KESOPV		1	1		100
KESOU1P03	1	1	1	0.5 / 0 / 0 *	25
KEWI25P00		1	0.9	See Appendix 4.4	25
KEWI30P00		1	0.85	See Appendix 4.4	25
KEHYDMS01		1	0.944	0.45	40
KEHYDMS02		1	0.944	Based on results from WEAP	50
KEHYDMS03		1	0.944	Based on results from WEAP	50
KEHYRRS01		1	0.944	0.512	50
KEHYDMS04		1	0.944	Based on results from WEAP	50
KEHYDMS05		1	0.944	Based on results from WEAP	50
KEHYDMS06		1	0.944	Based on results from WEAP	50
KEHYDMS07		1	0.944	Based on results from WEAP	50
KEHYDMS08		1	0.944	Based on results from WEAP	50
KEHYDMS09		1	0.944	-	50
KENULWP00	2.85714	1	0.9	0.85	40
KEUR00I00		1	1		25
KEUR00X00		1	1		25
				* Day / Evening / Night	

SOURCE: (PAPPIS 2016; KENGEN 2015; MINISTRY OF ENERGY AND PETROLEUM 2016; LAKO 2010)

APPENDIX 4.4 – CAPACITY FACTORS WIND

The Capacity Factors for Wind Power Plants were extracted using the online tool Renewable Ninja, accessed at https://www.renewables.ninja/# (Staffell and Pfenninger 2016; Pfenninger and Staffell 2016). The position for accessing wind capacity factors for KEWI25P00 was Meru Wind Farm (planned) at (latitude 0.184, longitude 36.631) and for KEWI30P00 at Lake Turkana Wind Farm (under construction) at (latitude 2.8, longitude 36.832). An assumption was made that wind capacity factors follow the same patterns during the entire modelling period.

TIMESLICE	KEWI25P00	KEWI30P00
JAND	0.115	0.449
JANE	0.115	0.449
JANN	0.115	0.449
FEBD	0.102	0.327
FEBE	0.102	0.327
FEBN	0.102	0.327
MARD	0.166	0.452
MARE	0.166	0.452
MARN	0.166	0.452
APRD	0.197	0.457
APRE	0.197	0.457
APRN	0.197	0.457
MAYD	0.244	0.512
MAYE	0.244	0.512
MAYN	0.244	0.512
JUND	0.175	0.485
JUNE	0.175	0.485
JUNN	0.175	0.485
JULD	0.15	0.417
JULE	0.15	0.417
JULN	0.15	0.417
AUGD	0.178	0.401
AUDE	0.178	0.401
AUGN	0.178	0.401
SEPD	0.226	0.524
SEPE	0.226	0.524
SEPN	0.226	0.524
OCTD	0.222	0.424
OCTE	0.222	0.424
OCTN	0.222	0.424
NOVD	0.158	0.388
NOVE	0.158	0.388
NOVN	0.158	0.388
DECD	0.134	0.392
DECE	0.134	0.392
DECN	0.134	0.392

APPENDIX 4.5 – RESIDUAL CAPACITY

TECHNOLOGY	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
KEBACKSTOP																										
KEBM00I00																										
KEBM00X00																										
KEBMCHP00	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
KECO00I00																										
KECO00X00																										
KECOSCP00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KEDS00I00																										
KEDS00X00																										
KEDSRCP03	0.62	0.62	0.62	0.62	0.62	0.62	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.35	0.27	0.15	0.06	0.06	0.00	0.00
KEEL00T00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KEEL00TDI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KEEL00TDR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KEGOCVP00	0.62	0.62	0.62	0.62	0.58	0.58	0.58	0.58	0.58	0.58	0.53	0.53	0.53	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.41	0.39	0.04	0.00
KEHF00I00																										
KEHF00X00																										
KEHFGCP00	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.15	0.15	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.00
KENG00I00																										
KENG00X00																										
KENGCCP00																										
KENGGCP00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KESOC1P00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KESOC2P00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KESOC3P00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KESOPV																										
KESOU1P03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KEWI25P00	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
KEWI30P00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KEHYDMS01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
KEHYDMS02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KEHYDMS03	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
KEHYRRS01	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
KEHYDMS04	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
KEHYDMS05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
KEHYDMS06	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
KEHYDMS07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
KEHYDMS08	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
KEHYDMS09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KENULWP00																										
KEUR00I00																										
KEUR00X00																										

SOURCE: (MINISTRY OF ENERGY AND PETROLEUM 2016; ENERGY REGULATORY COMMISSION 2015)

APPENDIX 4.6 – TOTAL ANNUAL MIN CAPACITY INVESTMENT (GW)

Based on projects that are under construction and/or have reached financial closure.

TECHNOLOGY	2015	2016	2017	2018	2019	2020	2021
KEBMCHP00		0.002	0.01				
KEGOCVP00		0.02			0.3185		0.14
KESOU1P03					0.05		
KEWI25P00				0.05	0.06	0.08	
KEWI30P00			0.1	0.1	0.1		
KEHYDMS01			0.017	0.007	0.011		

SOURCE: (MINISTRY OF ENERGY AND PETROLEUM 2016)

APPENDIX 4.7 – SPECIFIED DEMAND PROFILE

TIMESLICE	SHARE OF YEARLY ELECTRICITY CONSUMPTION
JAND	0.0437
JANE	0.01711
JANN	0.02282
FEBD	0.03954
FEBE	0.01533
FEBN	0.0209
MARD	0.0429
MARE	0.01663
MARN	0.02277
APRD	0.04222
APRE	0.01591
APRN	0.02177
MAYD	0.0438
MAYE	0.01677
MAYN	0.02327
JUND	0.04323
JUNE	0.01646
JUNN	0.02253
JULD	0.0452
JULE	0.01728
JULN	0.02349
AUGD	0.04568
AUDE	0.01737
AUGN	0.02308
SEPD	0.04474
SEPE	0.01697
SEPN	0.02315
OCTD	0.04559
OCTE	0.01756
OCTN	0.02419
NOVD	0.04437
NOVE	0.01675
NOVN	0.02295
DECD	0.04397
DECE	0.01705
DECN	0.02295

SOURCE: DATA PROVIDED BY KENYA POWER LIGHTNING COMPANY FOR ELECTRICITY CONSUMPTION IN KENYA 2015 (KPLC 2016)

APPENDIX 4.8 – TECHNOLOGY ACTIVITY

TECHNOLOGY	TOTAL TECHNOLOGY ANNUAL UPPER LIMIT
KESOC1P00	55436.4
KESOC2P00	55436.4
KESOC3P00	55436.4
KESOPV	82965.47
KEWI25P00	80913.6
KEWI30P00	22269.40

SOURCE: (PAPPIS 2016)

TECHNOLOGY	TOTAL TECHNOLOGY MODEL PERIOD UPPER LIMIT
KECO00X00	11400
KEDS00X00	0
KEHF00X00	0
KENG00X00	0

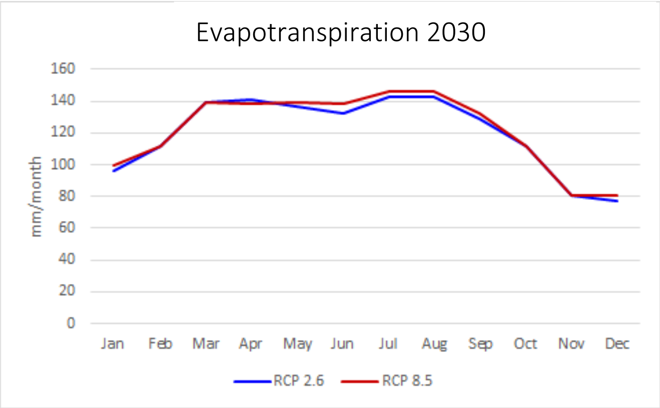
SOURCE: (PAPPIS 2016)

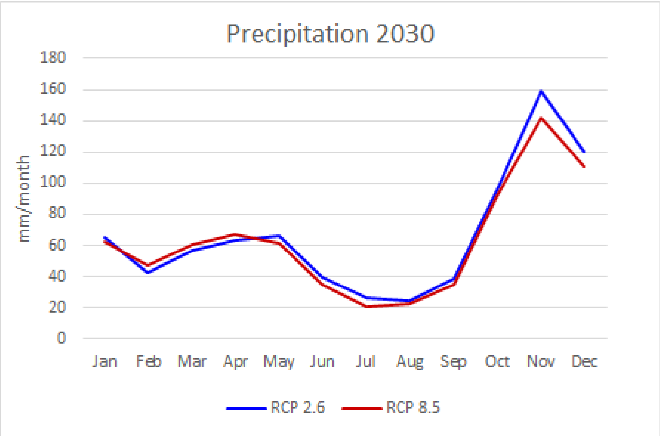
APPENDIX 4.9 – EMISSION ACTIVITY RATIO

TECHNOLOGY	EMISSION ACTIVITY RATIO
KECO00I00	0.0893
KECO00X00	0.0893
KEDS00I00	0.0693
KEDS00X00	0.0693
KEHF00I00	0.0747
KEHF00X00	0.0747
KENG00I00	0.0503
KENG00X00	0.0503

SOURCE: (PAPPIS 2016)

APPENDIX 5 – EVAPOTRANSPIRATION AND PRECIPITATION IN KENYA 2030 IN RCP 2.6 AND 8.5





APPENDIX 6 – INTEGRATION OF MODELS

APPENDIX 6.1 – CALCULATION OF SPECIFIEDANNUALDEMAND

Kenya´s national electricity demand and the household electricity demand were harmonized between OnSSET and OSeMOSYS following Equation 1 and Equation 2.

EQUATION 1

$$SpecifiedAnnualDemand_{KEEL3R} = Total\ hh\ electricity\ demand\ \cdot \%\ on\ National\ Grid$$

EQUATION 2

$$SpecifiedAnnualDemand_{KEEL3I} = Scenario\ total\ electricity\ demand - Total\ hh\ electricity\ demand$$

APPENDIX 6.2 – CALCULATION OF GRID PRICE

The grid price used as an input in OnSSET was calculated out of results from OSeMOSYS. The calculations were done following instructions provided by KTH-dESA (KTH-dESA 2017).

APPENDIX 6.3 – CALCULATION OF CAPACITY FACTORS

Capacity factor = the actual activity in a certain power plant, expressed as the ratio of electricity output to the maximum possible electricity output over a month was calculated with Equation 3.

EQUATION 3

$$CapacityFactor_{monthly} = \frac{Monthly\ electricity\ generation\ [MWh]}{Installed\ capacity\ [MW]\ \cdot hours\ in\ that\ month}$$

As High Grand Falls HPP was not installed in any of the scenarios in OSeMOSYS step 1 for any of the scenarios, it was not activated in the WEAP model.