Laying foundation for energy policy making in Uganda by indicating the energy flow

Amanda Nilsson | amanil@kth.se
Ingrid Johansson | injoh@kth.se

2015-06-03

Bachelor of Science Thesis
KTH School of Industrial Engineering and Management
Energy Technology EGI-2015
SE-100 44 STOCKHOLM
Bachelor of Science Thesis EGI-2015

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Amanda Nilsson
Ingrid Johansson

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<th>Approved</th>
<th>Examiner</th>
<th>Supervisor</th>
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<tr>
<td></td>
<td>Prof. Mark Howells</td>
<td>Vignesh Sridharan</td>
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<th>Contact person</th>
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I. Abstract

This study aims to support the policymakers of Uganda to develop a sustainable and environmental friendly energy system by indicating the energy flow. An analysis of the interconnections between Climate-, Land-, Water- and Energy use (CLEWs) is conducted, and the most important connection between the hydropower and agriculture’s water use is identified. In this report, the sections energy and economy are analysed, please see “...” for a further analysis of the water- and land use. Uganda is today a country with large dependence on both agriculture and hydropower, which might become a problem in the future as the electricity demand grows and the environmental condition changes. In this report a future electricity demand is projected and used as an input in the Open Source Energy Modelling System (OSeMOSYS) to find the least cost solution (NPV) to meet the future growing energy demand for different scenarios. This resulted in an energy mix where all the hydropower potential in the country is utilised in the country together with a large installed capacity of natural gas, which will be extracted from the national reserves. The report discusses the results in detail and provides further direction on how Uganda can develop their infrastructure and energy system with regards to policies and external factors. It also enlightened the dangers of inefficient and inflexible policies in the country. The modelling data and detailed calculations will be made publicly available.

II. Sammanfattning

III. Acknowledgements

We would like to thank everyone who in some way has supported us and provided guidance when conducting this study.

First of all, we would like to express our gratitude to our mentor and project assigner, Professor Mark Howells for believing in us and giving us the opportunity to be a part of this experience.

We would also like to thank our supervisor Vignesh Sridharan for providing both expert knowledge and data in the area and supporting us.

Last but not least, we would also like to acknowledge James Baanabe and the Ministry of Energy and Mineral Development in Kampala for providing us with useful data and for being helpful and welcoming when we visited.
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1. Introduction

Uganda is today struggling with the challenge to develop their political system, infrastructure and energy system in a sustainable and efficient way to enable an economical growth in the country. Since all of these sections are dependent upon each other it is difficult to develop one without the other, which is a challenge many challenges developing countries are faced with. Uganda has experienced a strong economical growth over the past decade, why it is considered to be an interesting country to analyse.

As a part of the UNDESA/DPAD’s project “Supporting the Design of Sustainable Development Policies with Policy Modelling Tools 2014-2015” this study aims to support Uganda in formulating a sustainable development policy (KTH, 2015). To maintain a consequent and integrated policy making system it is important to analyse the system as a whole, and to see how the different factors affect each other. The Climate-, Land-, Energy- and Water use (CLEW) is a tool, which analyses the linkages and relations between the four areas (Department of Energy Technology, 2015). The approach has been used in this study to highlight the way the resources need to be allocated in a thought through and efficient way to secure an efficient economical growth.

![Diagram](image)

Figure 1 Identified interconnections between the areas Climate-, Land-, Energy-, and Water use in Uganda (Source: Appendix #1)

To include and integrate the four areas in a sufficient way the analyse has been conducted in two separate, but connected, reports. In this part a modelling of the Ugandan energy system has been conducted, together with an economical analysis, by using the Open Source Energy Modelling System (OSeMOSYS) and with the Model for Analysis of Energy Demand (MAED). In the report “Water and Agriculture in Uganda – Supporting a CLEW assessment” the analysis has focused
on what effects this would have for the Ugandan water- and land using the Water Evaluation Planning System (WEAP) and the Global Agro-Ecological Zones (GAEZ) (Lindblad et al, 2015). Both reports are however based on each other’s modelling results. It is important to note that, although the individual analysis may differ, the results will greatly affect the outcome of the other. The report focusing on the Ugandan water and land use may therefore limit or show further possibilities regarding an expansion of the energy sector.

To analyse the energy and economy the Ugandan energy system has been modelled in the Open Source Energy Modelling System, (OSeMOSYS), where the demand has been projected in an excel-based analysis of the future energy and electricity consumption in Uganda.

All the values in this report are given in Giga Joules (GJ) or Peta Joules (PJ). For other conversions of the values, please see appendix 1 and appendix 2.

1.1 Review of Past Studies

Generally, due to limited resources and lack of necessary knowledge in developing countries, strategies and specified future projections do not exist in the same extent as it does in industrialized countries. This is also the case in Uganda, where there especially is an absence of larger energy studies with the aim to guide the country towards a sustainable development.

The project “Supporting the Design of Sustainable Development Policies with Policy Modelling Tools 2014-2015” undertaken by UNDESA/DPAD aims to assist governments and other policymakers with guidelines and specified frameworks to enable a sustainable development. Strategies are obtained by the use of well-developed tools, designed to facilitate the analysis of how different areas interact (KTH, 2015).

Previous studies from the perspective of sustainable development opportunities regarding the interconnection between Climate-, Land-, Energy- and Water use (CLEWs) include those that have been performed on Nicaragua and Bolivia (KTH, 2015). The analysis of how the sectors interact with each other can favourably be applied when developing a sustainable and resource integrated strategy for future development in other countries (Campos et al, 2014).

Previous studies that have been performed on Uganda are projections for future population and GDP. The Government of Uganda has developed the report “Uganda Vision 2040” (NPA, 2007), which aims to guide the country in the transformation from a low-income country to a stable middle-income country. The expected population growth in Uganda has been mapped by the United Nations (2013) in the report “World Population Prospects: The 2012 Revision”.

1.2 Statement of the Objectives

The objective of this study is to, by modelling and projecting the future of the Ugandan energy system in the Open Source Energy Modelling System
(OSeMOSYS), support efficient and sustainable development policies. This is to be done by identifying the interconnections between the sections Climate, Land, Energy and Water. An adequate resource management is to be determined and analysed.

2. Ugandan context
This section presents general information about Uganda, which aims to increase the understanding of the country’s internal possibilities, as well as the challenges Uganda faces today.

2.1 General
Uganda is a today categorized as a poor and developing country, and it is located in East Africa. The capital of Uganda is Kampala, a city with over 1.5 million inhabitants located a little north of Lake Victoria. In 2014 the total population of Uganda was estimated to be 35 918 915 people (UBOS, 2014a), a value which has been growing steadily, see figure 2. Approximately 18% of the country’s total land area of 241 038 square kilometres consists of water. The country is landlocked without a coastline, which limits transportation methods to rail and roads. Neighbouring countries are Kenya, Tanzania, Rwanda, South Sudan and the Democratic Republic of Congo (CIA, 2015).

![Historical Population](image)

Figure 2 Historical population, thousands (Source: UN, 2013)

2.2 History
During the colonization of Africa in the late 1890’s, Great Britain declared a protectorate over Uganda, taking control over the several kingdoms in the area and uniting them under the Uganda Protectorate (History World). Not until 1962 Uganda got full internal self-government and the Ugandan politician Milton Obote got elected prime minister. Obote was the founder of the Uganda People’s Congress (UPC), in opposition to the leadership of the largest kingdom, Buganda (African Studies Center). Though, in 1966 Obote attacked the kingdom in Buganda, where he successfully oppressed the leaders and in the process killed over 2000 civilians (Tripp, 2010, p. 160). One year later, in 1967, Obote imposed a new constitution and declared himself president without having any elections. In 1971 Idi Amin, chief of staff of the Ugandan army, overcame the Obote
government, (Keatley, 2003) and here a dark period of the Ugandan history began.

Overall, Idi Amin was a self-appointed president for eight years, which was a period of brutal genocide and economical mismanagement. The regime of Idi Amin ended after the war between Tanzania and Uganda in 1978 and Obote regained power, which also ended up being a period of brutal killings (Keatley, 2003).

A new more democratic era began when Yoweri Musevni came to power in 1986. It was a start of a new more fair-minded and pleasant society. Development of human rights became more prioritized and the foreign investments in the country increased, which in turn resulted in an increasing and stable economic growth (Our Africa).

2.3 Economy

Even though Uganda has had an average GDP growth of 6% from the later part of the 1980s, relatively unfavourable living condition still dominates the country (Bird et al, 2013). The positive trend was negatively affected by the global economic financial slowdown in 2007/2008, which resulted in a standstill in economic growth (Ministry of Finance, 2013), see figure 3.

![Annual Historical Growth of GDP](Source: The World Bank, 2015a)

With a current GDP per capita of 657.4 US$ (The World Bank, 2015b), Uganda is one of the poorest countries in the world. In 2012/2013 almost 6.7 million people, representing a share of 19.7% of total population were categorised as poor. This was though a decline from the previously estimated share of 24.5% in 2009/2010 (UBOS, 2014b). In the same year as the last estimation was made there was also a clear difference between rural and urban areas. The rate of poverty in rural areas was measured to 22.8%, compared with 9.8% in urban areas (UBOS, 2014b). The gap between the standards in the areas is also increasing, since most of the development takes place in the urban areas, see figure 4.
2.3.1 Socio Economic Approach

Despite the steady decrease of poverty and the economical growth, one fifth of the population is still living in poverty (UBOS, 2014b), which prevents further growth and development of the country.

2.3.1.1 Household

The number of people living in households was estimated to be roughly 34.4 millions in the year 2014, representing a share of 98.5% of total population. The standard of a main household in Uganda is low and most of the households consist of only one or two rooms, which in average also are shared by 4.7 persons (UBOS, 2014b). A big problem for the standard of living is the limited access of electricity, safe water and sanitation. In 2013 the household electrification rate was estimated to 14.9%, which was an increase from 10% in 2010 (MEMD, 2014c). The access to safe drinking water varies substantially between urban and rural areas. In 2012 the access to safe drinking water was 94.8% in urban areas compared to 71% in rural areas. On a national basis the share was amounted to be 74.8% (CIA, 2015).

2.3.1.2 Labour Force

The share of the population within the age range of 14-64 is defined as the working age population and it is used as a measurement to estimate the number of potential workers in an economy. In the year 2012/2013 the share of the working age population was estimated to almost 48.4% of the total population. Of these, 84% were actually economically active (UBOS, 2014b), which means that 16% of the potential labour force did not participate.

Agriculture is the main source of labour since almost 72% of the active labour force work within this sector. The rate of self-employment is relatively high in Uganda and even if people have an actual job, there are no guaranties of a sufficient and safe income, especially since 17% of the employed workers have such a low income that they still are categorised as poor. According to the “Uganda National Household Survey 2012/13” the monthly median income for workers in employment was estimated to approximately 36.7 US$ (UBOS, 2014b), compared to a value of 51 324 US$ in the United States (Noss, 2013).
The degree of labour and employment and thus the amount of income varies considerably between different regions and between rural and urban areas.

2.3.1.3 Education
Because of the clear correlation between level of education and employment, the limited access to education negatively affects the growth. Education and knowledge plays a key role in a country’s socio-economical welfare and development. According to the “Uganda National Household Survey 2012/13” 18% of the total population do not have any education at all, and only 22% of those who attended secondary education actually finished (UBOS, 2014b). Education is strongly related to factors such as innovation, development of new technologies and it is also important in aspect of health and human development. According to the Vision 2040 (NPA, 2007) there have already been some improvements in literacy rate, however there is still much room for further progress. In 2006, the share of population aged 10 years or above and with the ability to read was measured to 69%, compared to 73% in 2010 (NPA, 2007).

2.3.1.4 Health Care
A major part of the population in Uganda is suffering from fatal diseases and other conditions that negatively affect the living standard. There is a clear health problem in the country, which has resulted in a high level of mortality and an overall young population. In the year 2013 the rate of child mortality was measured to 44 out of 1000 births, a 13.7% decline from 2010 (UBOS, 2014a). This can be compared with the same rate in the United States, which there are 6 out of 1000 births (The World Bank, 2015d). The two main diseases that are predominated in Uganda are HIV and malaria (UBOS, 2013), and the lack of knowledge of them is also a major problem since it increases the risk of further spread.

2.3.1.5 Future Development
In recent years Uganda has made some progress, however there is still a long way to go before they can reach the target of becoming a middle-income country. The most dominating shortcomings identified today are the lack of fundamental services and poor access to them, for example poor access to education, underdeveloped industry and lack of health services. The government as well as other institutions are already aware of several of the mentioned shortcomings, and the problem is the lack of resources and functional policies to improve them.

A high degree of education is a necessary foundation for a developing welfare state. In many ways, education and knowledge is the engine and driving force for growth, innovation and improvements of other factors (Ministry of Finance, 2003). In the future the school and educational investments will be essential to consider, and above all, the share of population with access to education needs to increase. If the human capital does not increase together with the technological development and the objectives pursued, it will be impossible to achieve them.

The government announced that they will focus on the population and development of human resources to retain economical growth in the “Uganda Vision 2040” (NPA, 2007). They will also, in line with other countries, make
significant improvements by applying the latest skills, the most favourable technologies and already well-developed tools (NPA, 2007).

In order to achieve progress and improvements in present conditions it is also necessary to develop the current inadequate infrastructure. This is also dependent on a steady access to electricity as well as proper sewage and water systems. As a fundamental basis for industry and transportation, an underdeveloped infrastructure can put unnecessary limits on industry, agriculture, education and health services (NPA, 2007).

There is a strong motivation and desire to improve the current low level of development and to create a more prosperous country with greater opportunities. With good strategies Uganda can transition from being an extremely poor country to a middle-income country.

### 2.4 Uganda’s Energy System

Uganda has one of the lowest energy consumptions in the world, with an average energy consumption of 12.72 GJ per capita (Adeyemi et al. 2014), and an average per capita electricity consumption of less than 0.36 GJ (MEMD, 2014a). This is a consequence of a large share of the population living in rural areas with only 14.9% of the population having access to the national grid in 2013 (MEMD, 2014c), combined with a low installed generation capacity.

However, the Ugandan energy demand is anticipated to outgrow the energy supply in the next few years (GET FiT Uganda, 2014), and over the past years Uganda has experienced an increase of the energy demand at an average annual rate of 8% (EIPL, 2011). This is a trend that can be seen over the past two decades (MEMD, 2014a), and is partly because of the economical growth the country has felt in the same period. Although, the electricity supply has not increased in the same pace as the demand, which has led to an energy deficit. This deficit has mainly had an impact on the industrial and commercial sectors, leading to a decrease of the GDP growth from an expected rate of 6.5% to a value of 4.5% in 2006 (World Finance, 2013). To resolve this problem many construction plans are in process to increase the country's generation capacity.

#### 2.4.1. Energy mix

Uganda’s primary energy consumption consists to 88.9% of biomass, where the largest part is fuel wood, due to a large rural population and a low electrification rate. Petroleum products constitute 9.7% of the energy balance, and only 1.4% of the energy consumption is electricity (MEMD, 2014a).

#### 2.4.1.1. Electricity Supply

Due to the many water bodies in Uganda, and the Nile River running through the country, they have good conditions and possibilities for a wide distribution of hydropower. However, wildly inconsistent data has made the results of the estimation of the current total installed generation capacity in Uganda, vary considerably. According to the values found in Electricity Regulatory Authority’s (ERA) report “Developments and Investments Opportunities in Renewable Energy
Resources in Uganda” (2013a) the total installed capacity in the country was identified as 873.6 MW, consisting of about 80% hydropower. Of these 873.6 MW, 6 MW is off grid capacity.

Historically, hydropower has been the main source of electricity production, and in 2005 the first large thermal power plant was constructed due to the acute power shortage Uganda experienced in the early 2000's (MEMD, 2014a). Today Uganda has three large hydroelectric power plants with more than 50 MW installed capacity, which together contributes to 630 MW of the total installed capacity of 873.6 MW, see table 1. In addition to this, there is an estimated additional potential of over 2000 MW of hydropower capacity (Adeyemi et al. 2014).

<table>
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<th>Plant name</th>
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<td>Kiira</td>
<td>Hydro</td>
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<tr>
<td>Bujagali</td>
<td>Hydro</td>
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Table 1 Existing power plants in Uganda in 2014 (Source: ERA, 2013a)

![Installed Generation Capacity (MW)](image)

Figure 5 Current installed generation capacity in Uganda, megawatts (Source: ERA, 2013a)
2.4.1.1. Construction plans

Considering the growing electricity demand in Uganda and the predicted power supply shortage (GET FiT Uganda, 2014), power plant constructions and energy investments are essential for the country’s future development.

In accordance with previous studies there is a clear correlation between energy supply and improved industrialization and economic development (World Economic Forum, 2012). The access to electricity has a key role when increasing economic growth and status in a country (Tumushabe et al. 2014).

In Uganda, there has historically occurred situations when there is not enough capacity to meet the current demand, which leads to unwanted shortages of supply (Bujagali Hydropower Project). Large fluctuations and uncontrolled shortages of electricity have historically proven to impact the growth of GDP negatively. In 2006 Uganda experienced a fuel and power deficit and the gap between demand and supply was big enough to reduce the productivity of the country’s industries and other businesses, which in turn resulted in a slowdown of GDP growth. The expected growth of 6.5% decreased markedly to 4.5% during that year (World Finance, 2013). Such situations usually have major consequences, since it often takes a while before the economy recovers (Department of Disaster Management, 2012). This, once again, establishes the importance of a continued increase of the electricity supply and to uphold a good investment climate in the energy sector, to maintain a continued future economic growth.

At the “Suppliers and Contractors Conference” organized by UMEME in February 2015 (Bidasala-Igaga, 2015) the Ministry of Energy and Mineral Development declared plans on how they will meet the goals of increasing the electricity consumption per capita from today’s 75 kWh to Vision 2040’s goal of 3668 kWh together with an electrification rate of 80% in 2040 (NPA, 2007). To achieve these goals, the generation capacity needs to be increased to 41 738 MW. To increase the electricity generation a new energy mix is proposed according to table 2. (NBI, 2014)

<table>
<thead>
<tr>
<th>Future energy mix</th>
<th>Capacity (MW)</th>
<th>Identified projects (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro power</td>
<td>4500</td>
<td>2233</td>
</tr>
<tr>
<td>Geothermal</td>
<td>1500</td>
<td>100</td>
</tr>
<tr>
<td>Nuclear</td>
<td>2400</td>
<td>-</td>
</tr>
<tr>
<td>Solar</td>
<td>5000</td>
<td>200</td>
</tr>
<tr>
<td>Biomass</td>
<td>1700</td>
<td>150</td>
</tr>
<tr>
<td>Peat</td>
<td>800</td>
<td>-</td>
</tr>
<tr>
<td>Thermal</td>
<td>4300</td>
<td>53</td>
</tr>
</tbody>
</table>

Table 2 Identified potential generation capacity in Uganda (Source: Bidasala-Igaga, 2015)

For the more foreseeable future the Ugandan government are aiming to realise five large hydropower projects over the next seven years, with a combined capacity of over 2000 MW (The East African, 2013). However, only three of these have received financial funding and a construction date, see table 3.
<table>
<thead>
<tr>
<th>Plant name</th>
<th>Installed capacity (MW)</th>
<th>Commission year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karuma</td>
<td>600</td>
<td>2018</td>
</tr>
<tr>
<td>Isimbia</td>
<td>188</td>
<td>2016</td>
</tr>
<tr>
<td>Ayago</td>
<td>600</td>
<td>2019</td>
</tr>
<tr>
<td>Geothermal</td>
<td>33</td>
<td>2016</td>
</tr>
</tbody>
</table>

Table 3 Future power plant constructions (Source: EAPP et al, 2011)

2.4.1.1.1 Karuma

The Karuma Hydropower Project is a joint project undertaken between the Government of Uganda and the Chinese Government together with the Chinese construction company Sinohydro (MEMD, 2013a). The preparation constructions were completed in December 2013, and the power plant is scheduled to be on power in 2018 (EAPP et al, 2011).

At the Rural Electrification Programme the Karuma Project was identified to be the least cost solution of the identified potential hydropower sites and has therefore been prioritized (EIPL, 2011). When finished, the Karuma hydro power plant will be the largest power plant in Uganda (Harris, 2015).

2.4.1.1.2 Isimbia

Isimbia is a 188 MW hydropower plant (UEGCL, 2014), which also is a part of the government’s effort to increase generation and to lower the electricity prices (Wakabi, 2013). After having some financial issues standing in the way of the construction start, the Chinese government contributed with a $2 billion financial aid for the Isimbia and Karuma projects, which has allowed the Isimbia construction to begin (The East African, 2013).

2.4.1.1.3 Ayago

The Ayago hydropower project is a 600 MW power plant with a planned commission date in 2019 (UEGCL, 2014). It has received funding from the Japanese company JICA and construction is expected to be starting soon (JICA).

2.4.2 Policies and Initiatives

2.4.2.1 Investment Climate

The recently discovered oil reserves (NRGI), together with a predicted increase of the energy demand and abundant construction opportunities of hydro power plants, has created several investment opportunities in Uganda and has attracted foreign private investors. Despite these opportunities, circumstances as bureaucracy, corruption, poor infrastructure and the lack of access to energy negatively affect the investment climate (U.S. Department of State, 2013).

2.4.2.2 Feed in Tariffs

When exploring the possibilities to increase the generation capacity in the country and to create an encouraging investment climate, the Ugandan government took the opportunity to promote a sustainable energy mix by introducing the regulatory mechanism, Feed in Tariffs (FiT). The Feed in Tariffs are an economic incentive provided by the Ugandan government that aims to encourage private investors to participate in renewable power generation projects (ERA, 2013a).
2.4.2.3 The GET FiT Program
In May 2013 the Government of Uganda together with Uganda’s Electricity Regulatory Authority (ERA) and several international parties, launched the GET FiT Program (GET FiT Uganda, 2014). This is a program which main goal is to eliminate the barriers for investments in renewable energy projects to provide capacity for the acute energy shortage in Uganda (Deutsche Bank, 2013). Today the on-going projects add up to a total planned installed capacity of 128 MW. The aim is to increase the Ugandan energy supply with about 20% over the next 3-5 years (GET FiT Uganda, 2014). The investment incentives created by GET FiT Uganda are a top-up payment on the feed in tariff.

2.5 Sectorial Approach
In this section the different sectors agriculture, industry, service, transport and household and their current status are presented.

[Table showing the contribution to GDP by sector 2013]

Figure 6 Sectorial contributions to total GDP, % (Source: UBOS, 2014b)

2.5.1 Agriculture

2.5.1.1 Energy
Although being the largest industry in Uganda the agriculture is a minimal consumer of electricity. In 2013, the agricultural industry consumed 0.4% of Uganda energy output and no electricity (MEMD, 2014c). The reason for the low consumption is an undeveloped sector with primitive working methods (UNFPA, 2013). Even though the agriculture has a nature of non-mechanical use, there still exists a consumption of fuel, which is primarily fuel wood and heavy diesel (MEMD, 2002).

2.5.1.2 Present Status
Agriculture is one of the most essential sectors in Uganda since it is the core of the economy. The contribution of agriculture to total GDP was 20.9% in the calendar year 2013, which was a decline of 1.1% from the previous year (UBOS, 2014b).

There are several targets set for an industrialization of the agricultural sector. The future growth of the sectorial contribution to GDP is expected to be stable at
an average rate of about 5% (NPA, 2007). This value was 1.5% in 2013/2014, compared to the lower value of 1.3% in 2012/2013 (Ministry of Finance, 2012). Despite the hopes of a positive development of the sector, the sectorial contribution to total GDP is projected to decrease to 10.4% from today's level of 20.9%. This is because of projections of a high growth rate for the other sectors, which not have such a substantial role in the Ugandan economy as the agricultural sector has today (NPA, 2007).

Being such a large part of the Ugandan economy, the agriculture is a big source of labour opportunities. The targeted growth rates of the sectorial work force are, in the same way as for the sectorial contribution to GDP, higher for the other sectors than for the agricultural sector whereas the agriculture composes such a large share of today's labour force. This will, as earlier mentioned, lead to a decrease of the agricultural share of the total labour force, even though the agricultural work force increases. The goals for the high growth rates of the work force in the industrial and commercial sector, indirectly leads to a target of a decline in the agricultural share of the work force from 72% (UBOS, 2014b) in 2012/2013 to a value of 31% in 2040 (NPA, 2007).

The different activities in the agricultural sector are categorized as food crops, cash crops, livestock, forestry and fishing (Ministry of Finance, 2012), where the subsector of cash crops is the most essential for Uganda, especially in terms of export. The most common cash crops are coffee, tea, cotton and tobacco, and especially coffee has been an important source of export for a long time, and accounts for more than 60% of the total sector of cash crops (Ministry of Finance, 2012). Considering all formal exports in Uganda, the contribution of coffee was 17.7% in the calendar year 2013, a value that has been increasing the past years. Overall, the share of cash crops to total exports was 27.5% in 2013 (UBOS, 2014b).

The cultivation of food crops represents over 50% of the agricultural sector and it primarily consists of 16 major crops. Traditional food crops are for example maize, rice, cassava, oil crops and beans. In contrast to cash crops food crops are mostly used for domestic consumption and plays a key role in household welfare as well as macroeconomic stability (UBOS, 2014b).

2.5.1.3 Future Development and Challenges
Something that is common for practically all developing countries is that the agriculture constitutes a major part and from an economic perspective is almost exclusively the country's most important sector (The World Bank). The fact that the agriculture has such a major role in the Ugandan economy makes it difficult to predict and secure Uganda's future growth, since the agricultural sector is characterized by high volatility and fluctuations. The harvests rely on good conditions regarding climate and rainfall and the knowledge of and opportunities to pesticide is limited, which makes it an unpredictable source of income. The fact that there is an absence of efficient irrigation systems and rudimentary working methods complicate the work of farmers. All these factors make the sector vulnerable to climate change, which constitutes a major threat to the population and the entire country. It can also result in increased food
prices and a limited food supply, and if the situation is allowed to transpire it may result in malnutrition. Aside from the physical factors, the agricultural sector also suffers from unpredictable price changes, whereupon the variations can affect the farmers negatively and increase poverty.

In recent years, the agriculture has experienced a decrease in productivity, which primarily is because of inefficient production, lack of knowledge, unfavourable weather conditions and a limited access of functional technology and new innovations (UNFPA, 2013). The biggest identified challenge for Uganda’s agriculture is therefore to move from today’s primitive operations to a more industrialized and commercial business. To achieve future growth the agricultural sector requires improved technologies and techniques as well as a method to achieve a higher level of water use efficiency. The hope is that it will generate a more sustainable, competitive and also a more profitable business (NPA, 2007). What needs to be prioritized to obtain a more stable and secure sector is development of efficient working methods, increased knowledge of pesticides and insecticides to ensure food security and nutrition, together with a higher productivity. The sector also needs a better adaption to the unpredictable circumstances, such as differences in prices and yields (UNFPA, 2013). By improving these areas Uganda can increase their competitiveness on the world market. As the agriculture becomes more industrialized, it will lead to an increase of energy demand, and especially electricity.

To achieve the goals for an industrialization of the sector and a commercialization of the business the government must assist with resources. Good strategies and a well-planned future development are necessary to see improvements in productivity and to increase Uganda’s international competitiveness. In Vision 2040 (NPA, 2007) the government agreed to provide sustainable methods and water resources for irrigation. The plan is to build a water transfer system that can provide large areas. This will benefit the harvest of food crops, since the limited access of water is the main reason for the low productivity. With increased access to water, combined with other improvements, the sector can grow further and result in an enlarged source of income and export (NPA, 2007).

2.5.2 Industry

2.5.2.1 Energy
The industrial sector in Uganda is constituted by the different subsectors mining and quarrying, manufacturing and construction (UBOS, 2014b). According to MEMD (2014c) the industrial sector consumed 20.2% of the total energy consumed in 2013, which was a value of 104.0 PJ. Compared to the other sectors in Uganda, the industry is the largest consumer of electricity and used 65% of the total electricity supplied in 2013 (MEMD, 2014c).

2.5.2.2 Present Status
In respect to the industry as a whole, the sectorial addition to total GDP at current prices in the fiscal year 2013/2014 was 26.3%. In the same period, the
sectorial growth was identified to 5.6%, a decrease from 6.8% previous year (UBOS, 2014b).

Old technologies and inefficient processes dominate the majority of all industries in Uganda. The potential of efficient energy use is limited and compared to other countries the processes are less advanced and developed (MEMD, 2002). Except of the lack of new technologies with improved energy and cost efficiency, there are other deficiencies that create difficulties for the industry and its performance. Further shortcomings that complicate the operations are lack of proper instrumentation and skilled work force. The fact that there is a limited knowledge obstructs the productivity, and to establish a powerful and competitive industry a better structure and stronger competence must be obtained (MEMD, 2002).

Of the industrial subsectors mining and quarrying is the smallest one compared to the slightly more dominant ones, manufacturing and construction. In the fiscal year 2013/2014s mining and quarrying only constituted 1.3% of the total industrial economical activity. In the same period, the contribution by manufacturing and construction was 29.4% and 52.5% respectively (UBOS, 2014b). In terms of contribution to total economical activity, construction is the largest subsector of the industry.

Although mining and quarrying represents a small part in aspect of contribution to total economic activity, the value added for the subsector recorded a growth of 4.3% in the fiscal year 2013/2014. Compared to manufacturing and construction, mining and quarrying was the only subsector that experienced a strong growth in activity (UBOS, 2014b).

![Subsectorial Contributions to Industry](image)

Figure 7 Economic contributions of the subsectors to total industry in 2013, % (Source: UBOS, 2014b)

### 2.5.2.3 Future Development and Challenges

Uganda has a rich deposit of natural resources, which leads to a great potential for the mining industry in the country (Kigozi). Historically, the extractive industry has mainly consisted of commercial mining such as gold, steel, iron, copper, diamond and cement. The main reason why Uganda has been focusing on commercial mining is the large exports of produced minerals (NRGI). Although,
the mining industry is anticipated to be an important resource for future development in construction, manufacturing and infrastructure, why the domestic use is projected to increase (NPA, 2007). To develop the sector successfully the process needs to be handled in an efficient manner with clear targets.

In recent years the government has more or less neglected the mining industry and instead made investments to develop the industry of oil and gas. Though, there are a lot of development opportunities in sight for the mining industry, whereupon the subsector has to be prioritized. The mining industry is expected to play a key role in the country’s future development and economical growth, especially since steel, uranium and other minerals are expected to be important resources for further development of the country (NPA, 2007).

The subsector of mining and quarrying will be an important input and foundation to the future manufacturing in Uganda. The government has an optimistic view on the development of the manufacturing, and will therefore provide resources to manage a transformation of the subsector to make it a more successful and essential part of the industry (NPA, 2007). By improving the integration between mining and manufacturing, the use of local recourses can easier be ensured as well as it favours the national industry.

The discovery of oil is something that is expected to be a crucial part of the future industry, continued development and economical growth. Yet, there is no oil production in Uganda but ever since the first discovery was made in 2006, in the Lake Albert Rift Basin, there have been plans to develop and invest in a national oil production (EIA, 2014b). The production of oil will be important for several reasons. It will be an important asset in an economical perspective, since it will improve the country’s competitiveness and industry, but also as a useful input to existing industries. According to “Uganda National Climate Change Finance Analysis” the oil and gas reserves will result in an increase of revenues for Uganda (Bird, 2013). Before 2020, the government endeavours that the country will have its own oil refinery, with the capacity to produce up to approximately 66 000 barrels per day (EIA, 2014b).

In order to ensure a sustainable development and to obtain a successful and competitive industry in Uganda, there are some shortcomings that need to be managed. Today’s lack of energy efficient technologies and techniques must be improved. If Uganda develops in line with set goals and transforms to a modern and industrialized society, the sectorial energy demand will increase, which is why more effective methods must be developed. What also needs to be improved is the limited infrastructure. The inadequate infrastructure prevents the growth of the industry, as it, among other things, makes it difficult to exploit minerals, something that the government agreed to improve in the “Uganda Vision 2040” (NPA, 2007). The government also needs to implement policies and strategies to obtain a good investment climate and a to create a good platform for scientific and technologic development for the industry and its subsectors. With the right strategies for future development the industry is expected to become a good source of employment, revenue and security for the Ugandan economy. The hope
is also that there will be a movement of labour force, where some of the workers who currently work in agriculture instead would be distributed to the industrial sector (Don Binyina, 2014).

2.5.3 Service

2.5.3.1 Energy
In 2013 the service sector consumed 6.9% of the total energy in Uganda. Of the energy consumed, 22% was electricity. This makes the service sector the third largest consumer, after the industrial and residential sectors (MEMD, 2014c).

2.5.3.2 Present Status
In a financial perspective, the service sector is the largest sector in Uganda and it is the foundation of the macro-economical growth that has been experienced over the recent years (Bird et al, 2013). Today, but also historically, the service sector is identified as the sector with the largest contribution to total GDP and is therefore considered to be a strong part of the country's economy and growth. In the fiscal year 2013/2014 the contribution to total GDP at current prices was 45.4%, an increase from 45.1% in the previous year (UBOS, 2014b). Compared to the agricultural and industrial sectors, the growth of the service sector has been more stable and rapid. The success is mainly due to the positive development of economic reforms and expansion in different areas such as transport and communication (Bird et al, 2013). According to the “Uganda Vision 2040” (NPA, 2007), the service sector will continue to be an important part of the Ugandan economy even in the future. The future annual growth is expected to an average of about 9%. Tourism is one part of the service sector that is expected to have an extensive role for further improvements of the economy (NPA, 2007).

The service sector is also important in terms of labour force. According to UBOS “Statistical Abstract” (2014b), almost 15.8% of the total working population works within the service sector, 75.7% if considering the share of working population only within Kampala. The service sector is expected to become an even larger source of labour in the future, especially since one of the government's future targets is to reduce the country's dependency on the agriculture. It is also a result of a more industrialized and modern society (NPA, 2007).

2.5.3.3 Future Development and Challenges
Compared to the agricultural sector, the service sector is a more secure source of income. The service sector is not that sensitive to various conditions, such as changes in climate (Bird et al, 2013), whereupon it is a more stable foundation in an economic perspective. Due to improved infrastructure and new technologies, the service sector is expected to continue being a large contributor to total GDP in the future (NPA, 2007).

With an economical growth there will be an increased demand of services such as education, health care and communication amongst others (The World Bank). As Uganda develops in line with set targets clear policies and strategies will be needed to be able to meet possible changes in demand.
2.5.4 Transport

2.5.4.1 Energy
In 2013 the energy consumed by the transport sector was 34.9 PJ, which is the sum of the total energy used by road and by air (MEMD, 2014c). The share of energy consumed by road and air was 88.3% and 11.7% respectively. Of total energy consumption in Uganda, the transport sector represents 6.9% and is the main consumer of fossil fuels. None of the energy consumed by the transport sector today is electricity (MEMD, 2014c).

2.5.4.2 Present Status
The transport sector creates a foundation for several of the country's businesses, for example tourism and services, but above all for transport of goods and passenger movements. Uganda is a landlocked country, which has lead to the major part of the transport of goods and freight being conducted by road (Mwebesa). Since transport by road is the dominating alternative, it becomes a problem that the vehicles used are inefficient and requires a lot of unclean fuels. Of the total amount of vehicles the proportion of used cars is 92%, which results in low energy efficiencies and an increased level of pollution in the transport sector (Banaga-Baingi, 2013). Compared with other sectors, the transport is currently the sector with the largest use of fossil fuels and has the highest emissions of greenhouse gases. Oil products represent a share of 9.2% of the total country’s energy consumption, which primarily is used by the transport sector (MEMD, 2014b).

Considering the number of vehicles in the country, there has been a stable growth over the years. The Electricity Regulatory Authority (2008) expects that the number of vehicles will keep increasing with an annual growth rate of 9%, as a result of increasing population, better welfare and a more stable income for the people in Uganda. As a consequence of a continued increase of the number of vehicles, the transport sector is expected to have a larger energy demand in the future.

2.5.4.3 Future Development and Challenges
The transport sector in Uganda is undeveloped and in several aspects in great need of improvements. Old vehicles and defective roads dominate the sector and to enable future growth the infrastructure must be improved. In order to facilitate the expected industrialization and to enable the modernization of Uganda, a functional infrastructure will be required. Therefore it is necessary to prioritize an improvement of today's inefficiencies and connection possibilities in the transport sector (The World Bank, 2015d).

As the country develops and the living standards improve, the transport sector is expected to have an increased use of energy. It will result in an increased consumption of fossil fuels and thus directly a higher level of carbon dioxide emissions. Due to the lack of official policies and guidelines, there are no incentives to increase the energy efficiency of newly registered and imported vehicles (MEMD, 2014b). To ensure sustainable and environmental friendly
future development, it will require higher standards and improved technologies to handle the increased energy demand in the transport sector effectively.

Uganda is in great need of development of policies and strategies for fuel efficiency, and there is a desire to do so (MEMD, 2014b). The Ministry of Energy and Mineral Development (2014b) has developed an initiative, Fuel Efficiency Initiative (FEI), which aims to facilitate the development by assisting with strategies. The plan includes policies and frameworks that will improve the transition towards a more sustainable sector with a larger use of clean fuels and more energy efficient vehicles. The FEI has been developed based on “The Uganda National Climate Policy” (2013), which has established several specific developing strategies for the transport sector such as promotion and encouragement of the use of fuel efficient vehicles and reduction of greenhouse gas emissions from the transport sector (Bird et al, 2013).

In line with the Vision 2040 (NPA, 2007), the government wants to develop a more secure and efficient transport sector. There is a strong desire to develop the current system of transporting goods, since it is highly inefficient both in terms of costs and in volume transported (Ministry of Finance, 2013). What should be prioritized is further exploitation of rail and marine transport, as it is a more cost-effective option. In the year 2040, a railway network designed for high-intensity trains will have been constructed. It will enable larger volumes to be transported by rail, whereupon the share of cargo freight on rail to total freight is expected to increase from the share of 3.5% in 2010 to an expected share of 80% in 2040 (NPA, 2007).

In order to obtain economic growth and to develop the country in the desired direction, it is necessary to adapt the transport processes according to set goals. To allow further progress in the other sectors, the transport sector must urgently be improved. In addition to the construction of the high-intensity railway, the government also wants to expand the Entebbe International Airport and increase the use of rail, water and air transport modes as well as several other plans to transform the country into a modern society (NPA, 2007). According to the “Background to the Budget 2013/2014” (Ministry of Finance, 2013), the government is planning to keep focusing on improvement of the infrastructure, as it expects to help the country to keep developing in line with the targets stated in Vision 2040. Considering transport by air, the imports increased by 1.4% and the export traffic grew by 10.7% in the fiscal year 2012/2013 (Ministry of Finance, 2013).

2.5.5 Household

2.5.5.1 Energy
The energy used in the household sector was estimated to a value of 322.9 PJ in 2013 (MEMD, 2014b), which was a decrease of 1.3% compared to the energy consumed in 2012 (MEMD, 2013b). The energy supply of the Ugandan households is very primitive and the most commonly used fuel is biomass (MEMD, 2014b), which primarily is a result of the limited access to electricity. For example, in 2012/2013 the extent of biomass used for cooking was 96% and
58.3% of “Tadooba”, paraffin, was used for lightning (UBOS, 2014a). The existing households are simply constructed and the household members are living with rather restrained assets.

2.5.5.2 Present Status
The infrastructure in Uganda is limited and undeveloped, which also is the main reason why the share of households with access to electricity is restrained. Despite that, the household sector is one of the few sectors that consumes any electricity at all, and in 2013 the sector constituted 22% of the total electricity consumption in the country (MEMD, 2014b).

In addition to electricity, the access to sanitation in households is also defective and almost 83% of the household population still use pit latrines (UBOS, 2014a).

2.5.5.3 Future Development and Challenges
An important factor that the government wants and needs to prioritize is to increase the share of population with access to the national grid. Improvement in access to electricity will be crucial for the country’s continued development and economical growth. By 2040 the government wants an increase of the share of population with access to electricity, to a total share of 80% (NPA, 2007). These improvements will have positive effects on the country’s welfare and it is also expected to result in more preferable living conditions for the population. As an example, the fact that biomass is such a dominant fuel becomes a problem in aspect of health. People do not have enough money to afford clean fuels and are therefor using fuels with a high degree of contaminations, which has a negative impact on their health (UBOS, 2014a). As the access to electricity becomes more secure and available, it will result in an increased use of energy. The energy consumed by the household sector will also be affected by a possible increase of income, since it may result in changed behaviours and standards of living.

Another factor that requires improvement in today’s households is the lack of sanitation. The current system is unsustainable, especially in terms of health. To reduce the risk of diseases to be spread, it is necessary to increase the availability to toilet facilities.

3. Methodology
Here the different methods used, when conducting the analysis, are described together with the data approach used in the study.

3.1 Data Collection
The data used for all the future projections have been retrieved from the Ministry of Energy and Mineral Development’s energy balance in the “Annual Report, 2013” (2013a). Though, a huge error was detected in the energy balance, where all the numbers were about a thousand times too big to be reasonable, and therefor the assumption was made that the energy unit was supposed to be tonnes of oil equivalent (toe) instead of thousand tonnes of oil equivalent (ktoe). This was the case for all the values except for the electricity consumptions, which
appeared to have been given in the correct unit. Given this assumption, the values for the 2013 energy balance corresponds to the energy balance for the years 2012 and 2011 as well, see table 4.

<table>
<thead>
<tr>
<th>(ktoe)</th>
<th>Final energy consumption</th>
<th>Final electricity consumption</th>
<th>Share of electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Balance 2013, Original</td>
<td>11 710 640</td>
<td>178</td>
<td>0.002%</td>
</tr>
<tr>
<td>Energy Balance 2013, Edited</td>
<td>11 888</td>
<td>178</td>
<td>1.497%</td>
</tr>
<tr>
<td>Energy Balance 2012</td>
<td>11 710</td>
<td>166</td>
<td>1.421%</td>
</tr>
<tr>
<td>Energy Balance 2011</td>
<td>11 374</td>
<td>149</td>
<td>1.309%</td>
</tr>
</tbody>
</table>

Table 4 Edit of units in Energy Balance 2013, ktoe (Source: MEMD, 2013a. MEMD, 2013b. MEMD, 2012)

3.2 Modelling

3.2.1 MAED – Model for Analysis of Energy Demand

The MAED model, Model for Analysis of Energy Demand, is a modelling tool that aims to calculate the future energy demand based on different scenarios of development of technology, socio-economy and demography. To obtain an easily accessible and a transparent model, the software of MAED is Excel based (IAEA, 2006).

In order to calculate future energy demand there are several factors that needs to be taken into consideration when performing the analysis. The model proceeds from a structure, reviewing end-use energy consumption activities and economic sectors (IAEA, 2006). In MAED, all of the calculations and future projections are conducted on a sectorial and subsectorial basis.

3.2.1.1 Sectorial Calculations

The different main groups evaluated in MAED are the sectors of industry, transport and household. Within each major sector a more extensive and detailed analysis is made. For the industrial sector the model focuses on six economic subsectors, which are agriculture, manufacturing, mining, construction, service and energy. It is possible to define all of the above-mentioned sectors into ten subsectors and for some of the economic sectors it is also possible to accomplish a deeper analysis with even more factors in aspect. By doing a more detailed and specified analysis of all the areas and subsectors it is easier to identify possible issues and factors that must be given priority. It also contributes to an analysis of the way future development affects the different areas.

When analysing the transport sector in MAED the energy demand is calculated with aspect to two main categories, freight and passenger. The category of passenger is also predefined into inter-city and intra-city. In these categories, different modes of transportation as well as fuel used for each specific mode are taken into consideration.
The household sector is evaluated in aspect of rural and urban areas, which also can be further predefined into different types of dwellings. The maximum amount of various types is the same amount as for the sub-sectors in the industrial sector.

The MAED model aims to facilitate necessary calculations that are used to accomplish an analysis of the projected future energy demand of a specific country. The model also considers development factors such as socio-economy, technology and demography. The estimation is based on scenarios of medium- and long term planning. The model then projects future energy demand based on the specific demand of different goods and services that has been specified in the model. In addition, it also shows how they are related to the above-mentioned factors. As a first step, the end-use of energy is calculated for several specific categories in all of the different sectors, where each category corresponds to a production of a specific good or a specific service (IAEA, 2006). The total energy demand of all of the different categories is then summarized to obtain the total energy demand.

The projected energy demand is strongly affected by the changes of future demand of different goods and service, which in turn depend on a great variety of factors. The most important of these factors are changes in population and economic status. As the population increases, combined with economic growth it automatically leads to changes in consumption and behaviour and the same is true for energy consumption. This is one of many examples of scenarios that are considered in the MAED model.

The first step in creating the model is to choose a base year, which should be a historical year where all the necessary data is available. The purpose of selecting a base year is to have a stabile foundation to proceed from, as well as it facilitates further calculations based on the base year energy balance. The base year energy balance is obtained by collected data, together with necessary adjustments and assumptions to get the correct input parameters for the MAED model. When this is done and the base year is defined, the next step is to further calculate and project values for the future scenarios. When performing further calculations, factors and situations that need to be considered are country specific situations and objectives that are set for the country’s development and future growth.

When using the model to generate useful and credible results, the user must have good knowledge of which factors that are important for the specific country, and also which assumption that needs to be made. It is important to have a good understanding of how the different factors are connected to each other, especially since the model actually is based on assumptions for the scenarios and future energy demand.

When the base year energy balance is collected and adjusted, and all the other necessary input data for future demand are obtained, the calculations can be made. It is important to make reasonable assumptions for the data that cannot be found, and they should be based on strategies as well as future objectives. The
output generated by the model is final energy demand, electricity demand and hourly electric load (IAEA, 2006).

3.2.1.2 Uganda
In the case of Uganda, there is an extremely limited access of data, which led to many assumptions and difficulties in adapting the model and still ensure the accuracy of the results. The modelling came to a point where the amount of assumptions compared to the amount of retrieved data was unreasonable, and the results were therefore considered to be too unreliable. The decision was made not to complete the model because of the misleading results, and a simpler calculation in Excel, together with a written analysis based on the retrieved data and MAED structure, was instead conducted. Worth acknowledging is that the MAED model is a useful and well-developed tool and if there would have been more data available, it would have provided a good estimate of the future energy demand in Uganda.

3.2.2 OSeMOSYS
To analyse Uganda’s energy system the Open Source Energy Modelling System, OSeMOSYS, has been used. OSeMOSYS is an easily accessible optimization tool used for long term energy system planning. It can by small means provide the least-cost solution (NPV) for future energy system planning by presenting the energy mix that will meet the future demand at the lowest net present cost (Howells et al, 2011). The model technologies include parameter values for the years 2010 to 2035, and the model therefore gives a projection 20 years ahead in time. The model was developed in a collaboration of several organizations such as the Royal Institute of Technology (KTH), the International Atomic Energy Agency (IAEA) and the UK Energy Research Centre (COMMEND).

OSeMOSYS have been constructed into different blocks, making the model easy to adapt and customize to different analysis scenarios, which enables the user to choose the amount of details to include in the model (Howells et al, 2011). This enables a diversity of applications of the model and an adaption to the desired complexity and requirements.

4. The Ugandan Energy Model
In this section the different procedures in the modelling of the Ugandan energy system are explained. Calculations, assumptions and results are presented consecutively.

4.1 Electricity Demand Projections
In order to perform a realistic analysis of the future Ugandan energy system, it is necessary to use an energy demand projection as a foundation for further analysis. The demand projections that were conducted were calculated based on two different scenarios, a base scenario and a modernization scenario. The calculations for the two scenarios will here be explained separately.
4.1.1 Base Scenario
In the base scenario reasonable assumptions and estimations were made based on Uganda’s current economical status and its historical development. The energy demand projections have been conducted separately for each of the sectors industry, services, agriculture, household and transport. An energy-intensity factor was identified on a sectorial basis. This factor was then multiplied with a future projection for either GDP or population. The projections for future GDP and population were made in earlier studies conducted by the Government of Uganda (2007) and the United Nations (2013) respectively, see figure 8 and 9. A future sectorial electrification rate was then assumed to obtain the sectorial electricity demand from the energy demand.

Figure 8 Projections of sectorial future GDP, billion US$ (Source: NPA, 2007)

Figure 9 Projections of future population in Uganda, thousands (Source: UN, 2013)

4.1.1.1 Energy Intensities
The energy intensities were calculated for the three different sectors industry, services and agriculture, the sectors that all directly contribute to the GDP. The energy intensities were obtained by dividing sectorial energy consumption by corresponding sector’s contribution to GDP.

The electricity energy intensities were also calculated, but because of a predicted growth of the sectorial electrification rates they were not considered to be realistic factors to include in the projections. Instead, the energy intensities were used in the calculations together with a projection for the electrification rates.
### Table 5: Sectorial electricity and energy intensity calculations (Source: Appendix #2)

<table>
<thead>
<tr>
<th></th>
<th>Consumption (PJ)</th>
<th>Sectorial GDP (billion US$)</th>
<th>Energy Intensity (PJ/US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Services</td>
<td>65.4</td>
<td>10.74</td>
<td>6.09359E-09</td>
</tr>
<tr>
<td>Industry</td>
<td>58.1</td>
<td>5.82</td>
<td>9.98795E-09</td>
</tr>
<tr>
<td>Agriculture</td>
<td>2.2</td>
<td>4.7</td>
<td>4.74658E-10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>497.7</strong></td>
<td><strong>21.32</strong></td>
<td><strong>2.33464E-08</strong></td>
</tr>
<tr>
<td><strong>Electricity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Services</td>
<td>0.9</td>
<td>10.74</td>
<td>8.57631E-11</td>
</tr>
<tr>
<td>Industry</td>
<td>4.9</td>
<td>5.82</td>
<td>8.34482E-10</td>
</tr>
<tr>
<td>Agriculture</td>
<td>0.0</td>
<td>4.7</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7.5</strong></td>
<td><strong>21.32</strong></td>
<td><strong>3.49555E-10</strong></td>
</tr>
</tbody>
</table>

4.1.1.2 Sectorial Calculations

In this part of the study the procedures for calculations of the different sectorial projections are presented.

4.1.1.2.1 Household

The projections for future electricity consumption of the household sector were based on governmental goals for the share of population with access to electricity in 2040, which is expected to a rate of 80% (NPA, 2007). The electricity consumed per person of those with access to electricity in Uganda today was calculated to an average of 1.4 GJ. By 2040 the goal is set for an electricity consumption of 13.2 GJ per capita (NPA, 2007), a value that was assumed to have increased linearly. According to the Energy Balance 2013 (MEMD, 2014c), 22% of the total electricity consumption came from the household sector, a rate that was assumed to be constant until 2040. This, together with the projected population and an electrification rate of 80%, means that the electricity consumed per person with access to electricity will increase to a value of 16.5 GJ, a total increase by over 1000%.

By multiplication with a projected population of 82.7 million people (UN, 2013), and an electrification rate of 80% (NPA, 2007) the total electricity demand of the household sector was calculated to a projected value of 245.3 PJ in 2040, according to figure 10.

![Household electricity consumption projection](https://example.com/figure10.png)

Figure 10: Household electricity consumption projections, PJ (Source: Appendix #2)
4.1.1.2 Transport

Since the transport sector does not consume any electricity as it is today, the electricity demand projection was based on the projection of total energy demand and an assumption of the sector's electrification rate in 2040.

The projected energy consumption by road was calculated by identifying an average annual growth rate of the number of vehicles in the country based on historical data, which was projected to a rate of 9% (ERA, 2008). The energy consumption per vehicle was found by dividing the transport sector's present energy consumption by road, by current number of vehicles. The calculated value was assumed to be constant, since it both is a measure of the efficiency of vehicles and of the total distance travelled per vehicle. The improved efficiency of vehicles was instead accounted for in an efficiency parameter included in the calculations, where the efficiency was assumed to have increased with 10% by 2040. Since it is difficult to predict human behaviour it is unwise to do any assumptions for an increase or a decrease of distance travelled per vehicle, why this value was kept constant.

The future energy consumption by air was projected based on the assumption of a growth equal to the growth of GDP, motivated by the fact that the way people tend to travel internationally and consume international goods, can be almost directly related to their economical status. This resulted in an exponential growth of the energy consumption by air. To receive a projection of total future energy consumption of the transport sector, this value was added with the projected energy consumption by road.

In 2040 the electrification rate for the transport sector was assumed to 5%, based on their current plans of constructing an electric train transportation line at the country's most heavily trafficked road between Kampala and Entebbe (New Vision, 2014). This resulted in a projected total electricity demand of the transport sector of 16.7 PJ in 2040, according to figure 11.

![Electricity Demand Projection](chart.png)

Figure 11 Projection of future energy demand of the transport sector, PJ (Source: Appendix #2)

The same calculations were also made based on the assumption that the entire transport sector's energy consumption would grow directly related to the GDP.
This resulted in an even more exponential growth of the energy demand and an electricity demand of 2.18 PJ in 2040, a number that was not considered to be realistic. Find the detailed projections in figure 12, where calculation B is the later one of the calculations and calculation A is the calculation first described.

![Comparison Demand Projections Transport](image)

**Figure 12** Comparison of transport sector electricity demand projections, PJ (Source: Appendix #2)

### 4.1.1.2.3 Agriculture

Since the agricultural sector currently does not have any electricity consumption, it is not possible to project a future electricity consumption based on the sectorial electricity energy intensity. Therefore calculations were made to obtain a projection of the future energy consumption, based on the energy intensity and future projections for the sectorial GDP. An electrification rate of 30% in 2040 was anticipated based on the current agricultural electrification rate in South Africa, a country that today has about the same GDP as Uganda is projected to have in 2040 (DoE, 2012). This resulted in a projected electricity consumption of 8.6 PJ in 2040 for the agricultural sector.

![Demand Projection Agriculture](image)

**Figure 13** Electricity- and energy demand projections agriculture, PJ (Source: Appendix #2)

### 4.1.1.2.4 Industry

The future industrial electricity consumption was calculated by using the energy intensity of the industrial sector multiplied by the projected future sectorial GDP. Also for this sector, an increased electrification rate was included in the projections. In this case the share of electricity was assumed to increase from

34
4.7% in 2013 (MEMD, 2013a) to 30% in 2040, which is the industrial electrification rate in South Africa today (DoE, 2012). This resulted in an electricity demand of 527.1 PJ in 2040.

![Demand Projection, Industry](image)

Figure 14 Electricity- and energy demand projections industry, PJ (Source: Appendix #2)

4.1.1.2.5 Service
The future commercial electricity consumption was, in the same way as for the industrial and agricultural consumptions, projected by multiplication of the sectorial energy intensity and the projected future sectorial GDP. Today 2.6% of the energy consumption consists of electricity (MEMD, 2013a), a value that was assumed to increase to 40% in 2040, which is the current rate in South Africa (DoE, 2012). This resulted in a projected electricity consumption of 823.4 PJ in 2040.

![Demand Projection, Services](image)

Figure 15 Electricity- and energy demand projections service, PJ (Source: Appendix #2)

4.1.1.3 Transmission and Distribution Losses
To obtain a projection for the final electricity demand, an estimation of the future distribution and transmission losses were made. In an earlier completed study a projection of the decrease of the losses were obtained, with improvements of 18.2%, 12.5% and 8.7% for the industrial, commercial and residential distribution respectively (Sridharan, 2015a). According to the study, the rate of transmission losses remained unchanged. Uganda’s current rates of losses were based on historic data and calculated to an average of 31.4%, of which the
transmission losses constitutes about 10% and the distribution losses constitutes around 90% (MEMD, 2014c).

Since there was no data to be found for the sectorial shares of the distribution losses as it is today, the losses have been assumed to be equal between the different types of distribution. The identified improvement rates were then applied to the current rate of losses, which resulted in losses according to figure 16, and the total rate of losses in 2040 was calculated to an average of 18.3%.

![Projection of Transmission & Distribution Losses](image)

Figure 16 Projections of transmission and distribution losses, % (Source: Appendix #2)

4.1.1.4 Results of Base Scenario

After applying the losses to the sectorial calculated electricity demands, the primary electricity demand were obtained, see table 6 and figure 17.

<table>
<thead>
<tr>
<th>(PJ)</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>0.4</td>
<td>1.3</td>
<td>2.6</td>
<td>5.8</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>0.44%</td>
<td>0.50%</td>
<td>0.53%</td>
<td>0.49%</td>
<td>0.48%</td>
</tr>
<tr>
<td>Industry</td>
<td>17.7</td>
<td>66.3</td>
<td>139.2</td>
<td>389.0</td>
<td>719.5</td>
</tr>
<tr>
<td></td>
<td>20.48%</td>
<td>26.43%</td>
<td>28.48%</td>
<td>33.13%</td>
<td>34.75%</td>
</tr>
<tr>
<td>Services</td>
<td>21.6</td>
<td>87.2</td>
<td>188.3</td>
<td>542.2</td>
<td>1 008.2</td>
</tr>
<tr>
<td></td>
<td>24.92%</td>
<td>34.77%</td>
<td>38.52%</td>
<td>46.19%</td>
<td>48.68%</td>
</tr>
<tr>
<td>Transport</td>
<td>1.1</td>
<td>2.8</td>
<td>6.0</td>
<td>12.0</td>
<td>22.3</td>
</tr>
<tr>
<td></td>
<td>1.22%</td>
<td>1.11%</td>
<td>1.24%</td>
<td>1.02%</td>
<td>1.08%</td>
</tr>
<tr>
<td>Household</td>
<td>45.8</td>
<td>93.3</td>
<td>152.7</td>
<td>225.0</td>
<td>310.9</td>
</tr>
<tr>
<td></td>
<td>52.93%</td>
<td>37.19%</td>
<td>31.23%</td>
<td>19.16%</td>
<td>15.01%</td>
</tr>
<tr>
<td>Total</td>
<td>86.5</td>
<td>250.9</td>
<td>488.9</td>
<td>1 174.0</td>
<td>2 070.9</td>
</tr>
</tbody>
</table>

Table 6 Sectorial primary electricity demand projections, PJ (Source: Appendix #2)
4.1.2 Modernization Scenario

In the modernization scenario, the projections of the future electricity consumption were made based on the assumption that Uganda in 2040 will be a completely modernized country. It was then assumed that the sectorial energy intensities and the electricity consumption per capita would have the same values as those in the United States of America.

4.1.2.1 Energy Intensities

The United States’ electricity energy intensities were calculated based on the current sectorial GDP and electricity consumption. The sectorial GDP was calculated for the agriculture, industry and commercial sector respectively, using the GDP composition by sector of origin from CIA (2013). In the calculations of energy intensities two different types of values were used. First the final electricity consumption for the year 2012 from the International Energy Agency (2015), and then also the end user consumption for the year 2013, obtained from the U.S. Energy Information Administration (2015b).

Since the residential and the transport sectors do not directly contribute to the country’s GDP, the measurement electricity consumption per capita was instead selected for these calculations. These values were in a simple way calculated by just dividing total sectorial electricity consumption by the number of the current population in United States. The value for electricity consumption per vehicle in the United States was also calculated for the transport sector, as a sort of energy intensity.

4.1.2.2 Transmission and Distribution Losses

The transmission and distribution losses were, in the same way as for the energy intensities, calculated for the U.S. as they are today, based on historical data and were calculated to a total rate of 7.2% (IEA, 2015). Since there were no data to be found for the allocation of the losses between the transmission and the distribution, the current ratio for Uganda was used, where 90.0% of the losses will occur in the transmission network and 10.0% in the distribution network (MEMD, 2014c). This resulted in losses of 6.5% in distribution and of 0.7% in
transmission. These losses were then assumed to be the values in Uganda in 2040, compared to today's values of 2.9% and 30.0% for transmission and distribution respectively. No values for the allocation of the distribution losses between the industrial, commercial and residential distribution was to be found, why they were assumed to be equal at a value of 30%.

4.1.2.3 Results of Modernization Scenario
The calculated energy intensities were then applied to the future projections of the Ugandan GDP, population and number of vehicles in different combinations and scenarios to obtain a projection of the future energy consumption. This was done in a few different ways, taking different factors into consideration and using different sources of data. Scenario A was the scenario used in further modelling and calculations.

4.1.2.3.1 Scenario A
In Scenario A the sectorial energy intensities for the agricultural, industrial and commercial sectors were applied to the future sectorial GDP projections for Uganda, to retrieve the sectorial energy demand projections. For the household and transport sector the sectorial energy consumptions per capita were used and multiplied with the projected future population. Then the transmission and distribution losses were accounted for, to obtain the final energy consumption. As seen in table 7 the demand projections for the household sector were severely higher than in the other sectors and were predicted to constitute a share of 77% of the total electricity demand in 2040.

<table>
<thead>
<tr>
<th>PJ</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>14.0</td>
<td>23.2</td>
<td>38.2</td>
<td>60.1</td>
<td>89.9</td>
</tr>
<tr>
<td></td>
<td>1.390%</td>
<td>2.028%</td>
<td>2.895%</td>
<td>3.907%</td>
<td>4.937%</td>
</tr>
<tr>
<td>Industry</td>
<td>14.1</td>
<td>28.0</td>
<td>54.8</td>
<td>101.6</td>
<td>178.5</td>
</tr>
<tr>
<td></td>
<td>1.40%</td>
<td>2.45%</td>
<td>4.16%</td>
<td>6.61%</td>
<td>9.80%</td>
</tr>
<tr>
<td>Services</td>
<td>10.3</td>
<td>20.5</td>
<td>40.4</td>
<td>75.8</td>
<td>135.1</td>
</tr>
<tr>
<td></td>
<td>1.03%</td>
<td>1.79%</td>
<td>3.06%</td>
<td>4.93%</td>
<td>7.42%</td>
</tr>
<tr>
<td>Transport</td>
<td>5.3</td>
<td>5.8</td>
<td>6.4</td>
<td>7.1</td>
<td>7.7</td>
</tr>
<tr>
<td></td>
<td>0.52%</td>
<td>0.51%</td>
<td>0.49%</td>
<td>0.46%</td>
<td>0.42%</td>
</tr>
<tr>
<td>Household</td>
<td>961.9</td>
<td>1 067.9</td>
<td>1 179.0</td>
<td>1 293.5</td>
<td>1 409.2</td>
</tr>
<tr>
<td></td>
<td>95.66%</td>
<td>93.22%</td>
<td>89.40%</td>
<td>84.10%</td>
<td>77.41%</td>
</tr>
<tr>
<td>Total</td>
<td>1 005.5</td>
<td>1 145.5</td>
<td>1 318.9</td>
<td>1 538.0</td>
<td>1 820.4</td>
</tr>
</tbody>
</table>

Table 7 Electricity demand projections modernization scenario A, PJ (Source: Appendix #2)

4.1.2.3.2 Scenario B
The projected electricity demand was calculated in the same way as in scenario A, but here the values for the U.S. final electricity consumption were used, which means that the transmission and distribution losses already were included in the calculations.
4.1.2.3.3 Scenario C

In this scenario an overall total energy intensity of the U.S. total electricity consumption was used, and multiplied by GDP projections of Uganda. The calculations were based both on final consumption, where no further losses were taken into consideration, and on end user consumption where the projected distribution and transmission losses also were accounted for. This resulted in a projection of final energy consumption in Uganda according to table 9.

4.1.2.3.4 Scenario D

In scenario D the calculations were performed in the same way as in scenario A, with the difference in the calculation of the future electricity demand of the transport sector. In this scenario, the total electricity demand for the U.S. transport sector was divided by the number of vehicles and multiplied with a projection of future number of vehicles in Uganda in 2040, made in the base scenario and based on an assumed annual growth of vehicles of 9% established by the Electricity Regulatory Authority (ERA, 2008).

---

<table>
<thead>
<tr>
<th>(PJ)</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>3.3</td>
<td>5.8</td>
<td>10.0</td>
<td>16.5</td>
<td>25.7</td>
</tr>
<tr>
<td></td>
<td>0.439%</td>
<td>0.644%</td>
<td>0.923%</td>
<td>1.254%</td>
<td>1.593%</td>
</tr>
<tr>
<td>Industry</td>
<td>10.9</td>
<td>22.8</td>
<td>46.8</td>
<td>90.7</td>
<td>166.2</td>
</tr>
<tr>
<td></td>
<td>1.44%</td>
<td>2.52%</td>
<td>4.31%</td>
<td>6.89%</td>
<td>10.29%</td>
</tr>
<tr>
<td>Services</td>
<td>8.2</td>
<td>17.0</td>
<td>35.1</td>
<td>68.9</td>
<td>128.2</td>
</tr>
<tr>
<td></td>
<td>1.07%</td>
<td>1.88%</td>
<td>3.23%</td>
<td>5.24%</td>
<td>7.93%</td>
</tr>
<tr>
<td>Transport</td>
<td>3.7</td>
<td>4.3</td>
<td>4.9</td>
<td>5.6</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td>0.48%</td>
<td>0.47%</td>
<td>0.45%</td>
<td>0.43%</td>
<td>0.40%</td>
</tr>
<tr>
<td>Household</td>
<td>734.5</td>
<td>855.3</td>
<td>988.8</td>
<td>1133.9</td>
<td>1289.4</td>
</tr>
<tr>
<td></td>
<td>96.57%</td>
<td>94.48%</td>
<td>91.08%</td>
<td>86.19%</td>
<td>79.79%</td>
</tr>
<tr>
<td>Total</td>
<td><strong>760.6</strong></td>
<td><strong>905.3</strong></td>
<td><strong>1085.6</strong></td>
<td><strong>1315.6</strong></td>
<td><strong>1616.0</strong></td>
</tr>
</tbody>
</table>

Table 8 Electricity demand projections modernization scenario B, PJ (Source: Appendix #2)

<table>
<thead>
<tr>
<th>Final energy demand projection (PJ)</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Based on data from (IEA, 2015)</td>
<td><strong>34.2</strong></td>
<td><strong>69.4</strong></td>
<td><strong>138.8</strong></td>
<td><strong>265.3</strong></td>
<td><strong>481.9</strong></td>
</tr>
<tr>
<td>Based on data from (EIA, 2015b)</td>
<td><strong>42.5</strong></td>
<td><strong>82.3</strong></td>
<td><strong>157.2</strong></td>
<td><strong>287.4</strong></td>
<td><strong>500.1</strong></td>
</tr>
</tbody>
</table>

Table 9 Electricity demand projections modernization scenario C, PJ (Source: Appendix #2)
## 4.1.3 Comparison of Scenarios

As seen in figure 18 the two different methods used for projecting the demand, with only the projected GDP in common, still ended up at about the same values. The modernization projection had a more rapid increase of demand, while the base scenario resulted in a more exponential growth, because of a more frequent correlation to the projected GDP.

![Demand Projections](image)

Figure 18 Electricity demand projections for base- and modernization scenarios, PJ (Source: Appendix #2)

As seen in figure 19, the results did not differ that much when calculating them with different factors, values and assumptions. The results of scenario A, B and D were very similar, although the results of scenario C differed from the others. This shows the importance of doing the analysis on a relatively detailed level, rather than selecting the exact and correct factors and values for the projections.

<table>
<thead>
<tr>
<th>(PJ)</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>14.0</td>
<td>23.2</td>
<td>38.2</td>
<td>60.1</td>
<td>89.9</td>
</tr>
<tr>
<td></td>
<td>1.397%</td>
<td>2.038%</td>
<td>2.908%</td>
<td>3.924%</td>
<td>4.956%</td>
</tr>
<tr>
<td>Industry</td>
<td>14.1</td>
<td>28.0</td>
<td>54.8</td>
<td>101.6</td>
<td>178.5</td>
</tr>
<tr>
<td></td>
<td>1.40%</td>
<td>2.46%</td>
<td>4.18%</td>
<td>6.64%</td>
<td>9.84%</td>
</tr>
<tr>
<td>Services</td>
<td>10.3</td>
<td>20.5</td>
<td>40.4</td>
<td>75.8</td>
<td>135.1</td>
</tr>
<tr>
<td></td>
<td>1.03%</td>
<td>1.80%</td>
<td>3.08%</td>
<td>4.95%</td>
<td>7.45%</td>
</tr>
<tr>
<td>Transport</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>0.01%</td>
<td>0.02%</td>
<td>0.02%</td>
<td>0.03%</td>
<td>0.04%</td>
</tr>
<tr>
<td>Household</td>
<td>961.9</td>
<td>1 067.9</td>
<td>1 179.0</td>
<td>1 293.5</td>
<td>1 409.2</td>
</tr>
<tr>
<td></td>
<td>96.15%</td>
<td>93.68%</td>
<td>89.82%</td>
<td>84.46%</td>
<td>77.71%</td>
</tr>
<tr>
<td>Total</td>
<td>1 000.4</td>
<td>1 139.9</td>
<td>1 312.7</td>
<td>1 531.4</td>
<td>1 813.3</td>
</tr>
</tbody>
</table>

Table 10 Electricity demand projections modernization scenario D (Source: Appendix #2)
4.2 Open Source Energy Modelling System (OSeMOSYS)

4.2.1 Reference Energy System
To set the boundaries for the system and to identify the technologies included in the model, a reference energy system (RES) was drawn, see figure 20. Given the case of Uganda, the model included the electricity system from resource extraction to final consumption. The RES is then used as an overview of the model and as a tool when constructing the interface.

4.2.2 Demand
The electricity demand inserted in OSeMOSYS is divided into three categories, residential, commercial and industrial. The demand projection calculations were performed with regard to the future development of five different sectors.
industry, agriculture, service, household and transport and calculated based on projections of future population and GDP, conducted in Vision 2040 (NPA, 2007) together with implied policies. See section 4.1 for further details on the sectorial demand calculations. The obtained sectorial electricity demand for the base scenario can be seen in table 11.

<table>
<thead>
<tr>
<th>Base Scenario</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial</td>
<td>4.0</td>
<td>10.3</td>
<td>18.1</td>
<td>67.6</td>
<td>141.8</td>
<td>394.8</td>
</tr>
<tr>
<td>Residential</td>
<td>1.4</td>
<td>21.1</td>
<td>45.8</td>
<td>93.3</td>
<td>152.7</td>
<td>225.0</td>
</tr>
<tr>
<td>Commercial</td>
<td>0.8</td>
<td>10.5</td>
<td>22.6</td>
<td>90.0</td>
<td>194.4</td>
<td>554.2</td>
</tr>
</tbody>
</table>

Table 11 Inserted demand in OSeMOSYS based on projections, PJ (Source: Appendix #2)

To represent the variations of the load during the day, a time slice definition was defined in the interface according to the daily load curve patterns. In this case, because of the limited access of data for Uganda a study performed by IRENA (Sridharan, 2015a), with an average hourly load for the year 2013 in East Africa, was used. Based on these data a daily load curve was identified and the year was divided into 16 parts, four seasons and four parts of the day. These were then used to obtain a demand profile to apply in the model, see table 12.

<table>
<thead>
<tr>
<th>Demand Profile</th>
<th>Day Part 1</th>
<th>Day Part 2</th>
<th>Day Part 3</th>
<th>Day Part 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Duration)</td>
<td>01:00 – 06:59</td>
<td>07:00 – 19:59</td>
<td>20:00 – 22:59</td>
<td>23:00-00:59</td>
</tr>
<tr>
<td>Season 1</td>
<td>0.048248685</td>
<td>0.142326331</td>
<td>0.040401586</td>
<td>0.020662709</td>
</tr>
<tr>
<td>Dec – Feb</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Season 2</td>
<td>0.047153631</td>
<td>0.139840702</td>
<td>0.039898872</td>
<td>0.020184012</td>
</tr>
<tr>
<td>Mar – May</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Season 3</td>
<td>0.048473168</td>
<td>0.136834321</td>
<td>0.040566449</td>
<td>0.020908561</td>
</tr>
<tr>
<td>Jun – Aug</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Season 4</td>
<td>0.049376881</td>
<td>0.144028739</td>
<td>0.040281072</td>
<td>0.020814281</td>
</tr>
<tr>
<td>Sep – Nov</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 12 Demand Profile (Source: Appendix #1)

4.2.3 Supply Technologies

The supply side is defined by technologies included in the interface, which all in some way have a part in supplying the demand. Each type of power plant, refinery, natural resource, transmission etcetera is represented as a different technology, see appendix #1 for the full RES with all the technologies included.

When a technology is added to the interface, the parameter values can be adjusted for each specific technology to customize the model. The parameter values are values for installed capacity, capital cost, variable- and fixed costs, emissions, capacity- and availability factors, lifetime etcetera. The site-specific values were obtained from local sources or, when not found, general values for the technology type was used. In the cases of not yet existing technologies general values were used retrieved from IEA – ETSAP’s Technology Briefs (IEA – ETSAP, 2010), the East African Community (EAC et al, 2011) among others.

4.2.3.1 Extraction Technologies

The extraction technologies represent the relevant natural resources of the country. In this case the natural resources included in the model were crude oil, biomass, uranium and natural gas, of which biomass is the only one being actively extracted today. Crude oil has been periodically explored since the 1920s but the interest in the reserves has increased rapidly over the past years,
since a large oil discovery was made near Lake Albert in 2006 (NRGI), making
the total estimated value 2.5 billion barrels of crude oil (CIA, 2013). Together
with the oil discovery, natural gas was also found and the national reserves are
today estimated to 500 billion cubic feet (EIA, 2014). Uganda’s uranium deposits
have been estimated to a value of 52 000 square kilometres, and the Ugandan
government aims to make nuclear energy a part of the energy mix by 2050, and
then use the identified reserves (Senelwa, 2014).

For the reserves that possibly could be used up during the modelling period, the
available energy has been limited in the “Model Period Activity” parameter. This
is the case for the crude oil, which was restricted to an amount of 14 654 PJ,
representing 2.5 billion barrels (CIA, 2013). The other resources were left
unlimited, since they have been assessed as not likely to be used up during the
modelling period. The extraction costs for crude oil were retrieved from the EIA –
ETSAP Technology Brief (2010c), and for natural gas and uranium the
extraction costs were assumed to be the same as the international product
prices. Since no import price for biomass was to be found the cost was assumed
to be 10% less than the import cost of coal. The amount of emissions related to
the resources was accounted for in the extraction and import technologies to
make sure they only were included once.

4.2.3.2 Import Technologies
The import technologies included in the model were imports of coal, crude oil
and the refined oil products LFO and HFO. Here the costs were represented by
international import prices. Since no current prices for HFO and LFO were to be
found they were assumed to be 1.2 and 0.8 times the crude oil price respectively.
All of the fuel-based emissions were also included in the import technologies and
the emissions for HFO and LFO were assumed to be the same as for crude oil.

4.2.3.3 Refineries
The recent oil discoveries in the country have resulted in several investors being
interested in oil refinery investments. There have been establishments of
multiple contracts between the government and construction companies, but no
constructions have yet been started (MEMD). Since no data was found regarding
the output rates of the refineries, one unit of crude oil was assumed to produce
0.2 units each of LFO and gasoline and 0.6 units of HFO.

4.2.3.4 Power Plants
The parameter values for the power plants in the Ugandan energy system are
site specific and have been obtained from many different sources. See appendix
#1 for detailed data and references.

The today existing power plants included in the model are based on data from
ERA, see table 1. The hydro power plants with an installed capacity larger than 1
MW have been included as a separate site-specific technology, whilst the hydro
power plants smaller than 1 MW have been collided into a joint mini hydro
power plant technology. As seen in table 1 there are two existing thermal power
plants, which have been gathered in one technology since they do not have any
site-specific variations. The same principle applies to the two co-generation
plants.
For the hydropower plants a seasonal variation of the capacity factor, has been included as a result of the seasonal inflows and calculated based on historical generation data retrieved from the Electricity Regulatory Authority (2013b). An average value of these variations has been used for the power plant not yet constructed. Since all variations have been included in the capacity factor, the availability factor receives a value of 1.

The future power plant constructions included in the model are the ones identified in section 2.4.1.1, “Construction Plans”, and these have been included as set plans, whose construction plans not are a part of the model optimization.

For further plant construction in addition to the set ones, technologies for hydropower, nuclear, diesel, coal and natural gas have been included. This gives the model the opportunity to create future constructions of these technologies if it identifies it as the most cost effective solution given the circumstances. Therefore it is important for the costs of these technologies to be specified correctly.

4.2.3.5 Transmission
The most important parameters of the transmission technology are the capital cost and the efficiency. The efficiencies are used to obtain a primary electricity demand based on the secondary demand and the costs are relevant when the model wants to increase the installed capacity of the country. According to the efficiency projections in the future electricity demand calculations in section 4.1.1.3 the transmission efficiency was assumed to be constant at a value of 97%.

4.2.3.6 Distribution
The distribution is added as three different technologies representing the different distribution systems supplying the industrial, residential and commercial demand respectively. In the same way as for the transmission technology, the most important parameters here are the capital cost and the efficiencies. When the electricity demand projection was concluded, an estimation of the future distribution losses was made as well. They were based on historical data of the distribution losses (MEMD, 2014c), together with a projection for the improvements of the losses obtained from IRENA (Sridharan, 2015a). The projected efficiencies can be seen in table 13.

<table>
<thead>
<tr>
<th>Efficiency projections</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial Distribution</td>
<td>78.34%</td>
<td>80.86%</td>
<td>83.39%</td>
<td>85.91%</td>
<td>88.44%</td>
</tr>
<tr>
<td>Commercial Distribution</td>
<td>77.22%</td>
<td>78.95%</td>
<td>80.67%</td>
<td>82.40%</td>
<td>84.13%</td>
</tr>
<tr>
<td>Residential Distribution</td>
<td>76.48%</td>
<td>77.68%</td>
<td>78.88%</td>
<td>80.08%</td>
<td>81.29%</td>
</tr>
</tbody>
</table>

Table 13: Projections of distribution efficiency, % (Source: Appendix #2)

4.2.3.7 Off Grid Power Plants
The today existing off grid power plants were included as two separate technologies, one for the thermal power plants and one for the hydro power plants. These technologies were implemented in the same way as the on grid
power plants, with the difference that the electricity goes straight into the distribution network, without passing the transmission network.

4.3 Results

When running the model in the base scenario, the results seen in figure 21 were obtained. Because of the low production costs the model prioritized the constructions of hydropower plants, but the potential hydropower capacity of 2000 MW in the country was used up rather quickly. To supply the rest of the increasing demand, the model prioritized construction of natural gas plants due to the available gas reserves in Uganda, and to meet some top load a few LFO power plants were constructed. For more detailed results see appendix #3. Even though possibilities to construct nuclear and coal power plants were included in the model, it chose not to construct because of inefficient costs.

![Figure 21 Results obtained from the OSeMOSYS modelling in the base scenario (Appendix #3)](image)

4.3.1 Scenarios

To recognize the results and consequences of different policies and strategies, and to obtain a sensitivity analysis of the calculated projections, different scenarios were conducted in the interface and compared.

4.3.1.1 Not Adapting

The not adapting scenario aimed to enlighten the consequences of inefficient policies in a country, where no regards are taken to the future development of external factors. In Uganda’s case this is primarily relevant for possible changes in nature, affecting the inflows to the hydropower plants.
To accomplish the scenario, the availability and capacity factors of the potential hydropower technology was given a value of 100%. This is thought to represent the way policy makers may determine future investments plans if the factors of nature are not taken into consideration. The investments retrieved from the model, provided these circumstances, were then observed and in the next model-run included as fixed parameters. This means that the model is forced to construct the technologies as if the availability was unlimited, and only these technologies. Though, in reality the availability is not 100%, because of variations of inflow and this time, when forcing the model to construct the power plants, the availability is lowered to its actual projected value. This results in an undelivered demand and an extensive cost. In this scenario the undelivered demand added up to a total value of 0.28 PJ, see figure 22. The results of the undelivered demand are costs that can appear in different ways. It can be direct costs from rapidly constructed expensive power plants to meet the power shortage, which can be seen in figure 23 where the total annualised system cost is extensive in the years 2012, 2015, 2018 and 2023. The acute technology is in the model represented as a backstop technology, which is a technology much more expensive than the other ones and only used when there is no other supply available.
In some cases though, the power shortage is too unforeseen to be delivered from other power plants, which results in undelivered demand. This results in more indirect and long-term costs, but can have devastating consequences for the development of a country.

There is a large risk of not having sufficient capacity in hydropower to meet current energy demand. It is a threat to Uganda's development and economical welfare since shortages has proven to have a direct impact on GDP and GDP growth. Major shortages and fluctuations in a country's supply often contribute to long periods of economical slowdown, which also is evidenced by the situation that occurred in Uganda in 2006, when the country's economic development decreased as a result of drought and reduced rainfall.

A secure energy system and a stable balance between supply and demand are necessary for a successful development and improved status in Uganda. It is an essential asset for improved living conditions and human activates as well as an important factor for future industrialization and modernization of the country.

4.4 Sensitivity Analysis

4.4.1 Demand Projection

When performing a demand projection there are a lot of uncertain factors that are impossible to predict with 100% certainty. The factors can, to different extents, be predicted based on similar scenarios and correlations to other parameters, but the margin of errors are no matter what still high. In the projections in this study, assumption has been made for different types of...
parameters, which have had different kinds of significance to the result of the projections. To observe the sensitivity of different factors an analysis of the sensitivity has been executed. Worth noticing though, is the fact that all the projections contains large increases of today’s parameters, such as population and GDP, which results in the difference between the future values looking smaller than it actually is. It is therefor important to observe the absolute values instead of the relative values.

4.4.1.1 Electrification Rate
The electrification rate included in the calculations of future energy demand has been included for four of the five sectors as a rate for electricity demand directly applied on the energy demand. This results in the value of the rate having a considerable effect on the results. A sensitivity analysis was implemented to analyse the effect of changes in the projected future electrification of the four sectors on the total electricity demand. The originally assumed rates for 2040 were increased respectively decreased by 20% to evaluate the affects on the total demand. As seen in figure 24 it affects the total demand, with a change of 17.0%.

![Sensitivity Analysis of Electrification Rates](image)

Figure 24 Sensitivity analysis of electrification rates in demand projections, PJ (Source: Appendix #2)

Usually when performing demand projections, no increase of the electrification rates is included, and the share of the electricity demand of the total energy demand is assumed constant, as part of a constant energy intensity. Though, that is not a realistic procedure for Uganda, considering the fact that two out of five sectors today has zero electricity consumption. Also the share of electricity demand out of total energy demand is expected to increase for the other three sectors because of a future industrialization and urbanization. To analyse the effect of keeping the electricity energy intensities as a constant value, meaning no increase of the electricity's share of total energy demand, the demand projections were performed without including any electrification rates as well, see figure 25.
4.4.1.2 Energy Intensities
To observe the influence of the calculated energy intensities on the projected electricity demands, calculations for plus respectively minus 20% of the original energy intensities for the sectors agriculture, industry and services have been performed, see figure 26. The 20% change of the energy intensities resulted in a 16.8% change of the total electricity demand.

4.4.1.3 GDP Projections
To test the significance of the accuracy in the GDP projections the values of the projected GDPS were changed with plus respectively minus 20%, to see the affect on the total electricity demand. The 20% increase of the projected GDP resulted in an increase of 17.1% of the total electricity demand in 2040. The equally large decrease of projected GDP resulted in a decline of 16.7% of total electricity demand, see figure 27.
4.4.1.4 Projected Population

The sensitivity analysis of the projected population showed small differences in the total projected electricity demand, and changes of the 2040’s projected population by 20% did only affect the future electricity demand by 3.0%, see figure 28. The reason for this small impact on the total electricity demand is that the household sector is the only sector whose future consumption has been calculated based on the predicted population. The other sectors have mainly been based on projections of future GDP, a parameter which itself contains other projections of future population.

4.4.2 OSeMOSYS

4.4.2.1 Sensitivity to Demand

To analyse the outcome of the model when varying the demand, a demand analysis was done in four different scenarios. In the original and modernization scenarios the demand projections calculated in section 4.1 were used. To see how sensitive the model is to the demand inputs, a sensitivity analysis was made
and where the original demand plus respectively minus 10% was entered into the model. As seen in figure 30 the system cost is highly correlated to the demand, but can vary from year to year as a result of large initial investment costs.

Figure 29 Demand projections used as input in OSeMOSYS sensitivity analysis, PJ (Source: Appendix #2)

Figure 30 Comparison of Total Annual System Costs in demand sensitivity analysis (OSeMOSYS), PJ (Source: Appendix #4)

The reason for the high initial cost in the modernization scenario is a large construction to extend the transmission and distribution system, especially the residential distribution, together with large investments in natural gas power plants. The natural gas power plants expand with over 30 GW installed capacity in 2012 in the modernization scenario, due to an initially larger increasing demand than in the original scenario.

### 4.6 Model Critique

#### 4.6.1 Data
Because of the lack of correct data and difficulties in establishing new contacts in Uganda, some of the data entered into the OSeMOSYS interface has been assumed based on data for similar technologies. This, of course, has an impact
and results in some kind of error, which after analysis of the results has been valued as tolerable.

**4.6.2 Modelling**

**4.6.2.1 Demand Projections**

Projections always contain a certain level of insecurity, especially for developing countries where the development depend on several different parameters and the integration between them. Therefom, the projections performed and used in this study should be seen as rough estimations. With that said, the importance of conducting such studies is vital to lay a foundation for future planning and policymaking. The most insecure factors in this study have been identified as the projections for population, GDP and future electrification rates. Though, it can be seen in the sensitivity analysis that, even though varying these factors, the results still are in the same magnitude, which exemplifies the importance of including the factors rather than having an exact projection of them.

**4.6.2.2 OSeMOSYS**

In the OSeMOSYS model, a lot of parameter values were included of which some were site specific, some were general and some were mere assumptions. The most essential of the parameters to observe for the future development of the energy system are the cost parameters. Therefom, the accuracy of these values should be prioritized. In this model general values for the different future power plant technologies have been used, which of course might vary in reality. Also the identified construction and extraction potential of technologies might be an error, because of difficulties in finding accurate values.

**5. Conclusions & Future Work**

**5.1 Conclusions**

The study has shown that Uganda faces a number of challenges in order to obtain a sustainable and environmentally friendly future development.

The essence of formulating development policies and strategic goals in an integrated way has through the report been enlightened, and the importance of identifying the way the different sectors affect each other from a CLEW perspective has been manifested. In Uganda’s case this especially applies to the water parameter in the hydropower production and the agriculture, where the two sectors have been distinguished to have a large impact on each other.

Uganda has in the "Uganda Vision 2040" stated a clear goal and aspiration to improve the living conditions of the inhabitants by creating a modern and competitive society and thereby becoming a middle-income country. To achieve this and to facilitate the development, four main areas in need of improvements have been identified as infrastructure, education, investment climate, and energy security.
The lack of a functional *infrastructure*, both physical and informational, prevents the country from growing and from successfully becoming an industrialized nation. Today there are major deficiencies that obstruct efficiency as well as accessibility and with an increased population and welfare, the current system becomes unsustainable. A well-developed and organized infrastructure constitutes a foundation of a modern and successful society and must consequently be established to enable further development of the country.

In terms of the *infrastructure* of communication and information, it is necessary to provide the required data to create a good foundation for policymaking and strategic studies. If there is no knowledge of the current situation, it is difficult to develop strategies to improve it. The way to access, manage and analyse data needs to be improved. It will also require methods in which continued monitoring can be handled more efficiently. The overall base for communication and data approach in the country need to be enhanced to simplify and encourage studies and co-operation between institutions and facilitate continuous feed back, in order to develop more integrated policies. Information is a key for analysis and development.

To develop the knowledge base in the country, the human capital needs to be increased through a prioritization of *education*. Education is the motor of innovations and development in a country and is therefor an essential factor when transforming Uganda into a more stable and competitive nation.

When policies have been established and the knowledge required has been obtained, financial aids need to be provided to accomplish the development. To obtain economic growth private investors, both national and international, need to contribute. It is therefor important to create a good *investment climate*. Because of the recently discovered resources in the country, such as oil and uranium, the interest of investments has increased, why it is highly essential for the government to handle the situation in a correct way to best utilize the situation.

To obtain all of the above-mentioned conditions there needs to be a *secure access to energy*. The energy demand has been predicted to grow in a high rate and the consequences of a power shortage have been proven to be severe. Therefor it is important for the government, together with private investors, to stay one step ahead in order to avoid a deficit of electricity. An energy system with sufficient capacity to meet future demand is essential for almost all human activities, but above all, it is a necessary foundation for economical growth.

By examining how different areas, sectors and businesses are interconnected, synergies can easier be identified and exploited. An increased knowledge of the integrations simplifies resource efficiency and a balance between economic and environmental development can be obtained. A stable balance is the key for a
secure and sustainable development as well as it facilitates maximized utilization of existing opportunities. Uganda needs to refocus and implement continuous reconciliations of the current situation in order to constantly adapt the elaboration to the existing conditions, where special focus needs to be held on the water flow used for the agriculture and the hydropower.

**5.2 Future Work**

To complement this study a more detailed study of how to enable the future necessary investments and constructions may be conducted. A strategy to improve the Ugandan investment climate and to increase the responsiveness of the country needs to be set. This study may also be developed with more detailed study of the input data used in the modelling, such as projections and cost analysis, to increase the relevance and certainty of the retrieved results.

This study is meant to be used as a foundation and assist Uganda in future policymaking.
6. Reference List

6.1 Internet


6.2 Printed


6.3 Excel documents

Sridharan, Vignesh. (2015a). "Demand%20and%20Time%20slice%20calculations%20Recovered%29" [XLSX]


7. Appendices
All the appendices referred to in the report will be made publicly available. A description of the different appendices can be found below.

7.1 Appendix 1
Appendix 1 contains all the technology specific input data used in the OSeMOSYS interface, with complete references. Here the Reference Energy System and other sections related to the model can be found as well.

7.2 Appendix 2
In this appendix all the data and calculations used in the demand projections can be found together with a complete reference list and graphical demonstrations.

7.3 Appendix 3
Appendix 3 includes the OSeMOSYS excel interface with all the base values and a scenario comparison of the demand analysis.

7.4 Appendix 4
In appendix 4 some of the Raw Results obtained from the OSeMOSYS interface model-run has been collected and summarized to illustrate a graphic comparison of the different parameters included in the model.