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School of Energy Systems

Energy Technology

Business Model for Microgrids in Sub-Saharan Africa Rural Areas

A Case Study in Revon C, Namibia

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ABSTRACT

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Key words: Microgrids, business model, electrification, Sub-Saharan Africa

The Sub-Saharan Africa (SSA) has the lowest electricity access rate in the world, and the number is rising due to the rapid population growth. More than half of the region's population lacks electricity, and among those, nearly 80% are living in rural areas. Despite seeing a considerable increase in electrification across the region nearly 530 million people will live without access in 2040. In addition to the most stated challenges of supply and capacity developments, the SSA has multi-dimensional attributing factors for its energy poverty. These factors are mainly linked to the socio-economic fabrics of the region. Distributed energy resources (DERs) are currently perceived as one way of eradicating the energy poverty by lowering the high infrastructure cost, which used to be created by traditional grids systems. To enable deployment of DERs as reliable and sustainable energy resources, a suitable business model is essential. Energy business models can assure a delivery of affordable energy to customers, while creating a revenue and return on investment. In this thesis, different energy business models with a focus on energy access in emerging markets were assessed. Moreover, a case study in an ongoing Fusion Grid pilot project in rural Namibia was analyzed by using business model considerations and Net Present Value (NPV) as a financial viability tool. However, the results suggest that microgrid solutions were more expensive than the existing power supply excluding connection fees, which prompts further for studies regarding the value creation and pricing structure of the Fusion Grid concept.

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Henock Dandena Dibaba

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SYMBOLS AND ABBREVIATIONS

abbreviations

BOT	Build-Own Transfer
CPI	Corruption Perception Index
CSP	Concentrated Solar Power
DER	Distribution Energy Resource
DOD	Department of Defence
DNI	Direct Normal Irradiance
GHI	Global Horizontal Irradiance
GDP	Gross Domestic Product
ESPC	Energy Saving Performance Contract
FG	Fusion grid
GNI	Gross National Income
IEA	International Energy Agency
ICRG	International Country Risk Guide's
IMF	International Monitory Fund
ICRG	International Country Risk Guide's
IRENA	International Renewable Energy Agency
IPP	Independent Power Plant
IIAG	Ibrahim Index on Africa Governance
KWh	Kilowatt-hours

MPI	Multidimensional Poverty Index
Mtoe	Million Tons of Oil Equivalent
MFFs	Microgrid´s Failure Factor
NREL	National Renewable Energy Laboratory
NORED	Northern Namibia´s Regional Electricity Distributor
NREP	National Rural Electrification Programme
OECD	Organisation for Economic Co-operation and Development
OPHI	Oxford Poverty and Human Development
PAYG	Pay-As-You-Go
PTG	Power-to-Gas
PPPs	Public-Private-Partnerships
QAF	Quality Assurance Framework
RBF	Result-Based Financing
SSA	Sub-Saharan Africa
TWh	Terawatt-hours
TPES	Total Primary Energy Supply
UESC	Utility Energy Service Contract
WTP	Willingness-to-Pay
WGI	World Bank Governance Indicators

1 INTRODUCTION

The basis of the modern economy is founded upon an advanced energy system. However, Sub-Saharan Africa (SSA) is far from achieving this status. SSA has the lowest energy access rate in the world, and its current state represents a significant threat to its economic and social development. SSA accounts for a higher number of people living without access to electricity than any other part of the world. According to the International Energy Agency (IEA), more than half of the region's population (nearly 630 million people) have no access to electricity, which is also expected to increase due to the rapid population growth. In addition, almost 80% of the region's population lacking access to electricity lives in a rural part of the region. (International Energy Agency, 2014)

Access to affordable and reliable energy is essential for stimulating the social and economic progress in SSA. However, due to the diverse socio-economic aspect of the region, problem-solving strategies, and technological solutions requires distinctive consideration. Furthermore, it is vital to consider in creating and employing business models that encompass different aspects of the electrification processes. These aspects comprise the share of ownership, financial-related issue, operation & technical elements.

Decentralized renewable energy solutions stand to play a crucial role in expanding electricity access in SSA. This occurs mainly due to renewable-based energy systems are being perceived as durable solutions enabling to provide reliable and affordable electricity with their increasing efficiencies and reducing costs. Nonetheless, decentralized energy system projects require involvement from different stakeholders such as private investors and local communities; thus, attaining capital and determination of ownership roles.

The aim of this thesis is to study the current energy status of the region, examine renewable based-microgrids energy systems for rural part of SSA and develop a methodology for defining an appropriate business model for the community based on their income and willingness to pay. furthermore, the case study of electrification project in rural Namibia was analysed.

The main objectives of the thesis are:

- to overview the current energy status and challenges in the energy systems of the region,
- to examine different energy resources and technologies that are currently available in the region,
- to assess business models that are presently available in energy systems,
- to explore different business models that can create revenue streams and invite private investors without compromising the affordability and reliability of electricity for the community,
- to assess the feasibility of a community-owned and operated microgrids in rural area of Sub-Saharan Africa,
- to assess the project viability for ongoing pilot project in Namibia´s rural area.

2 ENERGY ISSUE IN SUB-SAHARAN AFRICA

This chapter presents the Sub-Saharan Africa (SSA) energy status. the region's socio-economic status, energy outlooks, and electrification challenges were overviewed.

2.1 Overview of Sub-Saharan Africa (SSA)

Sub-Saharan Africa is a region of the continent Africa that is located south of the Saharan desert. It consists of 48 countries excluding six countries in the North- Africa., the economic, demography, and governance outlooks of the region are discussed. below.

Figure 1: Sub-Saharan Africa (SSA). (Blimpo & Cosgrove-Davies, 2019)

2.1.1 Economy

The International Monetary fund (IMF) report highlights a growth projection for the recent years in SSA were 3 % and 3.5 % for 2018 and 2019, respectively (International Monetary Fund , 2019). Figure 2 shows a real GDP growth of SSA countries in relation to their economic status. Accordingly, the recent GDP shows a steady growth after the economic rebounding from slow economic growth in between years 2014-2016.

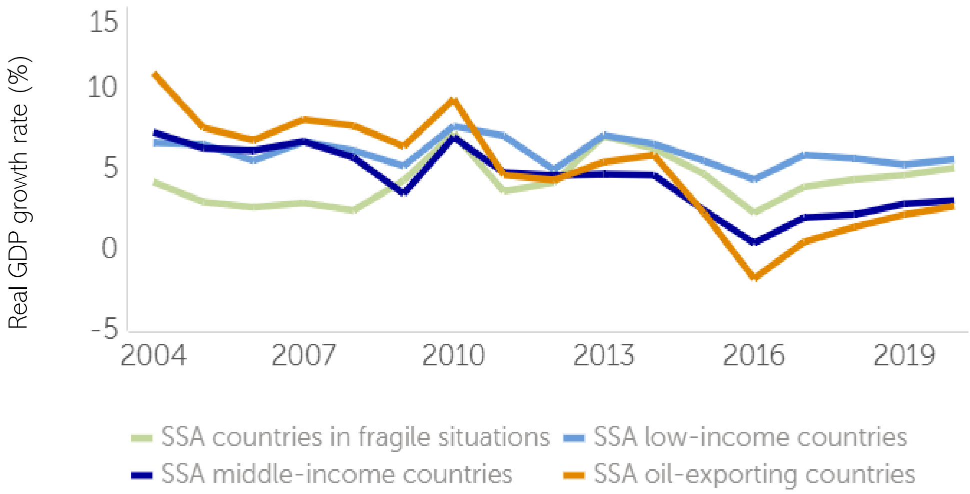


Figure 2: Sub-Saharan Africa (SSA): Real GDP growth rate (%). (International Monetary Fund , 2019)

Moreover, as reported by the IMF, the inflation rate shows a decrease from 12.7 % to 10% between the year 2016 and 2017; and expected to decrease further in the coming years. This is mainly driven by the falling food price and oil exporters' countries comprehensive restructured policies. (International Monetary Fund, 2018)

Nigeria and South Africa have the largest economy among the SSA countries. According to (International Monetary Fund , 2019) in 2017 their GDP were $375.6 and $347.7 billion, respectively. Together, they account for half of the SSA economy followed by Angola, Ethiopia, and Sudan (International Energy Agency, 2017).

Agriculture, mining and services are some of the common sectors attributing to the economy in SSA.

The agricultural sector remains traditional and dependant on rain-fed crops; making it vulnerable to damages caused by droughts and climate change. The sector accounts for about 20% of the region-wide GDP reaching from below 3% in South Africa and Botswana to above 50% in Chad, which is quite high compared with the 6% global average. (Hafner, et al., 2018)

Similarly, the mining sector is the biggest industrial activity in the region which attributes to the GDP and fiscal revenues in SSA countries. In some countries such as the Democratic Republic of Congo, Zambia, and Guinea, it accounts for more than half of the exports. Nonetheless, across the region, the sector´s contribution is mostly with direct employment rather than GDP and facial revenue. (Hafner, et al., 2018)

Other than above, low energy-intensive sectors such as textile industry, banking, and telecommunication are recently playing a significant role in economic growth.

In addition to the global economic growth and higher commodity prices, there are different regional factors attribute to the growth. These were; relative stability and security in the region, improved macro-economic management, rise of demand-driven middle class, population growth, and urbanization. (International Energy Agency, 2014)

However, the regions public debt continued to rise despite economic growth. In most countries of the region, public debt is more than 50% of GDP, posing another challenge in the economy and creating debt distress. According to the IMF report, six countries in the region are in debt-distress while two countries (Ethiopia and Zambia) are at high risk of debt-distress. (International Monetary Fund, 2018)

2.1.2 Demography

In 2018, the population of the SSA exceeded 1 billion. (The World Bank, 2019). An average growth rate of the region is around 2.3% per annum. Population growth through the years was quite rapid. Between the year 2000 and 2013, the population had increased by 270 million. The immense increase is concentrated mainly in west and east African countries. This is mainly due to the higher fertility rate, lower level of education, improvement of health care, and urban immigration. An average life expectancy in the region rose to 55 years in 2013, showing an increase of 5.5 years from the year 2000. (International Energy Agency, 2014)

The projected SSA population by the year 2050 and 2100 are 2 billion and 3.7 billion, respectively. By the year 2050, the youngest population (from 0-14 age group) is estimated to be 685 million, the working-age population (from 15-64 age group) is expected to be 1.25 billion, and the elderly (older than 65 years old) are expected to be 100 million. (International Monetary Fund: African Dept., 2015) Figure 3 shows the population projection for different regions of Africa.

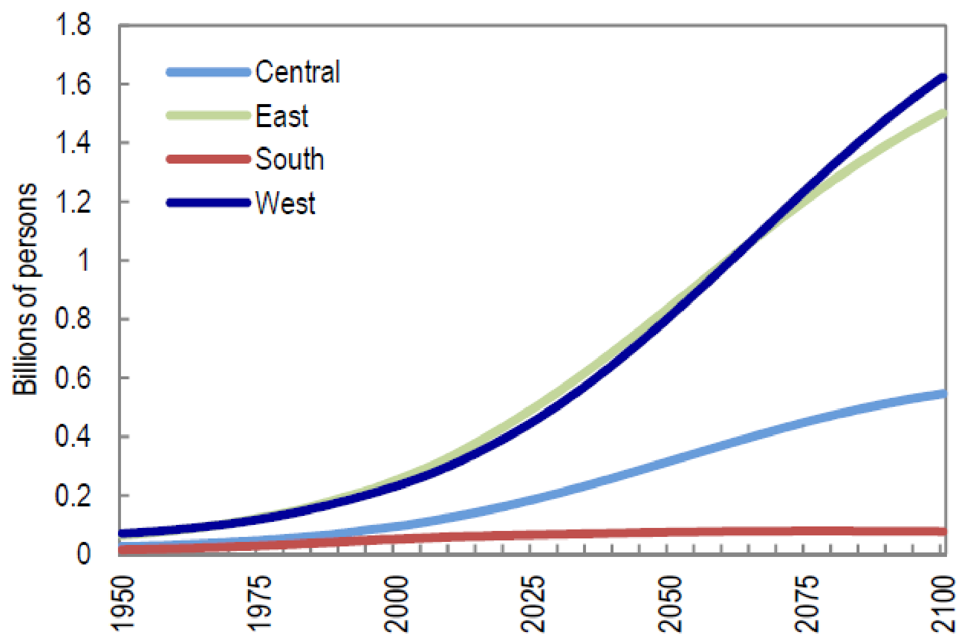


Figure 3: SSA: Population projection, 1950–2100. (International Monetary Fund: African Dept., 2015)

On the other hand, SSA’s demographic dividend can attribute to economic growth and job creation opportunities for the region. The demographic dividend is one way of describing the dynamic effects caused by the change in population age structure and economic growth (David, et al., 2015). This dividend is created due to the demographic transitions which describes how fast infant mortality and fertility rates decline.

According to (International Monetary Fund: African Dept., 2015) findings, the SSA region can benefit from the future demographic dividend depending on the rate of the transition and supporting policy frameworks. The demography dividend deferred if only countries fail to curb the infant mortality rate while having a high fertility rate. Thus, it is essential to establish a better economic and financial stabilities to enable support of the transition. Besides, policies concerning the labour market, human capital development, and global trades are also essential for the transition.

Furthermore, demographic development projections vary significantly across SSA. A significant increase in population is projected in the eastern and western part of SSA, in which the population is projected to surpass more than 1 billion by 2050. Among those countries, Nigeria is expected to have the most significant increase. On the contrary, countries in the south region, the growth projection remains flat; which is one indicator of the demographic transition. (International Monetary Fund: African Dept., 2015)

Figure 4 illustrates SSA’s population structure development and projections. The share of the working-age population (SWAP), between ages 15-64, is a primary indicator of the region’s employment capacity or labour force participation rate. Accordingly, the share of the working-age population (SWAP) showed a significant increase after the 1980s to the present after sharply decrease in the previous decades. Also, the SWAP is expected to increase significantly in the coming decades, with estimate reaching nearly 65% of the population in 2100.

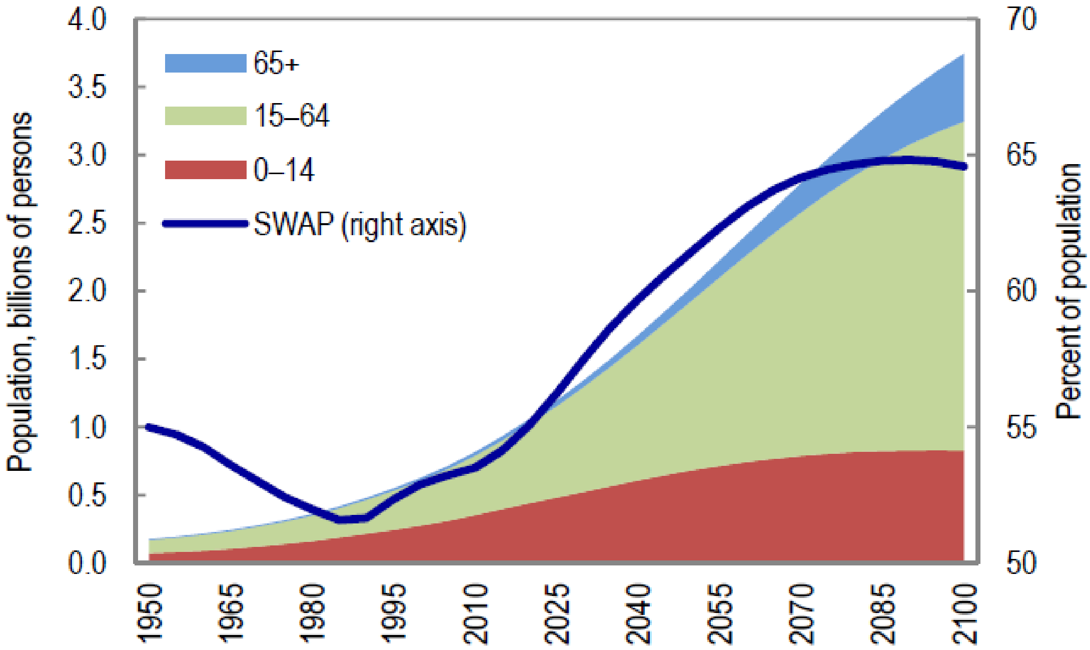


Figure 4: SSA population structure, 1950-2100. (SWAP = Share of Working-Age Population). (International Monetary Fund: African Dept., 2015)

Worldwide, the rapid global working-age population growth helped to support higher global growth in the previous decades. However, currently the trend is showing inclination over the years. As can be seen in figure 5, excluding SSA, in the year 2050, the world working age will start to decline. Advanced economies are most likely to face challenges from the aging population and decline of the share of working-age populations (SWAP). By the year 2035 the working-age population of SSA will surpass that of the rest of the world combined. This implies the current rapid growth in population and demographic transition, or the increase in the SWAP. Thus, SSA's labour force could play a significant role in the future global economy. From historical transitions in other parts of the world, the positive outcome can be in higher saving and economic growth by further industrialization job creation (International Monetary Fund: African Dept., 2015)

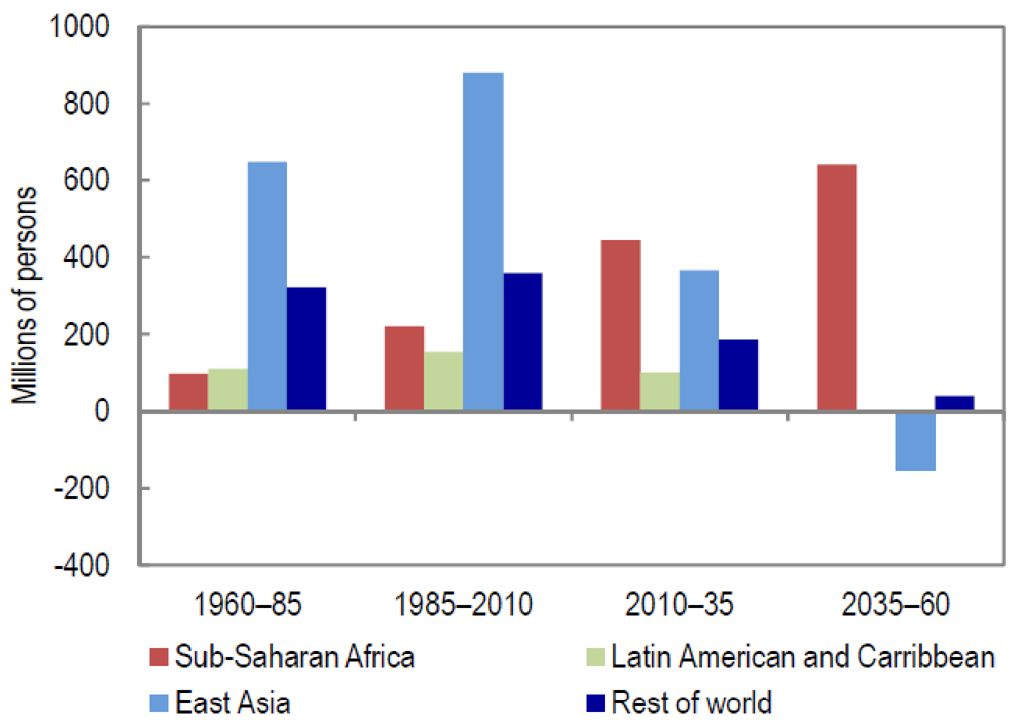


Figure 5: Changes in share of working age population (SWAP), 1960–2060. (International Monetary Fund: African Dept., 2015)

2.1.3 Governance

Sub-Saharan Africa (SSA) is one of the most poorly governed regions in the world. Poor governance is described by corruption, poor transparency & accountability of institutions, insufficient legal and regulatory system, and the likes. Nearly 80% of the SSA countries score below the global average in Transparency International's Corruption Perception Index (CPI), and more than half of countries that were listed the most corrupted were from the SSA. (Transparency International, 2018) In addition, only three countries (Ghana, Botswana, and Namibia) score above average in the International Country Risk Guide's (ICRG). (Hammadi, et al., 2019) On the other hand, Democratic Republic of Congo and Somalia are found to perform poorly in the regions. (International Energy Agency, 2014) Nonetheless, there are countries like Botswana, and Mauritania that improves their governance systems through the years.

Poor economic performances are mainly created by poor governance in developing countries, especially in SSA. Weak governance hinders social and economic performance through different channels such as higher tax evasion, poor lending practices, poor government spending practices, lower investment, etc. World Bank's Worldwide Governance Indicators (WGI) – comprising six leading indicators. These are: 1) Voice and accountability; 2) Political stability; 3) Government effectiveness (Governance efficiency); 4) The rule of law (Legal framework); 5) Regulatory quality (Law enforcement); and 6) Control of corruption. Accordingly, SSA countries scores lower in all the six indicators compared to the world's average. (The World Bank, 2019) Also, (Kaufmann & kraay, 2007) study showed that, among SSA countries, oil rich countries perform lower WGI score than the other non-oil rich countries. (See figure 6)

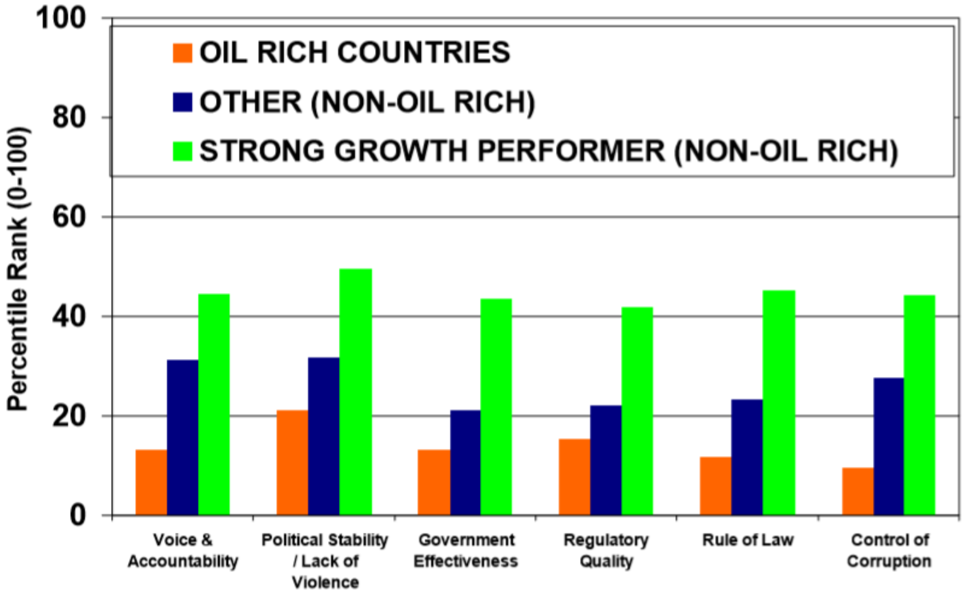


Figure 6: Governance in SSA: resource rich Vs non-resource rich countries. (Kaufmann & kraay, 2007)

Furthermore, a study made by (Hammadi, et al., 2019) regarding the correlation between governance and growth showed that weak government impacts GDP per capita growth in SSA stronger than the rest of the world. Figure 7 illustrates the correlation between more ineffective and higher corruption among SSA countries (orange dotted) and the rest of the world (blue dotted) between 1995-2015. Accordingly, the graphs indicate that weaker government with higher corruption and lower development are observed in SSA countries. This can also explain the income differences among SSA countries and other regions partly. Similarly, higher corruption rate can deteriorate fiscal performance. These imply a lower quality of public spending, such as eduation, infrastructure, and healthcare.

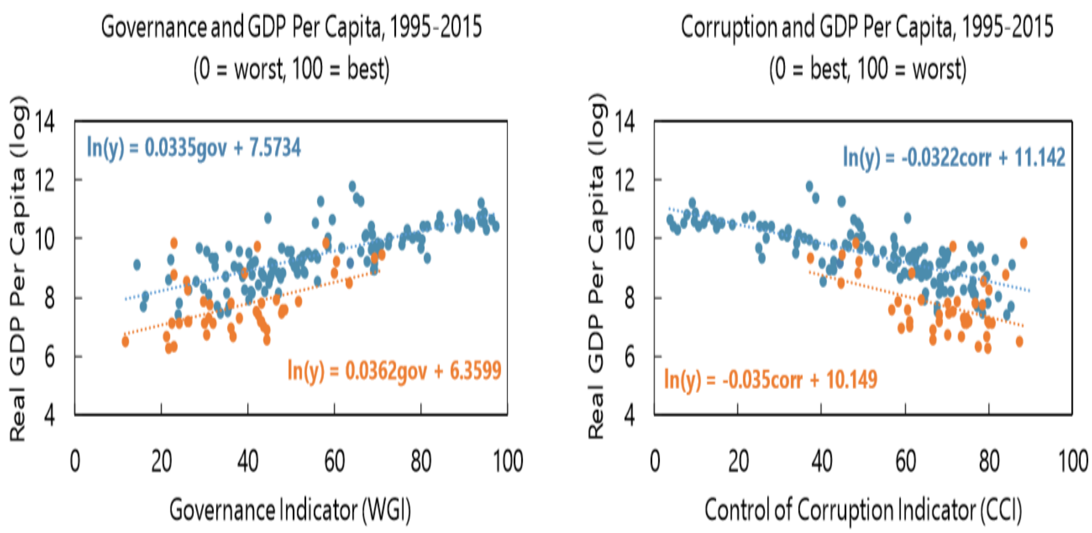


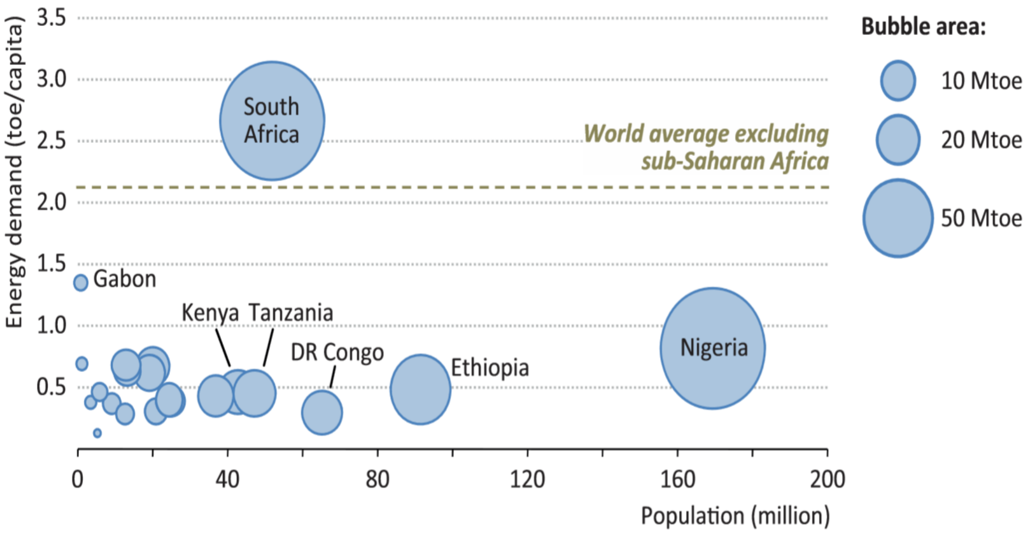
Figure 7: Governance and Corruption Perceptions and Level of Development. (Hammadi, et al., 2019)

Similarly, (M, et al., 2018) have assessed the influence of governance on the economic growth of three SSA countries (Nigeria, Ghana, and South Africa) between the year 1955-2015.The finding indicates that WGI has clear implication in economic growth; in which Nigeria’s economic growth is negatively impacted compared to Ghana and South Africa due to poor governance.

2.2 Sub-Saharan Africa energy status

The energy system of the SSA largely depends on primary energy consumption. Bioenergy accounts for 60-80% share in the primary energy supply (PES) mix. Biomass use in the region is traditional rather modern and mainly applicable for cooking. (Energy in Africa. 2018) Use of biomass has been also growing in the last decade despite the rising income of the region. This is mainly due to traded charcoal supply to urban areas and non-traded consumable biomasses in rural areas. (International Energy Agency, 2014)

Figure 8 shows the population and per capita energy demand by country in sub-Saharan Africa. As can be seen, SSA energy use per capita is equivalent to one-third of the world's average apart from South Africa. And, this energy per capita shows a vast inequality among the rural and urban area across the region. (Hafner, et al., 2018)



Note: The bubble size illustrates the relative size of the total primary energy demand.

Figure 8: Population and per capita energy demand by country. (Hafner, et al., 2018)

According to the IEA's 2017 report, the energy demand of SSA increased from 570 Mtoe to 619Mtoe between the year 2012 and 2016, accounting for 4.5% of the world's energy demand. The largest demands by country are in Nigeria (141Mtoe) and in South Africa (141 Mtoe) – which in total accounts for the 40% of regions energy demand and vaguely followed by Ethiopia (45Mtoe). SSA has a higher energy demand growth rate compared to most countries in the world. However, economic activity lags since they are low energy intense activities such as tourism and agriculture. (International Energy Agency, 2017)

2.2.1 Access to Electricity

According to the (International Energy Agency, 2014) report, the SSA accounts for nearly half of people without electricity access in the world. In the region, around 80 % of those lacking access are in rural areas. As can be seen in figure 9, only 43% of the people use electricity for lighting and 12% for cooking in the region, which is lower compared to the northern and southern African countries. (Hafner, et al., 2018) The average person electricity consumption in SSA is estimated to be 200 KWh/year in the urban area while 50KWh/year in the rural area. (Hafner, et al., 2018). The lack of electricity is one of the significant attributes for the non-stop cycle of poverty, child mortality, and repressed education system (Hubble & Ustun, 2017).

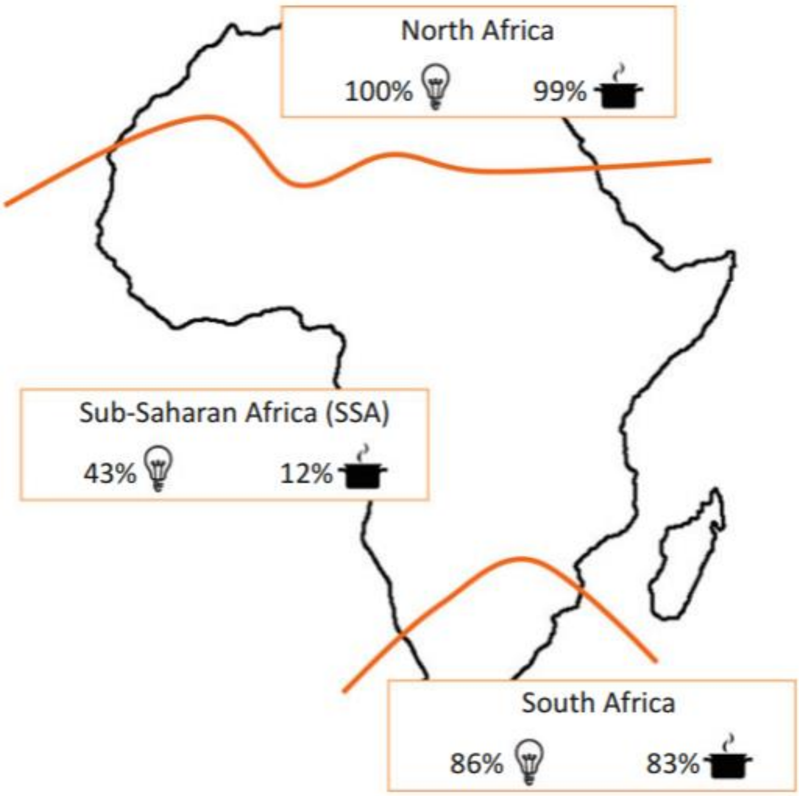


Figure 9: Electricity use for lighting and cooking in across Africa. (Hafner, et al., 2018)

However, the recent IEA report showed that electrification rate of the region has nearly tripled since 2012 compared to the previous period between 2000 and 2012. A good illustration can be observed in East Africa region, where the number of people without access to electricity declined by 14% since 2012 (accounting for the 80% of the decline in SSA). (International Energy Agency, 2017).

2.2.2 Electricity supply

Between the year 2000 and 2012 grid-based power generation capacity in the region has increased from 68 GW to 90 GW (Where South Africa is accounting for nearly half of the total capacity). The generation capacity in SSA comprise coal-fired generation (45%), hydropower (22%), oil-fired (17%), gas-fired (14%), nuclear (2%), and other renewables

(< 1%). However, the available capacity is not fully utilized mainly due to the poor operational and maintenance of the power systems. (International Energy Agency, 2014)

One hindering factor in electricity supply is the losses in the transmission and distribution networks. These technical losses signify economic loss for the region. In some part of the region (excluding South Africa), losses are estimated to reduce the supply for more than 20% (in average 18% across the region); which is quite high compared to OECD countries that has an average loss of 6%. This is mainly attributed by lack of maintenance and inefficient system design. (Hafner, et al., 2018)

Besides technical challenges, non-technical loses are another obstacle to the supply system. They are caused by action external to the power systems such as electric theft, non-payments, and administrative losses. Financial losses due to non-technical losses are more intensified on power utilities. Also, in many cases, these costs are randomly passed on the consumers as additional costs. (World Bank Group Energy Sector Strategy, 2009)

In addition, the generation cost of the region is quite high than the other part of the world. According to the IEA an average generation cost of the electricity in SSA was $115 per MWh in 2012. Power generation cost and distribution can be further increasing to $140 MWh due to the costs of transmission and distributions losses(International Energy Agency, 2014). Moreover, the cost associated with electrification of rural areas becomes much higher due to the small number of people for the service and distance from the transmission are mostly far. For transmission line in rough terrain cost up to 20, 000$ per km, leading for many countries to exclude electrification programs in rural regions. (Hubble & Ustun, 2017)

Furthermore, dependence on hydro dams creates unreliable power systems which also increase environmental and financial risk in the region. Droughts and the ongoing climate change can damage generation capacities of hydro dams. This has been shown in South Africa and Zambia, where extreme weather and drought put the countries power supply at risk and threatens the country’s economic activities. (Avila, et al., 2017)

2.2.3 Electricity demand

The supply constraints in SSA make electricity demand estimations difficult. These constraints can be defined or characterized by either people's access to electricity or people's ability to consume as much as they needed. For this reason, demand estimates are based on the on-gird and off-grid supply data and excluding the unmet demands. Accordingly, the IEA report shows SSA's total electricity demand increased since 2000 by 35%, reaching 352 TWh in 2012. This is comparatively almost 70% of South Korea's demand, which has 5% of the population density of SSA's. Also, the demand per capita of the SSA is around 400KWh, which far less than the North African region's (around 1200KWh). And, despite the consumption rate in the region is increasing due to the population rise, the demand per capita electricity remains largely constant, which also far less than the North Africa region's where demand rose by 80% in same period. (International Energy Agency, 2014)

2.2.4 Generation potential

The SSA has an estimated potential of generating 11,000 GW of electricity. This share is largely comprising renewables resources. Figure 10 illustrates renewable resource potentials across the continents. Accordingly, across the region, solar power potential is estimated to be 10,000 GW and wind power potential of 109GW. Moreover, the geothermal potential is estimated to be 15 GW (mainly located in The East Africa rift valley). And, exploitable hydropower in regional countries estimated to be 350 GW. On the other hand, fossil energy resources are mainly including coal, petroleum, and natural gas. Coal resources potential power generation are estimated to be 300 GW and are mainly located in the southern region of the content. Similarly, natural gas potential in the region is estimated to be 400GW. (Avila, et al., 2017)

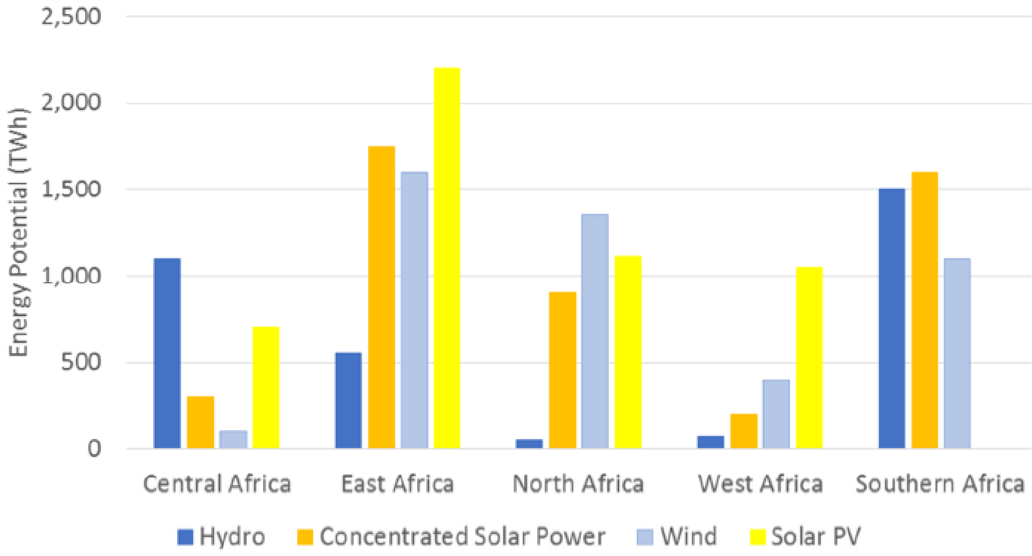


Figure 10: Renewable energy resource potential in Africa. (Avila, et al., 2017)

Despite abundant resources in the region, their geographical distribution is uneven. Thus, regional collaboration and grid interconnection are necessary for promoting low-cost, and clean renewable energy. For instance, as can be seen in figure 11, the highest generation potential in central and southern African countries comprising gas, hydro, coal, and wind. And, this can promote regional integration and collaboration by generation potential. This is also true especially since regions with the highest generation potential might not always have the highest demand. Besides, as various technologies of different generation potentials are present, it supports in balancing the grid and in lowering the need for backup generation and storage systems for intermittent sources such as wind and solar.

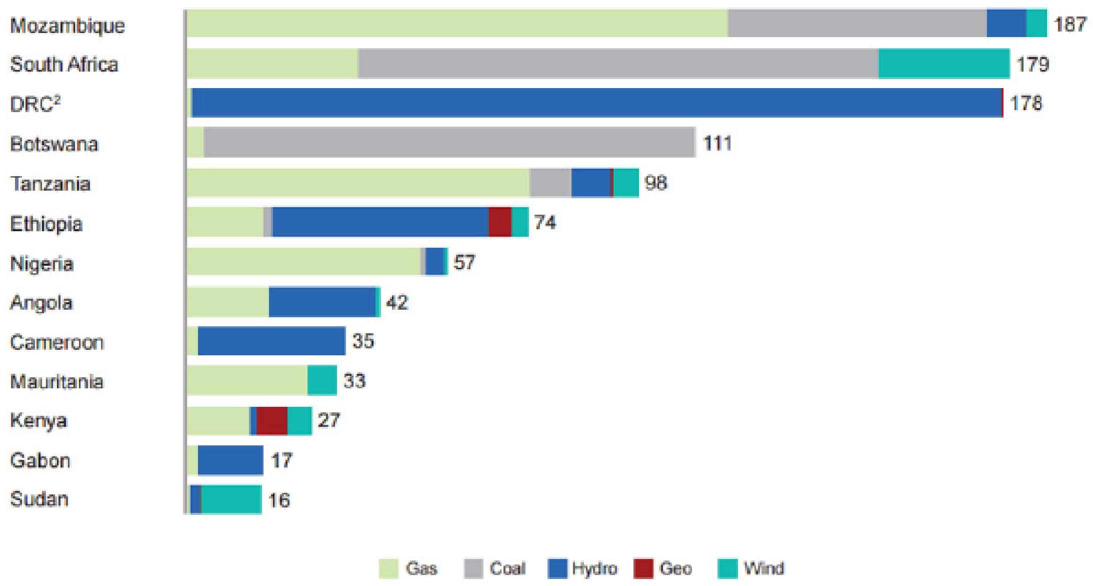


Figure 11: Electricity generation potential (GW) by technology in south and central African regions. (Avila, et al., 2017)

2.3 Sub-Saharan Africa future energy scenario

According to the IEA projection, in 2040, the total primary energy demand (TPED) of SSA is expected to exceed 1000 Mtoe. (See figure 12) At the same time, the pollution is expected to double in size and the economy to quadruple. The growth rate is likely to be 2% per year; which is 3% less from the previous decade. This is mainly due to improved energy-efficient consumptions trends. On the other hand, the energy per capita decline below 0.6 toe in the projected scenario. This is primarily due to factors such as the rapid population growth, improved cooking methods, improvement of efficiency energy systems.

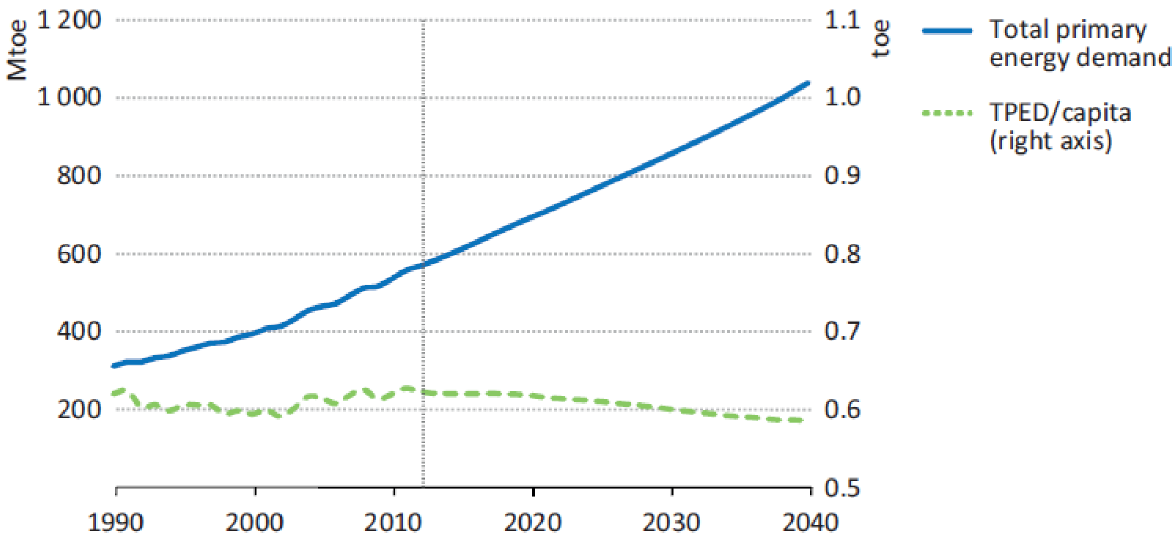


Figure 12: Total primary energy demand projection. (International Energy Agency, 2014)

Although the projected scenario impels increase in income per capita and the increasing share of other fuel in the region, bioenergy is still going to be dominant in the primary energy consumption mix. However, the percentage of bioenergy is projected to decrease from 61% in 2012 to 47% in 2040. (See figure 13) This can also be an indication of moving towards a modern form of energy consumptions such as improved cookstoves and efficient forms of biomasses such as pellet and biogas. Furthermore, oil demand is projected to be more than double with 4 million barrel per day in 2040, 60% of which is mainly from the transport sector. Next to oil, coal demand is expected to increase by 50% to reach 220 Mtoe; however, the demand in the energy mix will decrease from 18% to15%. Coal demand predominantly to remain in the southern African countries followed by Nigeria and some east African countries. (International Energy Agency, 2014)

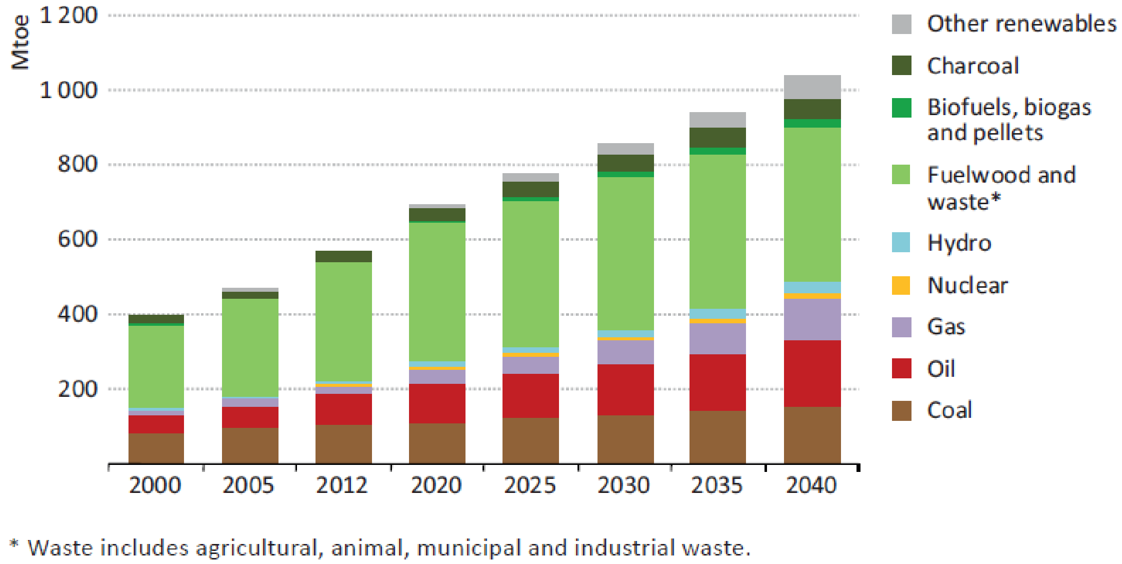


Figure 13: Primary energy consumption mix projection. (International Energy Agency, 2014)

Furthermore, a 100% renewable resource-based energy system viability in SSA is studied by (Oyewo, et al., 2018) for the year 2030. Accordingly, with appropriate geographical integration and energy sector coupling, renewable-based energy system can provide the power that can satisfy the SSA's demand for the year 2030. Also, the proposed study's energy systems models comprise Power-to-Gas (PTG) and Sea Water Reverse Osmosis (SWRO) distillation that can provide the region with Synthetic Natural Gas (SNG) and clean water powered by surplus renewable resources.

Nonetheless, according to (Morrissey, 2017), reaching the 100% vision requires several strategical and policy-wise actions in addition to technological developments**.** These actions can be: 1) polices which incentives renewables and discourage further fossil fuel development; 2) creating financial vehicles that facilitate integration decentralization along with future grid expansions; 3) creating frameworks encourages private investors involvement in the energy sector; 4) improving organizational procedures to support operational power pools in power-sharing and cost reduction; 5) incentivize and support decentralize renewable energy systems that enable to attain 100% affordable and reliable power with energy policies; and 6) drawing strategies that enables resource mixes which prioritize renewables and storage systems.

2.3.1 Electricity demand projection

In the 2040 IEA projection, the electricity demand is expected to triple to reach 1300 TWh. Despite seeing a considerable increase in electrification across the region, there will be 530 million people remaining without access in 2040. At the same time, industrial demand is expected to double (with improved efficiency) and residential demand to be five-fold from the current level reaching 520 TWh. (International Energy Agency, 2014)

2.4 Challenges for electrifications in SSA

The most noted features of electrification challenges in SSA are mostly linked to supply and capacity developments. However, it is also essential to underpin other attributing factors that play a significant role in the electrification process. These factors are mostly related to with the socio-economic factors of the region, particularly in the rural areas. Thus, in this section of the thesis, some of the major challenges and design consideration in the electrification process are discussed. For the study purpose, historical examples and events in relation to electrification are also used.

2.4.1 Challenges in relation to uptakes

Despite the common perception, demand-side challenges can create more obstacle than of supply-side for the full deployment of electrification in SSA. In the region, access deficit is formed mainly due to lower uptakes. The uptake rates vary significantly across the region, also with in the country's urban and rural areas. A high rate of uptakes can be seen in countries such as Cameroon, Gabon, Nigeria, and South Africa and lower rates in Liberia, Malawi, Niger, and Uganda. Also, the uptakes rates are much higher for the urban area rather than rural areas of the region. For instance, in Uganda, only in the capital and its surrounding areas have an uptake rate above 50%. Similarly, studies conducted in Kenya and Tanzania in several communities (even comprising with some relatively well-off households), shows the uptakes rates were meagre. (Blimpo & Cosgrove-Davies, 2019)

Moreover, the consumer's willingness-to-pay (WTP) can be considered one major drawback of lower uptake in the region. The WTP can be affected generally by three significant reasons: connection charges, household income, and the expected benefit of the electrification. (Blimpo & Cosgrove-Davies, 2019)

Firstly, for the lower-income SSA countries, connection charges are typically relatively high. Apart from connection charges, other factors related to bureaucratic processes significantly affect the WTP of the people. This can be roughly identified by features such as: 1) insufficient connection requirements and processes which does not address the existing constraints faced by customers, 2) long process times, and 3) variation of connection costs regarding labour costs for different areas of the region. (Blimpo & Cosgrove-Davies, 2019)

Secondly, household incomes of the impoverished part of SSA is another major factor for WTP. The household incomes are linked to income flow regularity and future income predictability. In poor households that generate income irregularly or seasonally (especially for small-scale traditional farmers), recurring payments are burdensome even in a small amount.

Thirdly, across the region cost of connection variation tends to be worsening and making it more difficult to afford by the poor; which can further discourage in pursuing electrification.

Moreover, low uptake limits the benefit for power supplier side by not enabling recovering their costs. And, this also brings another reliability challenge in maintenance and investment needed to improve systems. (Blimpo & Cosgrove-Davies, 2019)

2.4.2 Challenges in relation to cost and reliability of the supply

The other concerning challenge found in regions is regarding the cost of supply. In most of SSA countries, the cost of supply is higher than high-income nations such as the United States ($0.12 /KWh) and with developing countries like India ($0.08 /KWh). For instance, the cost of supply of Liberia is four times than of the United States. This can illustrate how electricity tariffs are highly priced and unaffordable in many countries; thus, hindering both in meeting the demand and expansion of access. (Blimpo & Cosgrove-Davies, 2019)

On the other hand, reliability plays a significant role in constraining power supply in the region. The SSA has the highest power outage incidence than any other part of the world. In fact, in most countries of SSA, outages are taken as characteristics features of their economy. According to the IEA report on average power outages in the region is reported to be 540 hr per year. Besides, apart from the frequency of outage characters, some countries such as Uganda, Sierra Leone, and Liberia, households experienced not even receiving power at all, despite being connected to the grid. (Blimpo & Cosgrove-Davies, 2019) Furthermore, in some of the studies conducted in the region, there were findings that imply access without substantial consumption, add another challenge to power utilities in terms of recovering their own operational costs.

Figure 14 illustrate the electrification experience in SSA's households that are connected to the grid. For instance, in Uganda and Liberia more than 30% of the households report never having electricity despite connected to grids.

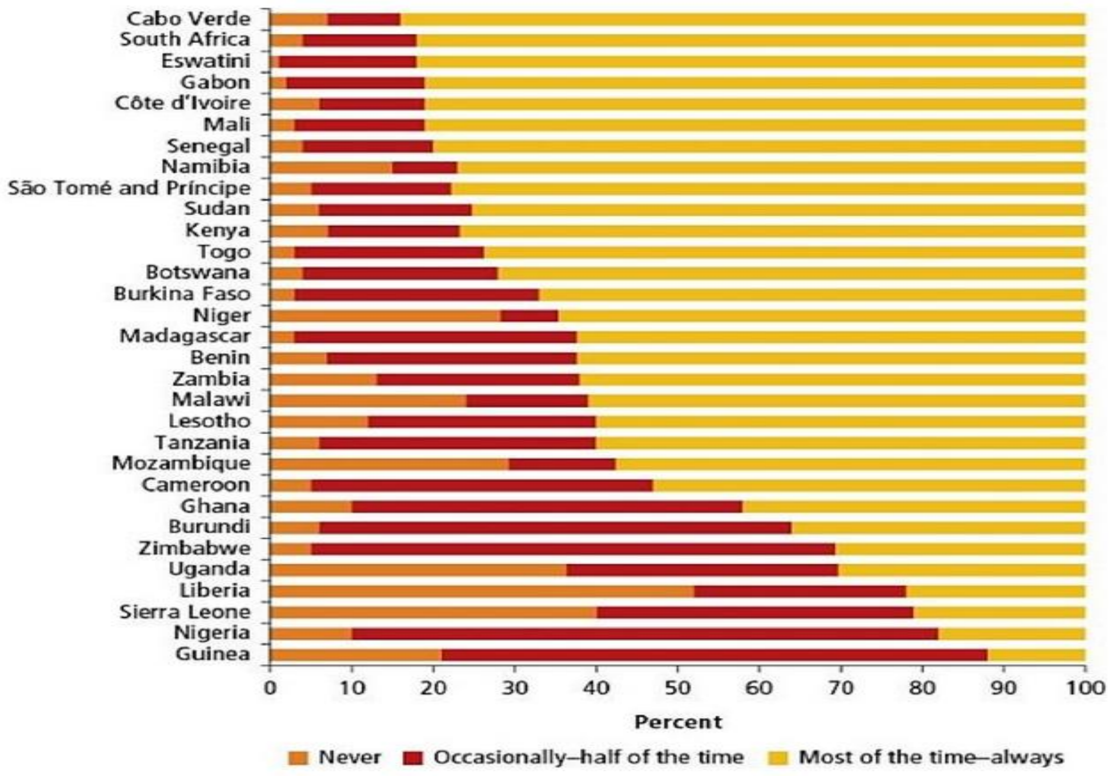


Figure 14: Electrification experience for grid-connected households. (Blimpo & Cosgrove-Davies, 2019)

2.4.3 Multidimensional Poverty in SSA

One of the significant characteristics determined in understanding the factors for infrastructural developments in the SSA is the level of poverty and inequality across the region. The Oxford Poverty and Human Development (OPHI) conducted a study to overview the multidimensional poverty level and trends in the region in 2014. The analysis was made using the global Multidimensional Poverty Index (MPI) – which is developed by the OPHI in 2010. The MPI is designed to further studies the poverty comprehensive means than the previously used measurements. It evaluates people's deprivation according to several indicators that are grouped into three major groups. These are: the level of education, health, and living standard. Accordingly, for a person to be multidimensional poor, it needs to at least to be deprived in one of the three weighted indicators. Also, for the case SSA, the 2014 study added a new measure of destitutions –

a measure of extreme deprivations – that is characterized by malnutrition, loss of children, children school attendance and practice open defecation. (Alkire & Housseini, 2014)

According to the MPI study – which covers the 37 countries of SSA – it was found that 420 million (58.9% of the total) people were living in multidimensional poverty. Out of these, West and East Africa have the highest share of 36.3% and 36%, respectively. Also, Central and South Africa account for 14.5% and 13.3% from the total. Of all the countries, Nigeria accounts for the 71 million MPI poor (15.4% of the total SS MPI poor). Moreover, it was found that 85.8% of the regions MPI poor lives in rural areas, which is higher than the 73.8% estimate for income poverty. (Alkire & Housseini, 2014)

Similarly, the destitution study encompasses 24 out the 37 SSA countries that were also covered in the 2014 MPI study. According to the study, 200.3 million (53.3% of the MPI) people are destitute. Niger has the highest destitute in SSA with 68.8% of the total population, followed by Ethiopia and Burkina Faso with 58.1% and 57.5 %. On the other hand, South Africa, Gabon and Swaziland have lowest in the region accounting for 1%, 3.2% and 5% of their total population, respectively. (Alkire & Housseini, 2014)

Nevertheless, improvement in multidimensional poverty reduction were recorded in many countries over the years. This can be seen in figure 15**,** where Rwanda and Ghana showed a significant decrease in MPI. Also, other countries such as Tanzania, Uganda, Ethiopia, Niger and, Mozambique showed a considerable MPI reduction.

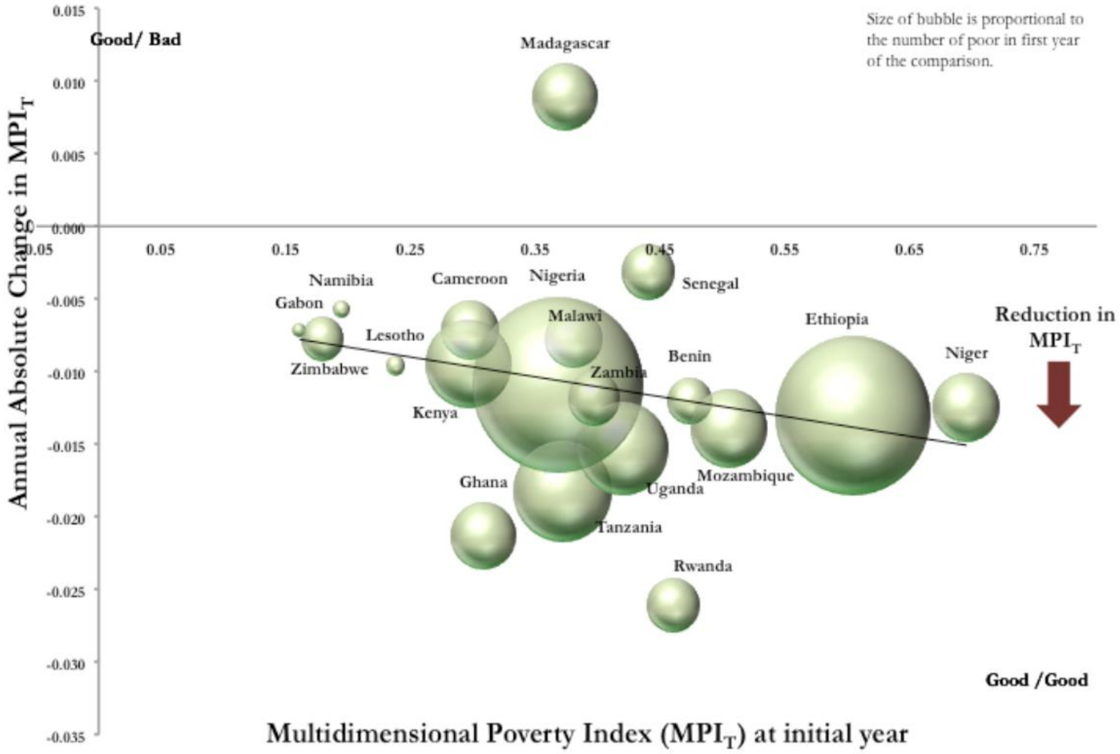


Figure 15: Level of MPI and rate of Poverty Reduction in SSA. (Alkire & Housseini, 2014)

2.5 Chapter summary

The chapter overviews the critical issues concerning the energy status in the SSA. Despite endowed with power generation potential, SSA still suffers from poor electricity access. SSA is the only region in the world where the number of people without access to electricity is rising due to the rapid population growth. Although population growth seemingly appears to create an opportunity for the new working-age population, it also exacerbates the existing challenges, including the demand for modern energy access.

The region's socio-economic status can further describe the challenges in the electrification process in SSA. Even though supply and capacity developments can be the main challenges in the region, demand and uptake can also discourage electrification due to the high cost of supply. Moreover, reliability issues even for the grid-connected customers can further add another challenge with frequent power outages - negatively affecting the economic activities. It is also noteworthy that broader assessment methods and indexes such as MPI help to deeper understand the SSA's poverty level and trends. Thus, the correlations in sub-national and ethnical level show a better understanding of the region's various interplayed socio-economic situations. This also can be vital to engineer and implement developmental projects in the region.

Most importantly, the overall poverty has driven electrification challenges mainly associated with poor governance. As reviewed in the section 2.1.3, poor governance is directly linked to poor economic and social development. Thus, improving governance elements can be the definitive solution that can lead to improving the socioeconomic status and further attracts infrastructural developments in the region.

Narrowing the gap for SSA's electricity demand is achievable mainly by increasing the power supply, in which initially, requires balancing renewable and non-renewable energy sources and then determining the role of centralized and decentralized girds systems for increasing accesses. Both are interlinked and requires a strategic framework and policy implementation.

3 CURRENT ENERGY TECHNOLOGIES IN SSA

The SSA is endowed with non-renewable and renewable energy resources; And, these vast energy resources are untapped and unevenly distributed across the region. The total energy production potential in the region is estimated to be 540Mtoe. Due to the lack of alternative energy sources, SSA mainly rely on traditional forms of biomass for energy supply accounting for 60-80% of the primary energy supply mix in the region. This is contrary to the northern African region's countries where fossil fuels cover 90-99% of the energy supply. Besides, other energy sources such as hydro, coal, oil, natural gas, nuclear, and other renewables comprise the energy supply in the region. (See figure16) South Africa is the only country in the region which currently produces electricity from nuclear power; however, other nations such as Kenya and Namibia are interested in using nuclear energy for power generation. (Hafner, et al., 2018)

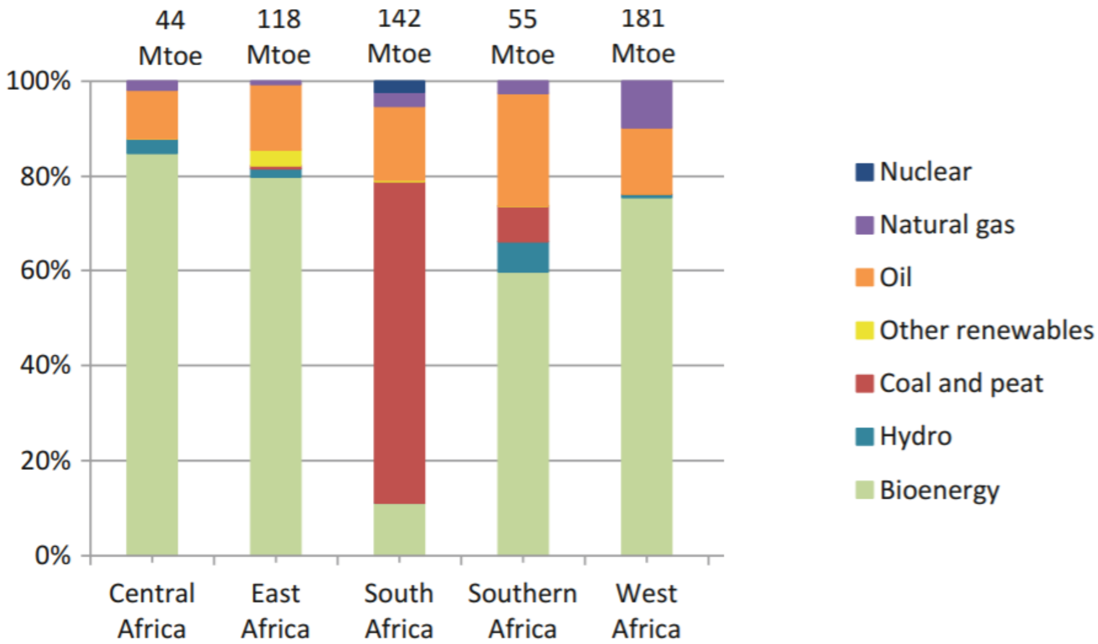


Figure 16: Primary energy supply in SSA regions. (Manfred Hafner, et al., 2018)

In this chapter of the thesis, energy resource potential in the SSA region and conversion technologies which are currently available (with a focus on renewables) are discussed.

3.1 Non-renewable energy technology

Non-renewable resource refers to those that cannot be replenished in a short period. These are fossil fuels such as crude oil, natural gas, coal, and uranium for nuclear power. Nearly 85 % of global energy consumption is satisfied by non-renewable resources.

3.1.1 Peat

Peat has been used for cooking and alternative heating source for many years. Recently the use of peat in power generation had been stimulated due to the rise of power demand. In countries like Finland, peat is used as a fuel for power plants ranging from 60-200 MW. In case of SSA, peat is harvested only in few countries such as Burundi, Senegal, South Arica, and Rwanda, and among those, Rwanda is the only country that produces electricity from peat powered power plant. (African Development Bank, 2017)

3.1.2 Coal

Coal is one of the most abundant fuels on the planet and, the cheapest fossil fuel to generate electricity. More than 95% of the coal reserve is found in South Africa, which also makes it the largest producers and consumer in the SSA region. (See table 1) Besides, South Africa is one of the major global producers with a share of 3.7% of global coal production. Other countries such as Zimbabwe, Zambia, Botswana, Swaziland, Nigeria, and Niger are also coal producer countries of the region; but their output is considerably low compared to South Africa. (African Development Bank, 2017)

Table 1: Coal production in SSA (Mtoe) (African Development Bank, 2017)

Country	Year						2015 share of global total
	2010	2011	2012	2013	2014	2015	
South Africa	144.1	143.2	146.6	145.4	148.2	142.2	3.7%
Zimbabwe	1.7	1.7	1.0	2.0	3.7	2.7	0.1%
Other Africa	1.0	1.3	4.5	5.4	5.9	5.9	0.2%
Total	146.8	146.1	152.1	152.8	157.8	151.4	4%

Apart from South Africa, coal reserves are undeveloped in the region mainly due to remoteness of the potential resources and lack of infrastructure. Besides, in oil-producing countries like Nigeria, gives more priority is given to oil and gas production than of coal. Moreover, finding investment for development becomes difficult and unworthy, because of poor quality of the coal reserves. (Hafner, et al., 2018)

3.1.3 Oil

Continental Africa has abundant crude oil reserves are mainly concentrated in the north part of the continent. Similarly, in the SSA region there are oil reserves that are primarily located in the western and central countries of the region. The rate of extraction is expected to increase in the region due to growing oil demand, which is mainly increasing across the subcontinent. In fact, it has surpassed coal consumption for an energy source in recent years. (Hafner, et al., 2018)

The transport sector is the largest oil consumer in the region, accounting for 70% consumption followed by industry and household use. (African Development Bank, 2017) Oil is also used as a backup fuel in power generation in the region, which is a crucial feature of the SSA industries. (Hafner, et al., 2018)

Figure 17 shows the share of sectors according to their oil consumption.

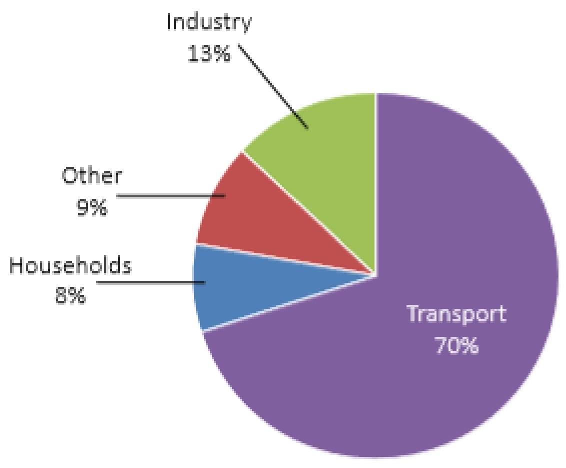


Figure 17: Share of oil consumption by sectors in SSA. (African Development Bank, 2017)

Among the SSA countries, Nigeria and Angola are the largest oil producer countries with 2,053 and 1,807 bbl./day respectively. Together they account for half of the production in the region. Moreover, oil is extracted in many SSA countries such as South Sudan and Chad which have high reserve-to-production ratios (R/P ratio). Nonetheless, due to the global oil price volatility and countries' political and security risks, the SSA tends to be less attractive for investments than other parts of the world. (Hafner, et al., 2018)

3.1.4 Natural gas

Natural gas is mainly comprised of methane and carbon dioxide. It is the cleanest among the fossil fuels, and emissions are nearly half of the coal. Besides, natural gas-powered plants take a shorter time to build and costs less than coal power plants. (African Development Bank, 2017)

Natural gas is the least demanded hydrocarbon in the SSA region at present time. This is mainly due to countries' prioritization of extraction and exports over developing the domestic market and infrastructures. More than 70% of the natural gas is produced predominantly by North African countries Algeria, Egypt, and Libya. Besides, Nigeria is the largest producer of natural gas in the SSA. (Hafner, et al., 2018)

Despite being cheaper to produce, transportation of natural gas requires complex systems which involved expensive infrastructure for compression or liquefaction and transport. Also, one-sixth of proven natural gas reserves is related to widespread gas-flaring – the practice of gas burning from oil extraction, which emits a large amount of carbon dioxide and wastes valuable energy. Particularly, Nigeria accounts for 60% of the gas flaring in SSA followed by Angola and Congo. (Manfred Hafner, et al., 2018)

3.2 Renewable energy technology

Renewable energy sources are theoretically considered to be limitless energy resources derived from non-fossil fuels such as solar, wind, geothermal, bioenergy, hydro, and tidal.

Most renewable sources can be used to produce power without combustion except for biomass. Renewable energy in modern terms implies the production and consumption of renewable energy as clean, sustainable, and efficient as possible.

Continental Africa is endowed with a vast and untapped renewable potential. As mentioned in section 2.2.4 the estimated power potentials are: solar 10,000 GW, wind 109GW, geothermal 15 GW (mainly located in The East Africa rift valley), and exploitable hydropower 350 GW. Also, bioenergy potential from forest surplus is estimated to be 520 GWh/year. (Hafner, et al., 2018)

In addition to hydropower, other renewables such as solar and wind are becoming more commercially viable on a large scale. Particularly, solar power becomes promising in terms of geographical distribution; in which it enables to harness everywhere in the region.

In the next section of the thesis, renewable energy resources and technologies in the SSA are discussed.

3.2.1 Solar

The SSA region receives a high number of sunshine hours annually. The region spans a large area crossing the equator and both tropics where there is high solar irradiation. The average solar radiation is evenly distributed in the region. Mainly, trough areas of the Sahel, the south tip of the continent, and the horn of Africa are sunny throughout the year. (Hafner, et al., 2018)

There are three main power generation options from solar energy in SSA: utility-size PV (conventional or concentrated photovoltaic), concentrated solar thermal power (CSP) and small-scale PV systems (which is suitable for off-grid generation). Apart from minimal required Global Horizontal Irradiance (GHI), PV power generation project's feasibility relays mainly in technology used and installation designs. However, in case of CSP, power plants specifically require higher Direct Normal Irradiance (DNI) with a clear sky (mainly in desert areas). (Hafner, et al., 2018)

Besides power generation, solar energy can be used for heating (for domestic and small-scale industrial activities) and cooling purpose. Notably, for rural communities, solar energy can be also used in different sectors such as irrigation, food processing and storage, water treatment, and the likes.

In SSA, solar energy capacity shows exponential growth in the last decades. (See figure 18) PV-powered stand-alone system and microgrids systems are becoming the cheapest way of producing electricity, especially in rural areas, mainly due to the falling price of PV system equipment. Ghana has the largest solar market among the SSA countries. However, unlike the Northern African countries and South Africa, the SSA lags in cumulative solar power capacity installed, due to lack of strong policy commitment and investment. (Hafner, et al., 2018)

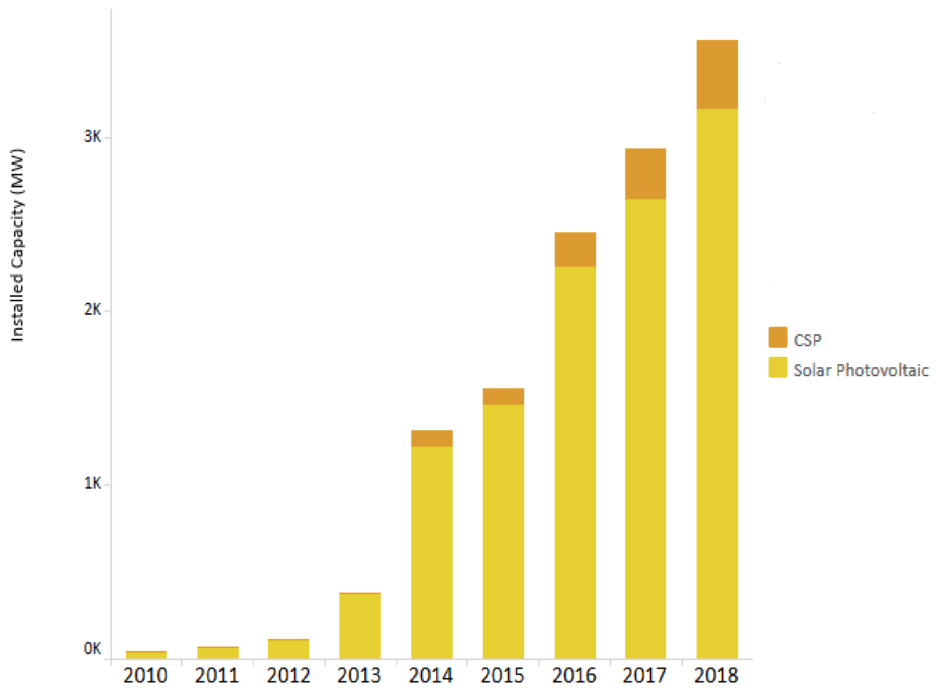


Figure 18: Solar PV and CSP installed capacity. (IRENA, 2018)

3.2.2 Wind

Wind potential varies across the SSA regions. This is mainly due to the difference in wind speed - which is majorly dependant on the pressure gradient and type of terrains. High wind speeds are more present in shorelines, deserts, and natural channels. High quality of winds is found in the rocky regions of Sahara and Sahel regions, coastal and mountain regions in South Africa, and also, part of East Africa mainly in the horn of Africa and the Great Rift Valley. (Hafner, et al., 2018)

Wind power capacity is also showing exponential growth in SSA in the last decade. (See figure 19) South Africa, Ethiopia, and Kenya create the biggest wind power markets in SSA. For instance, Kenya is building the largest wind farm in Africa, which is estimated to produce 310MW once completed. Also, Ethiopia had already built a120MW wind farm in recent years. So far, all the wind power plants installed are onshore since offshore solutions are more expensive. (Hafner, et al., 2018)

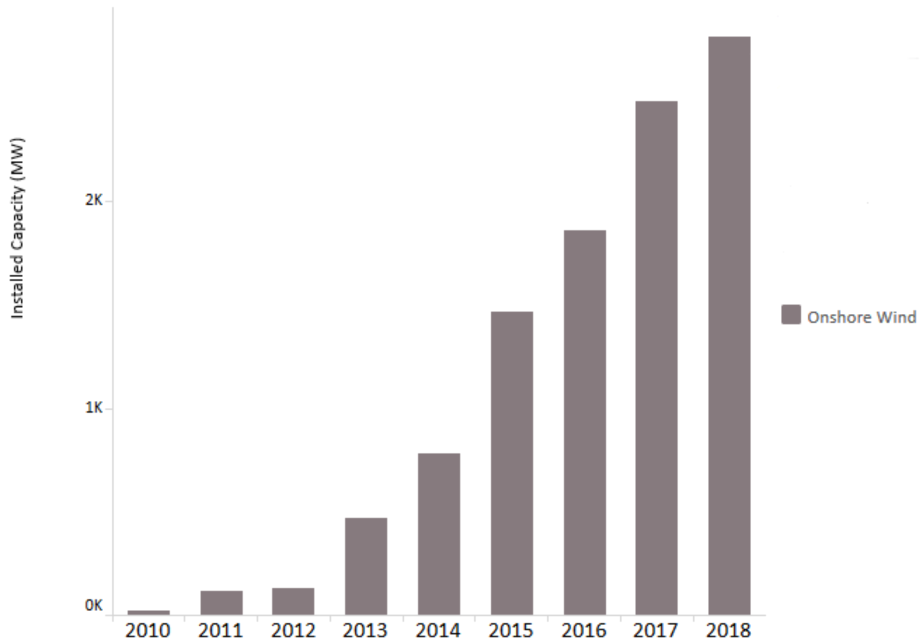


Figure 19: Onshore wind power installed. (IRENA, 2018)

3.2.3 Hydro

SSA is endowed with a considerable hydropower potential. Yet, only 10% of the hydro potential is currently tapped. It is also the most widely utilized renewable energy resource with the total installed capacity being more than ten times of solar or wind. Most of the hydro potential is located in central African countries, particularly, Congo, Democratic republic of Congo and Cameroon. However, only 3% of the of this potential is utilized in this region. Other regions also show notable potential, for instance, East Africa (Ethiopia), Southern Africa (Madagascar, Angola, Mozambique,) and West Africa (Guinea, Nigeria, Senegal). Also, the share of hydropower in generation mix is highly significant and can reach up to 99.9% in SSA countries such as Mozambique, Democratic Republic of Congo, and Zambia. (African Development Bank, 2017)

Hydropower is still the cheapest means of producing electricity in large scale compared to other renewables sources. Large hydropower can produce a significant amount of electricity which can cover a baseload in cities and industrial areas. Furthermore, apart from power generation, hydro dams are used for irrigation, and water supply.

However, the future of large-scale hydropower is facing challenges, and its future is rather uncertain due to social, environmental, and political pressures. The main future challenges for hydropower development are: 1) environmental and social impacts such as hydro-morphologic changes to river course and changes in habitat and land use in biodiversity-rich areas; 2) impact of climate change and rainfall variability in hydropower generation; 3) difficulties in acquiring funding for projects; and 4) trans-boundary political tensions among countries sharing water bodies, such as, Egypt and Ethiopia over the Nile River. (Hafner, et al., 2018)

Small hydropower plants can produce a stable amount of electricity for small industrial activities and local communities. Small hydro is one of the most straight forward systems to design and operate and has the lowest electricity generation price out of all the off-grid options. Yet, they also pose a notable environmental impact. In addition, hydropower is only suitable in areas where there is a nearby river. (Hafner, et al., 2018)

SSA has a huge potential for small hydropower. Particularly, Kenya, Ethiopia, Mozambique, Ghana, Nigeria, and Angola hold more than 800MW of generation capacity potential, respectively. However, less than 5% of that potential is exploited. Despite being a key element in local development, small hydropower infrastructures are often fallen out in several countries due to lack of maintenance, aging, and unaffordability of maintenance costs. (Hafner, et al., 2018)

3.2.4 Geothermal

Geothermal plants use a natural deep heat source from the underground to produce electricity. These underground heat sources are in areas (near volcanoes, geologic rifts, and hot springs) where they are easily accessible. Unlike solar and wind, which are known to be intermittent, geothermal power generation has advantages for being dispatchable generation. Also, geothermal has low variable costs; thus, it can be used as baseload power. (African Development Bank, 2017)

The SSA geothermal potential is located mainly in the East Africa Great Rift Valley, which runs through Djibouti form east till Mozambique. The total generation potential is estimated to be 15GW, and only 0.6% of the total is currently exploited. Nearly all the geothermal plants are in Kenya with 600MW installed capacity. Ethiopia is aiming to harness 1000MW from geothermal in the year 2021 whereas, others are less active in the process. Geothermal exploration requires extensive studies and drillings, making it economically risky and expensive, and the generation potential is only reviled after drilling has taken place. (Hafner, et al., 2018)

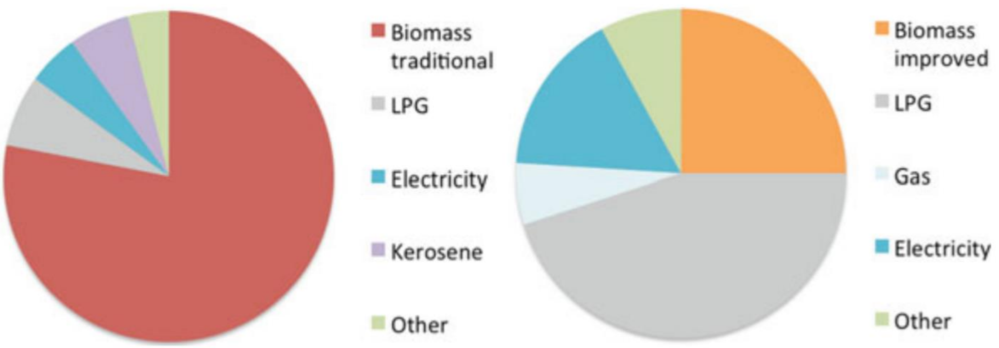
3.2.5 Bioenergy

Bioenergy is an energy from biomass. There are different ways of producing biomass. Biomass can be explicitly grown for energy use or produced as by-product in industries such as pulp and paper, agriculture, and food industries. Besides, biomass can be converted into solid (pellets, charcoal), liquid (biofuels) and gases (biogas) fuel forms before combustion.

The use of biomass in the SSA is mainly for cooking, heating, and lighting purposes. A large share of bioenergy potential in the region originates from agricultural waste and forest residues. This is predominantly practiced in an inefficient way of direct combustion; which is mainly caused by poverty, lack of alternatives, and geographical remoteness. Also, biomass appears to be cheap for low-income users in rural areas. This is also true for urban users; in which nearly 80% of the SSA's urban households use charcoal for cooking – in which its production processes are mostly inefficient. (Hafner, et al., 2018)

Moreover, the gradual increase in the use of forest wood for household use attributes to deforestation in the region. This further adds a challenge to the already existing threats caused by urbanization and agricultural land expansion.

Although a large share of cooking fuel in SSA is taken by traditional biomass, fossil fuels (LPG and kerosene) are expected to play a major role in cooking in the region in recent futures. (See figure20 a &b)



(a) (b)

Figure 20: Energy for cooking in SSA. (a) Present, and (b) future roles. (Hafner, et al., 2018)

There are different opportunities for improving bioenergy utilization in SSA. These can be: 1) improving the efficiency of cookstoves and highly efficient fuel; 2) promoting local innovations and local markets; 3) deploying modern bioenergy policies, and 4) building a sustainable value chain biomass production.

Moreover, modern bioenergy solutions such as treated biomass residues (e.g., pellet, biogas) and liquid biofuels (e.g., bioethanol, biodiesel) can further enhance the energy systems in the SSA. In particular, biofuel potential for the transport sector in the SSA can have a huge impact for the environment and climate change. According to IRENA 2050 scenario, liquid biofuel could meet the fuel demand of countries such as Ghana, Mozambique, Uganda, South Africa, and Nigeria. Besides, there is a huge potential for biogas in rural areas of SSA, which can significantly improve cooking for households. Today, biogas production and use are advancing across the region. However, unlike electrification, policies regarding clean cooking receive less attention. Thus, improvement in cooking technologies is still inefficient, mainly due to lack of innovations (e.g., in standalone solar and biogas cookers) that can be marketable for rural areas. For this reason, decade-old traditional cooking utensils are still used. (Hafner, et al., 2018)

Furthermore, the potential for municipal waste is huge and untapped in the SSA. Apart for the energy potential, municipal waste for energy can also solve a problem of waste disposal, which is also another major challenge in the region.

3.3 Chapter summary

The chapter reviews the current energy resource and technologies that are available in SSA. The SSA is gifted with both renewable and non-renewable resources. However, most of the resources are untapped and unevenly located.

Non-renewable resources, especially oil and gas, are expected to play a key role in future energy systems, especially in transport, agriculture (for fertilizer production), and cooking. Also, in the recent future, despite electric vehicles are likely become alternative means of transportation, heavy transport sectors such as cargo ships and airplanes are still unfeasible with current energy storage technologies; thus, making the sector to more rely on oil and gas.

The other role of fossil fuel is to produce fertilizers; which is mainly vital since the region´s soil productivity is decreasing steadily; despite their adverse effects in future production.

Furthermore, fossil fuel (mainly LPG and kerosene) are expected to play a significant role cooking in recent future, particularly in replacing fuelwoods; which are the leading cause of indoor pollution and deforestation in the region. Notably, improvements in cookstoves will have a significant impact in rural areas of the SSA where insufficient cookstoves are used.

Similarly, renewable energy sources are abundant in SSA. Also, renewable energy technologies are becoming vividly cheaper over the years. Thus, today, renewables can be a strategic asset for developing a country's energy system. Also, renewables are widely distributed, which can give an opportunity for faster-decentralized energy production development by local entrepreneurs.

Furthermore, variability of load occurrence due to intermittency can be forecasted and managed accordingly in both supply and demand-side using reliable energy-mix technologies, storage technologies, and pricing schemes.

Overall, improvements in electrification and clean cooking can be viable by bringing significant improvements to current trends and policy commitments.

4 BUSINESS MODELS FOR MICROGRIDS

4.1 Microgrid technology

A microgrid is a small version of a grid system. The most common definition for microgrids is made by the U.S. Department of Energy stating as: "*A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode.*" (Giraldez, et al., 2018).

Microgrid´s sizes and capacities can differ in relation to their applications. Based on their scales microgrids can be categorized range from mini, small, medium and large distributed generation technologies with capacities of 0.001–0.005 MW, 0.005–5 MW, 5–50 MW and 50–300 MW, respectively. (Salam, et al., 2008)Similarly, based on their application, microgrids can be categorized as: commercial, remote, military, campus, data centre, community, industrial, residential, critical service, and utility. (Microgrid Knowledge, 2018)

The microgrid concept began in the late 1990s by the U.S and Europe with the intention to integrate multiple distributed energy resources (DER's) in parallel with improving the reliability and resilience to external hazards while presenting itself as a small generator and satisfy the power demand. The aims of researches were to decrease the dependence on a vast communication system with a master control unit by shifting to peer-to-peer architecture; and to create a plug-and-play system which requires less redesigning of the distributed energy resources (DERs) and create flexibility in operation and maintenance. (Hirscha, et al., 2018)

Microgrids are becoming more popular due to their potential to achieve flexible, reliable and off-grid energy systems for different sectors. Figure 21 shows the current market share of microgrids estimate by (Navigant, 2016), which comprises remote areas, commercial, community, utilities, institution /campus, and military. Accordingly, much of the current market share primarily by remote areas followed by utility distribution and communities.

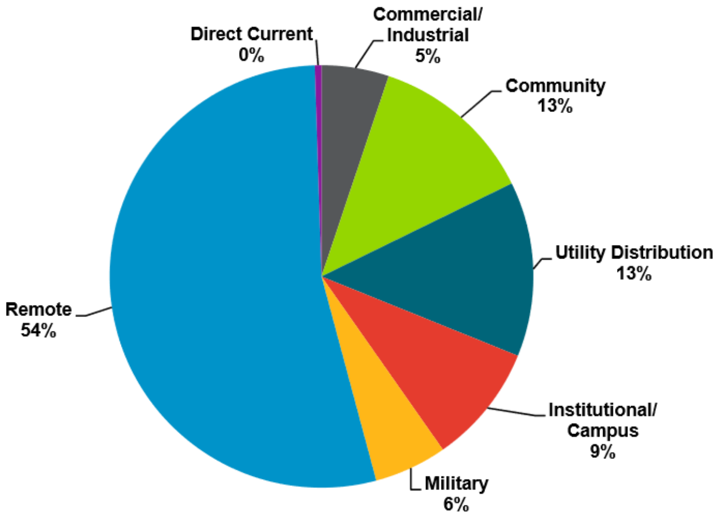


Figure 21: Total Microgrid Power Capacity Market Share. (Navigant, 2016)

Microgrids can be generally categorized as off-grid and grid-connected according to their connection mode. And, both models can be used for facilities or community based. (Borghese, et al., 2018)

- **Off-grid, facility microgrids**: these types of microgrids are predominantly found in remote areas far from the main grid. For instance, military bases, remote industrial sites, and isolated buildings like resorts. They integrate renewables largely as energy sources which is helpful in optimizing costs and the environment.
- **Off-grid, community microgrids**: these are found in rural or remote communities and islands. Similarly, they also integrate largely renewable resources in their energy mix.
- **Grid-connected utility microgrids**: these types of microgrids increase the reliability of energy systems which are already connected to the main grid. They are mainly used for institutes such as hospitals and business areas. It benefits in

saving costs, increasing the use of renewable energy, and improve reliability of the system.

- **Grid-connected, community microgrids**: these types of microgrids are applicable in areas like urban community, green villages, and the business campus of cites, where gird connection is already established. They are mainly used to optimize cost, increase the use of renewable sources, and ensure reliability.

The main drivers for microgrids development and deployment can be generalized into three main groups: energy security, economic benefit, and clean energy integration. Energy security implies the growing concern regarding power disruptions occurrences, which can be caused by severe weather, cascading outages, and, physical and cyber-attacks. Economic benefits imply infrastructure and fuel cost saving and added subsidiary services. And, clean energy integration means the importance of clean energy sources integration in the energy mix to address climate change. (Hirscha, et al., 2018)

Microgrids can be powered using different energy sources. These can be from renewable generation (i.e., solar PV, small-wind turbines, and micro-hydro), internal combustion engines (IC engine), microturbines, and fuel cells. Similarly, storage options are required since most microgrids generation options lack the inertia and the ability to respond to the imbalance of power demand. These options can be batteries, regenerative fuel cells, hydrogen from hydrolysis, and kinetic energy storage.

Inverters are another important part of microgrid systems. Power electronics interfaces (AC/DC or DC/AC/DC) using inverters are needed since most of the generation options are either DC power (such as solar PV) or AC power (microgrids, wind turbines). Also, the interface with the main grid can be either synchronous AC connection or asynchronous DC connection coupled with power convertors. (Hirscha, et al., 2018)

Regarding microgrid´s functionality and control, there are special requirements that are needed to be fulfilled for maximizing their technical and economic performance. These are: 1) to present as a single-self-control unit (for better frequency control); 2) provide power flow in accordance with the line rating; 3) regulating voltage and frequency during islanding; 4) maintain energy balance by dispatching resources; and 5) smooth islanding and safely reconnecting with the main grid. (Hirscha, et al., 2018)

Microgrids can also have the three-level hierarchical control system as of the main grid. The primary and secondary control levels are related to voltage and frequency control (which can be either centralized or decentralised manner) and a tertiary control systems that optimizes the economic and operations of the microgrids by managing storage systems, scheduling distributed generation and also managing electricity import and export between the microgrids and main grid. (Hirscha, et al., 2018)

4.1.1 Challenges for grid-connected microgrids

There are technical and non-technical challenges in grid-connected microgrid deployment. Technical challenges imply mainly challenges in relation to voltage and frequency control, islanding, and challenges in relation to safety measures. On the other hand, non-technical challenges arise from legal and regulatory issues, security concerns, and the likes.

Voltage and frequency control refer to adjusting the generated or consumed power (active and reactive power) in the predefined range. The unbalance conditions occur when demand and supply are not met. For microgrids voltage and frequency control challenges are raised when more than one distributed generation is used.

Islanding control approaches are vital in operating microgrid in autonomous mode. There are two approaches in autonomous operation: 1) the PQ inverter control (by setting active and reactive power ranges) and, 2) the voltage source inverters (which set the load with predefined values voltage and frequency). In addition, there are new approaches that use algorithms to detect islanding; thus, can act in matching loads with the distribution systems. (Hirscha, et al., 2018)

The legal issues that can impact microgrids can be seen in two main themes. These are: firstly, whether microgrids are considered as electrical distribution utilities thus they cannot be oversighted by the regulatory agencies, and secondly, if they do so are utilities, whether they can fit to the current electricity market and as a project finance viability in terms of cost of return of the investment and profitability. (Hirscha, et al., 2018)

Additionally, the interconnection policy regarding microgrids to connect to the main grid as distributed energy resources can raise legal uncertainties. In the case of both intentional and unintentional islanding cases, the standard protocols should cover the safety considerations, operation in both grid connection mode and islanding mode, reconnecting mode, and correction of voltage, frequency and phase angles. (Hirscha, et al., 2018)

4.1.2 Challenges for off-grid microgrids in rural areas

There are several challenging factors in microgrids deployment in rural areas, particularly in the SSA. These factors can be viewed in perspective of social, technical, economic, environmental, and policy (STEEP) frameworks. In a case study made by (Akinyele, et al., 2018), regarding the microgrid´s failure factor (MFFs) using the STEEP model, several challenges were pointed out and discussed.

Accordingly, the main MFFs in respect to the STEEP model were as follow:

- Social factors:
    1) lack of community engagement and interaction,
    2) lack of education especially in remote households,
    3) the question of ownership,
    4) installation of microgrid systems by unqualified practitioners,
    5) lack of preliminary survey in rural communities regarding their needs, preference, etc.,
    6) lack of awareness about renewable energy-based microgrids, and
    7) insecurity of microgrids due to vandalization and theft.
- Technical factor:
    1) poor design of the systems,

2) lack of standard for preventive/ corrective maintenance systems and international standard codes,
3) lack of local expertise for operating and maintenance,
4) The uses of sub-standard materials
5) poor project supervision, and
6) lack of monitoring system for operating and maintenance of microgrid systems.

- Economic factors:
  1) lack of government financial support,
  2) lack of accountability,
  3) lack of financial framework,
  4) lack of revenue generation (self-supporting regarding income form the community), and
  5) high cost of spare parts and components.
- Environmental factors:
  1) lack of comprehensive Energy Resources Assessment and Planned Environmental Assessment, and
  2) lack of environmental awareness.
- Policy factors:
  1) unproductive policy initiatives,
  2) lack of political willingness in promoting renewable microgrids,
  3) Ineffective quality control policies for products, and
  4) Ineffective framework that engage private sectors in renewable energy development in alliances such as Public-Private Partnership (PPPs)

4.2 Electrification approaches in rural areas

Conventionally, electrification is done by extending power lines from the main grid. As being distant from the urban areas, rural electrification requires extensive gird extensions. In many cases of the SSA, utilities find rural electrification as costly due to the high cost of power infrastructures. In addition, most rural area´s power demand is quite low, which also becomes another hinders factor for the electricity business. Besides, for developers, one major determining factor in the rural electrification is the payback period for their investment. In which, investing in the infrastructural projects becomes unviable due to low demands and delays in recurring payments. Furthermore, it should be noted that in a poor rural area of SSA, if the price is high for electricity, willingness-to-pay will decrease and, on the contrary, if the price is too low the vitality of the business is mired. (Hubble & Ustun, 2017)

Furthermore, microgrids are required to meet the demand of various customer groups, including the time of a day customer and weather conditions when the demand varies. These requirements can become more problematic in cases such as peak time for household; day-time demand for commercial enterprise and small-scale manufacturers; 24-hours load for public services (telecom towers, health services, banks and school etc). Hence, microgrid systems required a thorough approach and design for deployment, which also assess the demand development, thus it can align supply accordingly.

One way to approach rural customers is by comprising added values along with electrification. This innovative approach should encompass the activities and value chain of the local community. For instance, for a community that relies on agricultural activities, a microgrid developer should consider a means to add value to the agricultural products using electricity. This can be done, by placing fees for service along with the electricity tariff for the productive use facilities that developer establish along with providing electricity. Also, the developer can create geographical zones for business and productive uses which require higher service quality. This also can be done by centrally zoning the productive use near the power cells in the community. (Booth, et al., 2018)

4.3 Current microgrids business models

Microgrid business models are the basis for microgrid's financial and technical feasibility. The economic viability of the microgrid project requires to address both technical and commercial features. Technical viability relay on factors such as operation, components, and functionality. And, commercial viability relies on factors mainly in revenue, expense, and profit. (Navigant, 2016)

However, business model description for microgrids can be more complicated than the technical and commercial components. Figure 22 illustrates the various technologies and market actors in the microgrid business environment. And, this energy service ecosystem can either support or challenge the microgrid business.

Furthermore, there are also barriers in the deployment of microgrids from the outlook of utilities and customers. From a utility perspective; regulation, market competitiveness, and integration with other businesses can be a hindering factor in the deployment. And, form a customer's perspective, lack of standard financing, and loss of confidence due to the numerous vendors in the market are significant barriers for microgrids as a business. (Navigant, 2016)

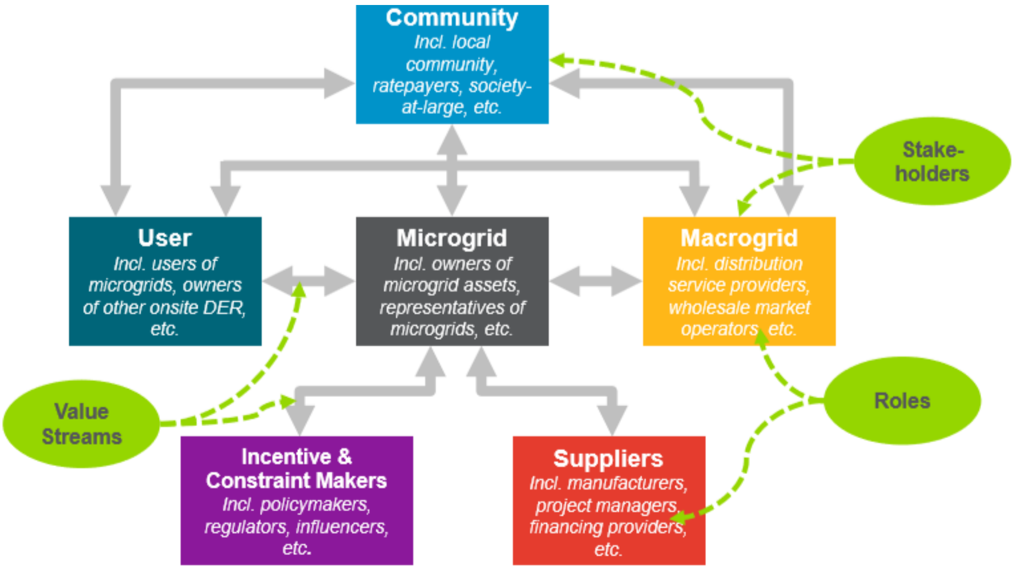


Figure 22: Microgrid commercial ecosystem mapping. (Navigant, 2016)

In the following section of the report, different business models for microgrids are discussed. These models encompass current models that are used in the energy business and as a financing vehicle for the development and deployment of microgrids. The business model's involvement in a project can be direct or indirect. This is to say that; the models can involve in fully delivering the energy systems or indirectly by providing auxiliary service which enhances the system reliance.

As can be seen in figure 23 of the Navigant report, current microgrids business models can be broadly categorized into five groups. These are: Energy-as-a-service (EaaS), Utility rate-base, Owner financing, government energy contracts, and other innovative business models that are involved directly or indirectly in microgrids deployment. (Navignt , 2017)

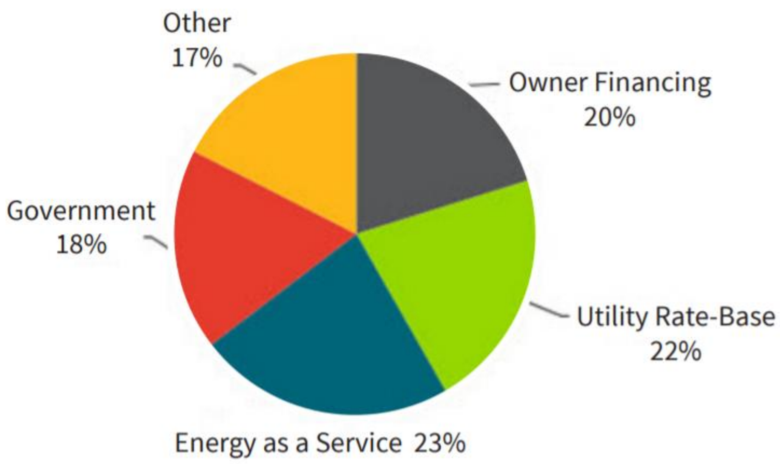


Figure 23: Current microgrids business models market share. (Navignt , 2017)

4.3.1 Energy-as-a-Service (EaaS)

Energy-as-a-Service (EaaS) is an emerging business model which arise from financial agreements and energy management services. (Eveline, 2017) EaaS manage customer's energy portfolio by applying new products, services, financing instruments, and technology solutions. The customer´s energy portfolio can comprise energy strategy, program management, energy supply, energy use, and asset management. (Navignt , 2017)

Also, the service provider gives assurances an end user's future energy costs by predicting energy use. i.e., if the end user's energy uses surpassed the expected consumption, the service provider pays the difference. On the other hand, the end user's electric consumption is less than the predicted service company profits from the difference. (Microgrid Knowledge, 2018)

Moreover, the service provider can give management solutions such as audits and baseline energy usage, and designing, and implements energy savings projects to guarantees the energy savings during the contract duration. And, these can be conducted using EaaS agreements; which incorporates a range of financial and contracting schemes such as Equipment Leases/Loans, Power Purchase Agreements (PPAs), Pay-As-You-Go (PAYG), Efficiency Savings Agreement Energy, Savings Performance Contracts, Shared Savings Agreements, and Energy Asset Concession Agreements. (Microgrid Knowledge, 2018)

The drivers for the use of EaaS by the end user are mainly to manage the fluctuating costs of electricity due to time-of-day rates, demand peaks and fossil fuel costs. And, for a service provider, it can be a means of creating energy supply management systems and having an incentive from the improved efficiency. (Microgrid Knowledge, 2018)

In the next section of the thesis, the most common EaaS financial and technological instruments are discussed.

4.3.1.1 Power Purchase Agreements (PPAs)

PPAs are a long-term contract for trading electricity between the power producer and buyer. The contract time often takes 20-25 years. The power provider takes ownership responsibilities, including operation and maintenance. The buyer/off-taker is responsible for buying the produced power form the supplier. In addition, a third-party financer can provide for capital for the project. A PPA secures the payment streams for Build-Own-Transfer (BOT) or project for Independent Power Plant (IPP). (Navigant, 2016)

One primary reason for the current use of PPA providers in the renewable energy market is the increased subsidies-cut for renewables in many countries - which led to renewable energy project developers to look for an agreement that generates an insured revenue streamline by using PPAs. For the buyer/off-taker, the need for getting power in less costly than the grid and the need for avoiding the volatility caused by deregulated market prices drive the demand for PPAs. Also, buyer/ off-taker can build an image and show commitments of their business on their use of sustainable green sources consumption directly. (De Meulemeester, 2018)

PPAs contract viability can be also depend on the regulation regarding grids fees and taxes, especially for offsite projects. In ideal cause, where grid fees and taxes are omitted for using PPA, the seller can sell above the market price, and the buyer pays less than the grid included cost. This is true in the case of Brazil offsite projects, where there are regulations for structural grid reduction cost when buying from offsite PPA projects. (De Meulemeester, 2018)

PPA agreement is different from other financing instruments; as such, it does not require upfront costs, and the power buyer pays for the produced power. In the case of other financial systems such as project finance and lease, the customer would be required to make a payment on the loan regardless of the system functionality. Moreover, for the ownership option, the PPA offers the buyer to buy the system with depreciating value after the contacts ended. However, the PPA does not have the production guarantee compared to the lease option. i.e., for instance, if a solar system is designed to 1000KWh and produces 500KWh in a particular month, the customer only pays to the solar company for the produced 500KWh. Whereas, in the case of leasing, the solar company owns the customer the deficit amount of power. (World Bank Group; PPPLRC, 2017)

4.3.1.2 Pay-As-You-Go (PAYG)

Pay-As-You-Go is a financial model which can be used to capture revenue stream from microgrids and solar home systems. PAYG model allows customers to digitally pay for power through instalment, which can help to resolve the challenge of capturing revenue streams for a sustainable business project in developing countries. The model shows promising results in infrastructure developments in rural electrification where the power demand is mainly for lighting and power household applicants. (Navigant, 2016)

The PAYG models are preferable for lower variable customer groups. Customers can pay directly for the service they use (often package of an appliance with the associated power supply) instead of regular and fixed payments. Thus, customers can make a smaller amount of payments which can give them control over their consumption and spending. Smart meters are a crucial technology for the flexible payment plans; especially for rural area microgrids to enable a sustainable market environment. (Scott & Charlie, 2016)

The PAYG system providers can be categorised in to three: 1) distributed energy service companies (DESCO) that provide service in exchange for the ongoing payments; 2) asset finance or microloan providers, which assists lease-to-own models, and 3) business-to-business (B2B) intermediaries; in which hardware and software support from global operations to the energy service located at the deployment sites. (Scott & Charlie, 2016)

The PAYG model´s effectiveness and adoption in reaching low-income customers is linked to mobile phone´s success in the last decade. Mobile phones flexible payments were made possible due to the relatively low user-specific costs.

Nonetheless, unlike the mobile phone, most off-grid energy solutions have high fixed costs – which cannot easily spread across the specific user base. For instance, for microgrids, customers require small infrastructures such as transformers, power lines, and internal wirings for individual or small groups of households. The PAYG model for mobile phone gives maximum control over the amount of payment and timing i.e., a customer buys a different amount of credit for the specified amount and uses at any given time. Thereby, it is difficult to stress that the PAYG model for mobile phones is fully replicated by the energy providers, particularly customer´s payment flexibility. (The World Bank Groups; ESMAP, 2015)

According to the case studies conducted by the (The World Bank Groups; ESMAP, 2015) regarding the payment flexibility in microgrids and solar home systems providers using PAYG model, there were different results in how PAYG is seen by the different vendors. In some cases (mainly micro and mini grids), there was full flexibility regarding when and how many customers can pay, while most restrict the amount and timing of payments. In other cases, weekly or monthly payments are required from customers, and in some cases total amounts of payments are required over a predetermined period. Besides, some companies restrict the amount of energy a customer can buy within a particular period.

In addition, from the study results, only a few companies can offer payment plans which give the full control over the size and timing of their expenditures. Nonetheless, almost all the providers offer more payment flexibility than traditional utilities, and customers may not require the full flexibility.

In addition, regarding ownership of the energy systems, the studied PAYG business models can be divided into two: 1) the lease-to-own model, which allows ownership of the systems passed to the customer one the agreed prices are payed, and 2) a micro-utility model, in which ownership of the equipment holds by the system provider while providing electricity. (The World Bank Groups; ESMAP, 2015)

There are other methods of payments for PAYG model apart from digital payment systems such as cash payments, scratch cards, and mobile money services. Nonetheless, remote digital payment systems provide much efficiency, profitability, and accountability of the system. Also, deploying electronic payments significantly enhances in providing transparency, affordability, and scalability of the system for both the customers and providers since, electronic payments enable to account for accurate revenue streams in real-time, provide data in repayment rates, and enhance customer relations. (USAID, 2018)

4.3.1.3 Hardware component sales and software as a service

Control platforms (comprising software and controlling devices) are essential for successful microgrid business model implementation.

Pure hardware component sales are a direct involvement of grid components supply for microgrids. For many vendors in the related energy business, microgrids are viewed as another business streamline for their product. In companies involved in supplying products such as smart meters, distributed generation, and energy storages creates partnerships to integrate with a different aspect of microgrids. Moreover, some companies include software controls sales in addition to supplying hardware for microgrids. (Navigant, 2016)

Similarly, Software-as-a-service mainly focuses on software needed for creating networks in microgrids. Although hardware sales capture a larger portion of the revenue, the functional network is the major challenging tasks. Thus, the need for integrating-software to optimize and control microgrids networks are vial.

4.3.1.4 Operation & maintenance contracts

The operations and maintenance business models are contractual agreement to maintain the overall performance of a microgrid. These contracts are mostly highly needed for rural microgrids deployment where skilled labour for operations and maintenance is rare. But for microgrids that are developed in campus areas, the operation and maintenance most likely are going to be carried out in-house. Operations and maintenance contracts are expected to be more popular alongside the increasing deployment of microgrids. Diesel generators maintenance is also included since most microgrids are equipped with backup power to stabilize the microgrid system. (Navigant, 2016)

4.3.2 Utility rate-base

The utility rate-base is the gross value of a utility's asset minus accumulated depreciation on which the utility earns a determined rate of return – which is provided by regulatory agencies. It used by regulatory agencies in order to protect the interests of electric utility customers. It also helps utilities in determining earnings which are critical for financial robustness that enables utilities to attract investors and achieve a better credit rating. (Jamison, 2018)

The regulatory agency grants exclusive right to the utility to sell electricity while determining how much to invest and it can charge, and what its profit margin can be – which is also known as regulatory compact. The agencies use rate case to determine the utility's total revenue requirement – that represents the amount of money needed to collect to cover the costs while making a reasonable profit. (Jamison, 2018)

The profitability is driven by the allowed rate of return according to the regulatory agency rules; and, the expenses pass through to the customers. The formula for the total revenue requirement is given as follow:

$$Total\ Revenue\ Requirement\ =\ Rate\ Base\ \times\ Allowed\ Rate\ of\ Return\ +\ Expenses \qquad (1)$$

However, according to (Coley, 2015), the rate of return regulations is criticized in demotivating utilities to operate in efficient ways, that is, by setting the rate of returns, utilities are incentivized to make additional investments (in order to increase their rate base) and makes it difficult to check whether the expenses are simply passed to the customers.

On the other hand, setting the rate of return benefits to utilities by enabling them to raise enough capital, which can help to improve their infrastructure and provide reliable services to customers. Subsequently, this gives investors for the low risk in investment which can also imply that utilities are required to secure a lower cost of capital relative to other businesses. (Coley, 2015)

In case the of microgrids, utilities are enabled to place the cost of designing, building, and maintaining the systems into rate base. However, it is less common that utilities participate in microgrids projects other than public power entities in rural areas off-grid markets such as community summer camps. Even so, utility-owned substations and distribution automation can be easily transformed to microgrids in the coming future. Thus, the primary aim of the microgrids would be into support the reliability and resilience of the utility by integrating the Distribution Energy Resource (DER). (Navigant, 2016)

4.3.3 Owner Financing

Owner financing business model involves ownership and asset management by facility owners and places all the financial risks in the owner (Borghese, et al., 2018) It is mainly used for grid-tied microgrids and applicable on already-existing power infrastructure. The facility owner occasionally involves financing the early-stage R&D and pilot projects. In many cases, the facility owners are seeking to diversify their generation portfolio with green energy on an existing non-renewable resource-based generation. And in other cases, it is to enhance the overall efficiency through new technology by adding microgrids to the energy mix.

Also, for the newly added technology in the resource mix, it requires sophisticated integration, in which the additional upgrade cost is covered by the owner. Thus, the operation cost will be reduced due to the increased efficiency and reliability - which also means gaining economic benefits for the owner. Furthermore, as the microgrid becomes more complex, the integration needed for renewables and energy storages are outsourced to private developers. (Navigant, 2016)

4.3.4 Government energy service contracts

This type of contract-based services models for microgrids were frequently deployed by the U.S Department of Defence (DOD), which is also primarily used to conduct business with other firms. There are two approaches for contracting: energy-saving performance contract (ESPCs) and the utility energy service contract (UESC). (Navigant, 2016)

Energy saving performance contracts (ESPCs) are made between energy service companies (ESCO) and a federal agency. Within, facility upgrading is rewarded for improving efficiencies through time, and this requires to be quantified within the time span. The ESCO conducts a comprehensive energy audit and potential improvements for energy-saving prior to the partnership. The ESCO design and constructs a project that meets the agency's needs and guarantees the cost-saving form the energy improvement will pay for the project work over the terms of the contract. At the end of the contract, all cost of savings accrues to the agency. (Energy.Org, 2018)

Utility energy service contracts (UESC) are used to procure electricity services from local utilities and energy efficiency projects. It involves local utility in energy management and overall economic value creation. These contracts can be:

- *Areawide contracts*: in which implies indefinite-delivery and indefinite-quantity in the service territory to the public utility service. Within the contract, the general terms and conditions are set to describe the technical specification for the service or project,
- *Model agreements*: in which a model utility service agreement serves as a template to establish master agreements.
- *Basic ordering agreements (BOAs)*: which are not contracts, rather contracting vehicles. They create general terms and conditions for future contracts and can be created by any agency with their utility and model agreements.

4.3.5 Innovative microgrid business models

There are also different emerging innovative microgrid business model approaches which some of are currently in conceptual and pilot level of developments. These models are driven mainly to further improve the microgrid deployment in terms of construction periods, cost recovery structures, and integrating other services to add values.

In the next section of the thesis, some of the business model discussed.

4.3.5.1 Design, Build, Operate, Own and Maintain (DBOOM)

DBOOM is a conceptual business model, which is based on delivering a microgrid system in a successive process of design, deployment, and operation. The model is already used by other sectors such as construction, energy systems, water utilities where a single contractor or entity is responsible for the designing, constructing the facility, and doing the operation and maintenance prior to commissioning. DBOOM also includes integrating software systems with production processes and service systems.

The advantage of this model is suitable for one-stop shopping customer groups that intend to avoid several vendors for microgrid systems. On the contrary, the current trend in microgrid business tends to be established based on different vendors for components and software. Thus, the model is currently more suitable for greenfield rather than brownfield projects. (Navigant, 2016)

4.3.5.2 The anchor/ ABC Load Model

The ABC load business model divides customers according to power consumption and financial stability. Accordingly, developers firstly target potential client as an *anchor* (Which is refers to as “A”) which have the potential to generate revenue in a stable means. These are typically telecommunication towers, mid-sized industries, and agricultural processing activities. Next, the rest of consumption trickle-down to customers with lower consumption and less reliable in their recurring payments. These are a small *business* and *community* customers (Which are referred to as “B” and “C”, respectively). (Booth, et al., 2018)

The anchor business model can also be modified according to the local community´s financial situations. This is true, especially for SSA´s rural areas developer that might lack larger consumers as an anchor client. Thus, small business and productive-use customers can be anchors for local community energy access. (Booth, et al., 2018)

4.3.5.3 The fusion grid models

The fusion grid (FG) model is designed to entwine power supply and storage systems with a mobile network solution and digital service as a single package for rural microgrids. The FG intention is to provide connectivity in addition to the electrification; thus, the digital divide narrows and consequently, a digital marketplace and service can prompt socio-economic activities in rural areas. The FG comprises Solar PV, which is backed by battery energy storage systems BESS and 4G portable mobile network base station (BTS). (Vandadzia, et al., 2018)

4.4 Chapter summary

Microgrids can improve the reliability and efficiency of power systems for businesses, communities, and organizations. They are becoming one of the drivers in affordable and flexible energy systems. Due to the advancement in energy technologies, and financing tools in recent years, microgrids are considered as DERs rather than tools used to provide power during blackouts.

Business models for microgrids are vital to providing the financial and technical viability of a microgrid. A business model outlines how a project meets the strategic objectives, which requires planning, implementing, and executing. Thus, in the case of microgrids different elements such as value preposition, customer groups, finance, energy resources, and revenue streams are required.

Among the above-mentioned business model, EaaS can be considered as a promising business model for rural SSA regions. Incorporating EaaS business model for microgrids benefit different service applications, particularly, remote areas. EaaS umbrellas different financial and technological solutions that enable power utilities, developers, and the customer benefit from microgrids. Similarly, DBOOM shows promising business model for microgrids in the future by one-stop-shopping of the system and improve the rate of deployment and reduce construction times.

5 BUSINESS MODEL EVALUATION

In this chapter of the thesis, different issues regarding the business viability of microgrids in rural communities are discussed. Also, based on the socio-economic status of customer groups, business models were proposed.

5.1 System configurations and distribution networks

System configuration is one of the major technical considerations in microgrid deployment. Technically, the microgrid's design layout depends on the availability of sources and conversion technology. Microgrids can be powered by different renewable sources and can also be backed by standby diesel generators and battery storage systems. Furthermore, system reliability and back-ups can be improved using integrating sources such as solar-biomass and solar-hydro combinations.

The distribution networks for microgrids can be designed either with AC or DC systems. It is also technically possible to combine AC and DC systems in microgrid systems. The selection of the systems can be influenced by generation source-type, costs, type of appliances used, condition for interconnection, and application type. DC systems are more convenient for low-power household applications such as lightning, mobile phone chargers, radio, TV, etc. However, DC systems are geographically limited and unsuitable to connection with the main grid without inverter. On the other hand, the AC system can handle high-power applications and more suitable to create a connection with the main grid.

Furthermore, according to (Reber, et al., 2018) - which developed hourly electrical load profiles for SSA's rural households and business/community entities using the information gathered from the literature review - the following load profiles were developed:

- For residential load, which is assumed to be made up of 100 households, each home uses 136 kWh/year. Theses comprises low and high wattages devices such as LED lighting (9 watts/unit), Mobile phone chargers (8 watts/unit), Radios (15 watts/unit), Televisions (150 watts/unit), DVD players (35 watts/unit), Clothes irons (1000 watts/unit), Refrigerators (average of 50 watts/unit with 50% on/off cycle)

- For business/community load, which is made up of two small shops typically run out of houses and one school the load is assumed to be 1,214 kWh/year for a small shop and 1,961 kWh/year for a school.

It should be noted that the above analysis assumed that there would be no variation throughout the weeks and the seasons.

Furthermore, (Prinsloo, et al., 2016) assess computer models in selected SSA´s rural regions in which steadily growing trends were observed in average daily power loads. Similarly, (Booth, et al., 2018) presents productive use load profiles of different microgrid customers in Tanzania´s rural villages. Accordingly, bars, phone charging kiosks, and guesthouses consumption sharply increase towards the evening, while residents, shops, beauty salons, and churches show a steady consumption trend throughout the days. (See figure26)

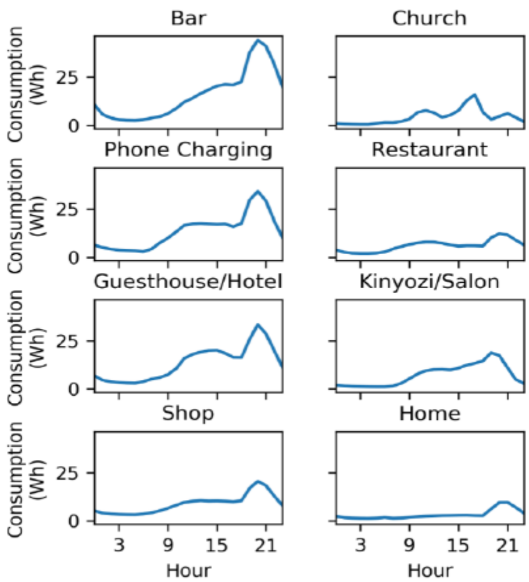


Figure 24: Productive use load profiles (Rural area in Tanzania) (Booth, et al., 2018)

5.2 Customer relations

The customer agreement is the basis of a project life cycle. (Eric, et al., 2018) A clear contractual agreement is needed to achieve the Quality Assurance Framework (QAF) – which is essential to establish a reliable and affordable micro-girds deployment. According to the National Renewable Energy Laboratory (NREL) – which conduct studies to address the QAF in the SSA microgrid – emphasises that a strong customer-developer relation helps to scale and expand electrification.

One of the key aspects of microgrid business for rural communities is building trust. This is essential since most of the rural parts of SSA are new for electrification experience. And on the contrary, for customers near the urban area – that are already tied with the grid – the price per KWh to deliver a similar amount of energy from microgrids can be found more expensive. (Eric, et al., 2018)

Furthermore, customer agreement becomes a key tool in the future scaling of the business from pilot to small scale and, later to large scale deployment. This is to say that, when the number of customers increases, the payment systems, and complaint reporting infrastructures becomes overwhelmingly challenging to handle. Thus, effective customer agreement becomes essential to restructure the organizational system in further growth of the developer. (Eric, et al., 2018)

5.3 Customer segment

Customer segmentation is essential for microgrid´s business viability. It helps the business to target and market each group efficiently and adequately. For this thesis, customer groups were made based on income-level, locations, and service application/occupation of the customer.

5.3.1 Income-Level

Customers income levels in SSA can be categorized into four groups: destitute, poor, lower-middle-income, and upper-middle-income. The income level encompasses customers of residential, business, agriculture, productive-use, and public services.

- Destitute customer groups are characterized by extreme deprivation lacking basic needs and have low MPI. For this group, access to basic electric is unaffordable and also has very low willingness-to-pay.
- Poor-customer groups are characterized by having low MPI. This group suffers either from the low power supply from the grid or not being connected to the grid at all. Also, their willingness-to-pay is low.
- Lower-middle income customer groups are considered to have basic needs and high willingness-to-pay. Nonetheless, they suffer from an inadequate power supply either being connected to the main grid or not.
- Upper-middle income customer groups are considered to be well-off and have access to better infrastructure. However, they suffer from lacks a constant power supply from the main grid despite having high willingness-to-pay.

5.3.2 Locations

Location is considered as another characteristic feature for classifications microgrids customers. For this thesis, locations are categorized into rural and semi-urban areas.

- Rural regions are characterized by being far from major cities or towns and also from the main grid. These imply small villages and communities that dispersed in the countryside.
- Semi-urban areas are those that are near the big cities (which mostly have better infrastructure and economic activities). These places can be small towns and suburbs which are intertwined with the economic and social activities of the nearby city.

5.3.3 Service applications

Service applications are another feature to categorize customers. These are households, agricultural activities, commerce, productive-uses, social institutions, and government & municipal function.

- Household uses implies lightning, electronic appliance, refrigeration, fan, etc.
- Agricultural activities imply mainly, milling irrigation and dairy process. Some agricultural activities such as irrigation pumps and small dairy processing machinery and refrigeration require electrical power.
- Commerce implies small businesses and retailers. These can be small shops, barbershops, café & restaurants, and the likes.
- Productive uses are small manufacturing enterprises that require more power than commercial businesses and households. These are milling, welding, carpentry, and similar technical application.

5.4 Ownership and operational role

Ownerships and operational roles after the commissioning of a microgrid project can be structured in three major ways. These are: 1) developer owned and operated model, 2) Government-owned and operated model, and 3) Public-Private Partnership (PPP).

In a developer owned and operated model, the developer becomes the owner and system operator of the microgrid. Also, private investor involvement in financing and ownership is possible while the developer maintains operational roles. In government-owned and operated model microgrid development projects are conducted by national utility agencies in electrification programs. In this model, the utility took the operation & maintenance responsibility.

Furthermore, both government and private developers can be joined into a public-private-partnership (PPP). In this case, both the government and the private sector mostly benefit from the project with special agreements. For instance, concessional funding can be provided by the government, and the developer can provide services below the market value. (Lockhart, et al., 2018)

5.5 Sources of financial support

Source of financial support for microgrids business development can be raised for a government, donor, private investors, and the community. The support can be financial or philanthropic. Communities and investors can benefit from the revenue stream generated, while government/ donor groups can achieve their goal to increase power accessibility.

Community involvement in one way of raising capital for microgrids projects. On the other hand, private investors are more suitable for businesses that have the potential of creating a revenue stream but lacks initial capital. These businesses are mostly located in a semi-urban area that lacks electricity continuously to conduct business and day-to-day activities.

Government support/donor's assistance and subsidies are needed for communities that are predominantly poor and destitute. This support or grants can be available in a different form: front capital, low-interest loans, and external aid. In these cases, electrification is needed for basic lighting and low-voltage applications which require low-level technology for system configuration and distribution.

5.6 Financial mechanisms

Financing a microgrid project by developers or through Public-Private-Partnerships (PPPs) can be done through different forms. The most common financial backings methods are subsidies and grants, concessional loans, and loan guarantee.

5.6.1 Subsides and grants

Subsidies and grants are one of the most common mechanisms of financing microgrid projects by private developers and PPPs. These mechanisms provide to cover the cost partly and mostly available after the project is commissioned. Thus, developers still cover the initial upfront capital for the project. Some of the common forms applying these mechanisms are: 1) up-front subsides provided to developers for each household connected; 2) annual subsides provided according to the quantity of energy produced; 3) subsidies made to buy-downs developer’s debt; and 4) cash subsidies or grants to developers for specified criteria. (Lockhart, et al., 2018)

In the SSA, many of the microgrid donor programs use result-based financing (RBF) to ensure subsidies are appropriately aligned. RBF is an instrument used to verify the agreed-upon result has been delivered; thus, payment can be made. Also, RBF connects grants or subsidies to new recipients that meet the criteria such as level of standards that aligned with the national electrification plans. Moreover, RBF is more effective for developers with project proposals that can be easy to verify due to their simplified designs and applications. The RBF mechanism, however, was reported by some developers in not distributing funds efficiently, meaning, they were too slow, amounts were less than expected or changing factors. (Lockhart, et al., 2018)

5.6.2 Concessional loans

Concessional loans are loans that are provided by the government or donor by partly filling the funding gap which commercial lenders unwilling to lend to microgrids developers. This unwillingness is mainly caused by a lack of knowledge about microgrids and risk-averse towards long-term unproven business models. As a result, commercial lenders tend to charge a higher interest rate and require significant collateral requirements. Also, in some cases, developers lack in determining lender types and ways of approaching; thus, they can effectively present their business model. Concessional loans offer more attractive terms such as longer tenor, and interests below-market rates (Lockhart, et al., 2018)

5.6.3 Loan guarantees

A government or donor can provide a loan guarantees for microgrids developer; thus, lender can be guaranteed if the loan defaults. As a result, the lender potentially reduces the risk and can also provide more attractive loan terms. Also, third-party organizations can provide loan guarantees. Loan guarantees can range from standard guarantees, which covers full and timely repayments for a predetermined amount to a risky guarantee, which covers for loan defaults for a specified risk. (Lockhart, et al., 2018)

Nonetheless, there were only a few individual loan guarantees for microgrids so far. This is because individual microgrids have relatively small size transactions, and the risk aversion of lenders, thereby causing the expensive cost for setting up the guarantees. Hence, a loan portfolio guarantee; where several multiple borrowers are bundled in a sector for a specifically defined parameter; is possibly a better instrument for microgrids developers. (Lockhart, et al., 2018)

5.7 Cost structures

Microgrids business has both fixed and variable costs. Fixed cost implies the costs that are incurred independent of the business activity. For microgrids, fixed costs include project development, plant equipment (inverters, storage systems, distribution network, generation plants, etc.), acquired debt with interest, taxes for infrastructure. Moreover, there are costs that are taken seemingly as trivial but costing even when the power unit is not operational. These are management costs, overhead, and transaction costs (i.e., administration costs, coordination, social and technical problems resolving, accounting, reporting to stockholders, etc.). (Prasad, 2016)

Variable costs are costs that vary according to the project’s business activities. These majorly include operation & maintenance costs, and fuel costs. Operational costs include expenditures to run the plants, billing customers, and services costs (security and cleaning). Similarly, maintenance costs include plants that are dependent on runtimes and load-dependent losses (inverters, transformers, and storage devices). Also, other costs regarding energy-taxes and fees can be considered to be variable depending on the plant's outputs. Moreover, customer relation costs, including resolving customer complaints and community-based training programs. (Prasad, 2016)

5.8 Pricing mechanisms and cost recovery

The costs of microgrids projects are required to be covered through different revenue streams for sustainable feasibility. These sources of revenue are mainly from electricity sales, connection fees, and added services. Also, the government or donner can be included as a revenue source if it is obtainable.

Tariffs for electricity are calculated in taking consideration of costs such as capital costs, operational costs, cost of finance, and return of investment. It is essential to underpin that financial viability and willingness-to-pay are in balance. This is especially true for rural electrification, where communities are highly price sensitive.

There are two ways of categorizing electricity tariffs in generic: energy tariffs and power tariffs.

Energy tariffs are based on a customer´s actual electricity consumption. These tariff systems can provide accuracy on measurement and found to be flexible for different customer groups. Payment mechanisms can be either pre-payed or post-paid. Pre-paid tariffs can be used by customers advance payment for the service and a consume certain amount of electricity depending on the available charged amount of money. Post-payed methods are based on meter readings of customer's consumption. This tariff system is adventurous for start-up small scale business, where their recurring revenue is mainly after the actual electric consumptions. However, post-paid tariff systems require metering devices and exposed to payment defaults from customers. (Prasad, 2016)

Energy tariff systems can become difficult for balancing the supply-demand calculation in cases where high fluctuation occurs. This is especially true for higher fixed costs solar PV-based microgrids projects when low power demand and fluctuations occurs. On the other hand, energy- tariffs are more suitable for projects with low initial costs and higher operating cost such as biomass-based systems. (Prasad, 2016)

There are different energy tariff models that are offered by microgrid developers. These models are mainly designed for a microgrid business revenues generate enough cash flow to stay afloat as a business. Also, microgrids developers offer customers trade-offs to enable them to compete for tariff offers from other power options such as diesel and electric motors. This is true particularly for productive use customers where diesel generators can provide a similar amount of power demand with less energy tariff while having comparable capital costs. (Booth, et al., 2018)

Some of these energy tariff models are: 1) standard tariffs, which charges fixed rate per KWh for consumption; 2) day/night tariffs, which are designed to differentiate daytime tariffs; 3) flat standing or connection charges, which charges for accessing electricity; and 4) prepayments, which customers pay before consumption using different payment methods. (Booth, et al., 2018)

Power tariffs are based on the determination of maximum power demand by a consumer on a Watt basis. Thus, initial anticipation of power consumption is required. For this tariff system to work, customers are initially provided with household appliances as a package and regulating instruments such as timer and load-limiters to regulate household consumptions. Then, accordingly, to the power consumption of the packaged appliances tariffs are determined and collected within intervals. (Prasad, 2016)

There are numerous advantages of using power tariffs: less capital and operation intensive; easy to control and limit high consumption; avoid overloading; and increase accessibility. Besides, the power tariff model can bring certainty in capturing revenue by incentivise users to decrease peak-power due to its regulatory character of consumption. Thereby, power-base tariffs are more suitable for projects such as solar PV microgrid with a higher initial fixed cost. (Prasad, 2016)

However, power tariff models can also hinder high capacity usage and offer less consumption flexibility.

To avoid the limitations caused by both tariff systems, it is also possible to combine both and acquire more flexibly and limit financial risks. Both tariff systems can also be further design according to consumer groups, consumption level (stepped-progressive and stepped-regressive tariffs), time of the day, and surplus energy.

Stepped-progressive tariffs imply the gradual increase of price in relation to uptakes. This helps to discourage higher consumption in places where there is higher willingness-to-pay than the actual available power. On the contrary, stepped-regressive implies lower prices for higher power consumption. In this case, higher power consumers are encouraged to uptake; thus, commercial viability is gained for the microgrid business.

It is also essential to underpin the essence of time of day for designing variable tariffs. Consumer demand varies at a different time of the day. Thus, tariffs can be designed to ease customer´s usage. Also, this is helpful for load scheduling of commercial and industrial consumers.

Besides, designing tariff systems can also be helpful in managing surpluses power. This can be done by using smart metering systems that optimize surpluses power and induce usage when it is available or dissuade when it is unavailable.

5.9 Proposed ownership share and business model

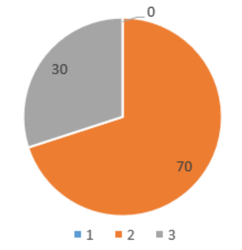
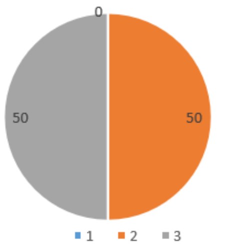
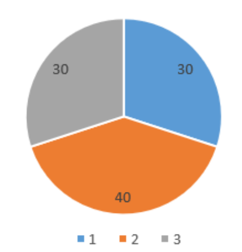
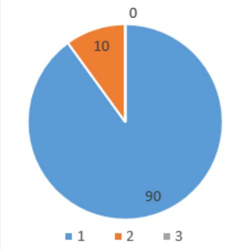
A microgrids business model can be crafted and modified according to the customer groups and service applications. Microgrids projects should also consider means of cost recovery so that it becomes self-sufficient and further consider in creating new businesses. Similarly, ownership share of a microgrid project and operational roles are significant for its viability.

In this section of the thesis, suggested ownership share, and business models for customer groups are discussed.

5.9.1 Ownership share

The ownership share by the income-levels suggestions are stated in table 2 below. The table comprises Community, Third-party (government, donor), and Investors as a stakeholder and the ownership share for different customer groups. The financial mechanism for the project viability can be ensured through the different financial backing systems.

Table 2: Proposed Ownership share Vs. income-based customer segment.

Customer segment	Upper- middle	Lower-middle	Poor	Distitute
Ownership Share (%)				

Note: 1= Third-party (government, donor), 2 = Community. and 3=Investors

Table 2 is designed by taking consideration of the involvement needed to deploy a microgrid fully. As can be seen from the suggested table, community ownership decreases from upper-middle-income customer groups to destitute. Due to the uptake level and profitability, poor customer segments require third-party involvement, unlike lower and middle-income customers. It can also be seen, lower-middle customers are more economically active. Hence, it is suggested that the involvement of investors in the ownership share further support to expand the grid and increase the quality of the power system. Moreover, for destitute income customers, involvement in the microgrids deployment can be with labour-intensive works. Thus, labour-intensive works of the projects can be covered by the community.

However, since a community usually comprises different customer groups, it is also essential to consider the majority of customer groups as a basis of the business model. For instance, in community predominantly lower-middle income customers, the business model should be based on their power demand and willingness-to-pay. This also can stimulate the economic activity in the community and help to uplift poor and destitute minority groups through job creation.

5.9.2 Business models for customer groups

Based on the above customer income-level segmentation, suitable business models, and tariff systems are suggested in table 3. Also, to decrease downtimes of the energy systems due to malfunctions, operational, and maintenance contracts were suggested alongside with business models.

Table 3: Household application business model matrix

Customer group	**Suggested business models /Technology**	**Method for capturing revenue streamline**	**Operation and maintenance**
Upper-middle	Owner Financing	Stepped progressive tariff	Operation and maintenance contracts
Lower-middle	Owner financing or PPA	Stepped regressive tariffs	Operation and maintenance contracts
poor	PAYG / DC microgrid	Energy tariff (Pre-payed)	Operation and maintenance contracts
Destitute	PAYG/Solar home system	Power tariff	In-house

Accordingly, owners financing is found to be best-fit for upper-middle-income customers. This is mainly due to customers being grid-tied and suffer from the inconstant power supply while having high willing-to-pay. Moreover, the service application´s power demand is higher and requires consistency. Thus, adding microgrids on the energy systems can increase the consistency and quality of power supply with large ownership share by the customer group. Furthermore, the contracts can be granted to maintain and operate the microgrids to enhance power quality and consistency. Regarding cost recovery, a stepped-progressive tariff system can be a suitable method of revenue capturing due to the customer group's higher willingness-to-pay. Thereby, the accessibility of power is achieved without impacting supply.

Similarly, the owner finance model with higher involvement of external investors is found to be more suitable for the lower-middle-income customer group. Also, having higher willingness-to-pay can prompt external investments to enhance the overall system quality. Besides, PPAs agreement can be used by microgrid providers; thus, the initial investment can be avoided. Moreover, the stepped-regressive tariff system is suggested to induce power consumption and continue the revenue stream.

For poor customer groups, the PAYG business model is seen as more suitable. In particular, the PAYG with lease-to-own means can assist to own and operate the microgrid of recurring payments to the provider. Also, DC microgrids can be preferable for its modularity and low-voltage applications using DC-based solar PV. The DC-based system can avoid using inverters to convert AC to DC as such in wind power plants which can reduce the component cost for the system. Also, maintenance contracts can be outsourced in rural areas to maintain the microgrid systems.

For destitute customer groups, the PAYG solar systems and DC-based microgrid systems are best-suited business models. DC solar PV systems are less capital intensive and can ease electrification in destitute predominate regions where there is less power demand occur. Also, a power tariff can be suitable since it is easy to control and limit high consumption and increase accessibility in limited supply.

5.10 Chapter summary

Microgrids business models require an inclusive consideration regarding customers, technical, financial, ownership, and operational roles. In particular, for SSA´s rural areas, different factors are needed for assessment since the regions tangled socio-economic structure makes microgrid electrification more problematic than of well-developed urban infrastructure.

Technically, microgrids are required to provide power to customers in a different environment. However, factors such as intermittency of solar power, weather, and time of the day can affect the supply, particularly during peak hours. This can be managed by using energy efficiency technologies such as power-saving appliances, storage technologies, power trackers units, smart meters, and the likes. It is also necessary to manage demand-side using demand response actions to shave peak hour demands.

Today, there is a growing number of financial vehicle options for developing microgrids which can help microgrids viability. Microgrid development project requires financial viability in terms of cost, pricing, and recurring payments for the investment in which includes the ability to generate cash flows, mechanisms for energy pricing, capturing revenues and loan repayment. Selecting the optimal microgrid financial vehicle for different customer groups requires careful considerations and studies.

Moreover, there are multiple options for project ownership structures for microgrids: direct, joint, and third-party ownership. Nonetheless, this requires a thorough process before project development.

Overall, microgrids development requires a holistic approach that encompasses finance, ownership, and operational roles. Besides, added values and service packages as innovative solutions are essential to acquire market share from other power options.

6 CASE STUDY–NAMIBIA

In this section of the thesis, a case study in Revon C district, which is located near Oniipa town in Namibia is assessed. Before that, the country´s energy status and electrification programs are overviewed. This section suggest business models for Fusion Grid implementation in Revon C, based on the methodology suggested in Chapter 5 and, based on the preliminary gathered social and financial data from the questionnaire in area Revon C village

6.1 Country’s profile

Namibia is located in the southern part of Africa, with a population of 2.6 million. The country’s total area is 825 615 Km^2, land bordering Angola, South Africa, Botswana and Zambia; and a long coastline of the Sothern Atlantic Ocean. Namibia is largely desert and the driest country in SSA with more than 300 days of sunshine per year. (Index Mundi, 2018)

6.1.1 Demography

The country’s 2.6 million population is predominant with a working-age population (15-65), and a young generation (0-14) is 59.07% and 36.97 %, respectively. The population growth rate decline from 3% in the 1990s to 1.95% per annum in 2016, mainly due to economic growth. The country’s life expectancy is 64 years. Namibia’s fertility rate declined from 4.5 children per woman in 1996 to 3.4 in 2016, mainly due to contraceptives uses, increased women’s educational attainments, and labour participants. The country’s 48.6% of the total population lives in urban areas with a rate of urbanization of 3.63%. Moreover, the literacy rates 81.9% with total enrolment ratio in primary school is 90.1% in 2015. (Index Mundi, 2018)

6.1.2 Economy

Namibia’s economy is heavily dependent on the export of extracted and processed minerals. Despite accounting for 11.5% of the GDP, export minerals provide more than

50% of forging exchange earnings for the country. (The World Bank, 2016) The main export minerals are diamonds, copper, gold, zinc, lead, and uranium. Namibia is the 5th largest producer of uranium and rich in alluvial diamond deposits.

Namibia is categorized as upper-middle-class with GDP per capita of 11,500 dollars (ranked 7th in SSA). The country's GDP (PPP) is 27.02 billion, with a growth rate of 0.8%. The GDP share by sector comprises: Industry 25.8%, agriculture 6.6%, and service 67.6%. The value-added tax in Namibia is 15%. Also, the inflation rate for consumer price is 6.7%, and the central bank discount rate is 7%. (Index Mundi, 2018)

The labour force occupied mainly in-service sector is 54% followed by agriculture 31% and industry14%. The country's unemployment rate in 2014 was around 28% and where 56.2% of which are in the youth age group of 15-24 (Index Mundi, 2018). Moreover, the population below the country's poverty line (which differs considerably among nations) was 17.4% in 2016 - which shows notable progress in poverty reduction compared to 28.7% in 2010. (The World Bank, 2016)

Despite having the high per capita GDP in the region, there is extreme socio-economic inequality in the country. The Gini Index (a measurement for economic inequality) decline from 64.6 in the 1990s to 60.1 in 2004, and further decline to 57.6 in 2015. (The World Bank, 2016) Besides, there are significant issues and bottlenecks interventions regarding investment and enabling environment in electrification in Namibia such as macroeconomic forces; lack of creditworthy utilities; and lack of strong, transparent regulators. (Power Africa U.S, 2019)

6.1.3 Governance

Namibia is one of the politically stable countries in Africa. The Ibrahim Index on Africa Governance (IIAG) puts Namibia in 5th place in best Africa governance. In addition, according to the aggregated world bank governance indicators (WGI), Namibia percentile ranks among all the nations in 2017 were: 30.48 for Voice and Accountability; 68.57 for Political Stability and Absence of Violence; 61.06 for Government Effectiveness; 46.63

for Regulatory Quality; 60.58 for Rule of Law; and 64.9 for Control of Corruption; which implies better governance compared to most of the other SSA's countries. (The World Bank, 2019)

6.2 Energy status in Namibia

Namibia's total primary energy supply (TPES) in 2016 was 2.02 Mtoe. This comprises 1.56 Mtoe from imports and 0.47 Mtoe from its own production. Moreover, the share of renewables is 22% in TPES. (International Energy Agency, 2019)

The country's electricity consumption in 2016 was 3.91TWh. The generation sources comprise 64.6% from hydro, 30.1% from fossil fuels, and 5.9% from other renewables. (Index Mundi, 2018) The total installed generation capacity of the country is 550MW, which comprises 347 MW thermal, 168.5MW hydro, 62.5MW solar and 5MW wind. Besides, the electricity access rate in Namibia is 45% with a rural and urban access rate of 19% and 70%, respectively. (Power Africa U.S, 2019)

Namibia imports power from cross-border suppliers which in times can reach more than 60% of the total demand. As can be seen in figure 27, the percentage of imports had increased over the years. In 2016 the country's electricity import was 3.07 TWh; showing a sharp increase in the last two decades. (The Global Economy, 2019) This shows the country´s critical dependence on import power. Besides, the regional supply capacities are becoming fully utilized, making difficulties for the country's economy. (Konrad-Adenauer-Stiftung, 2012)

The primary power supplier in Namibia is Eskom, a South African electricity utility, which contributes more than nearly more than 50% in the past decade. Following, Zimbabwe Electricity Supply Authority (ZESA), Mozambique's Electricidade de Moçambique (EDM) and Zambia Electricity Supply Corporation Limited (ZESCO). (Konrad-Adenauer-Stiftung, 2012)

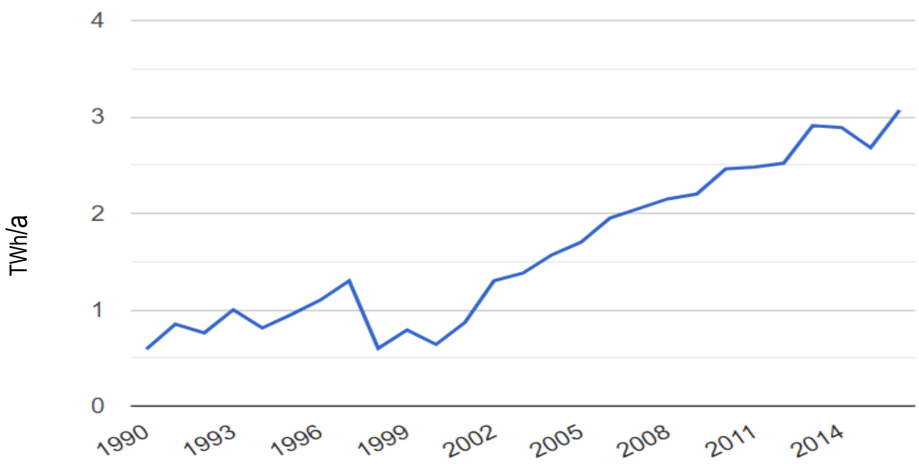


Figure 25: Namibia's electricity import from cross-border countries, (TWh). (The Global Economy, 2019)

The projected demand for electricity is estimated to reach 7 TWh and 5.2 TWh in 2031 with a maximum and minimum growth rate of 4.5% and 3.0% per annum, respectively. See figure 28 At the same time, the population is expected to reach 3.2 million with electricity demand per person of 0.34 KW. (Konrad-Adenauer-Stiftung, 2012)

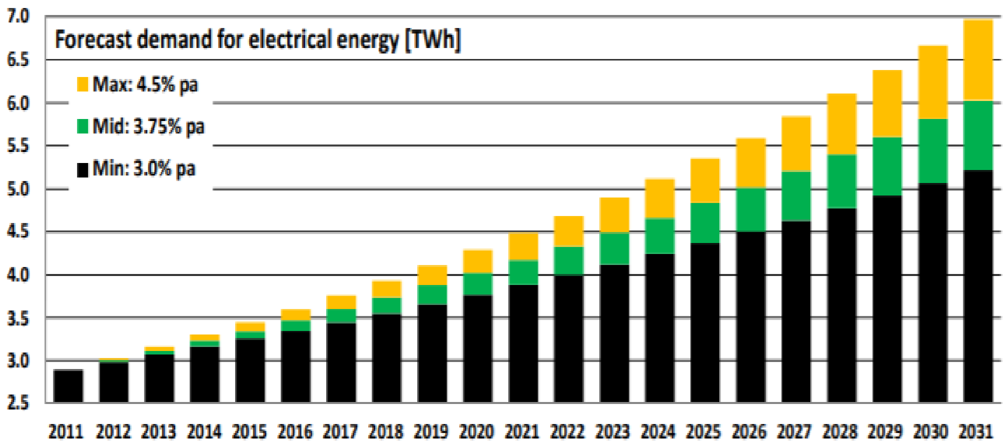


Figure 26: Forecast demand for electricity, (TWh). (Konrad-Adenauer-Stiftung, 2012)

The average electricity price in Namibia in 2019 is 0.12€ per KWh. Comparatively, the average price in the U.S in the same period is 0.13€ per KWh. The price of the electricity shows a gradual increase throughout the year, with the overall tariff increase from 0.042€ per KWh in 2006 to 0.12€ per KWh in 2019. (The Global Economy, 2019)

Moreover, the price of electricity varies across the country's distribution areas; where the Windhoek area being the cheapest and Keetmanshoop expensive. The price difference is based on several factors such as; 1) power distribution network; 2) infrastructure conditions, 3) network extensions scale, 4) energy demand forecast in the specified area, 5) the amount of energy sold in the network by distance, and 6) the energy sales per customers. (See figure 29)

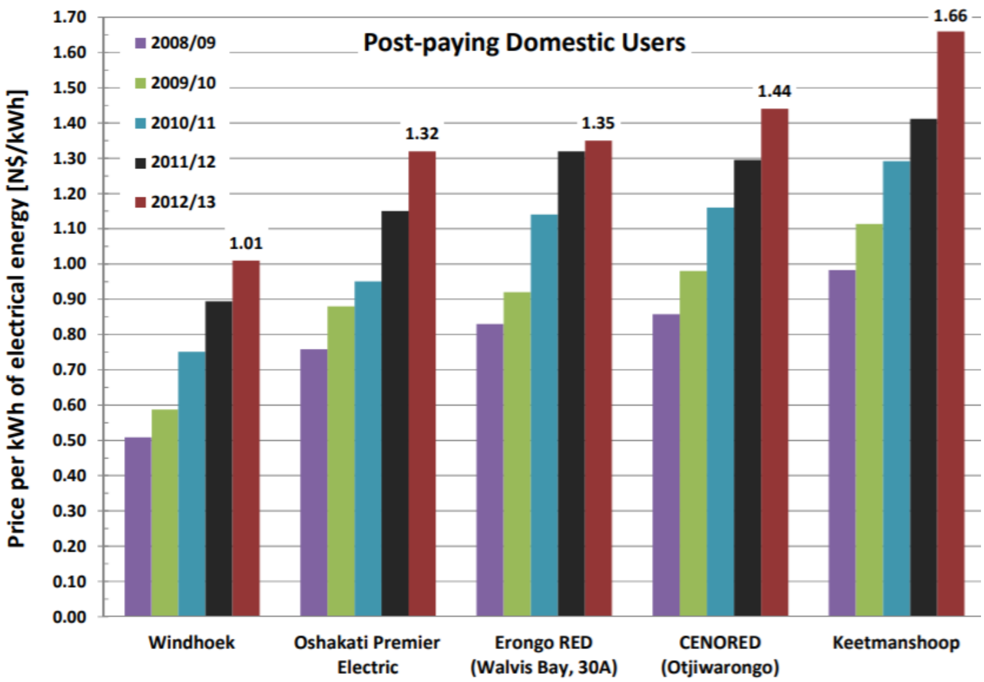


Figure 27: Price development in different distribution areas in Namibia. (Konrad-Adenauer-Stiftung, 2012)

6.2.1 Rural electrifications in Namibia

Namibia made a considerable amount of progress on rural electrification after the independence. Nonetheless, because of its vastly scattered population, most rural areas are most likely not to be connected to the national grid due to the high cost of maintenance and investments needed. According to (International Energy Agency, 2017), in 2017 the country's rural electrification rate was 34%, while for urban electrification was 78%. The government policy states that electrification through the grid extension covers areas where economic viability is determined. Hence, as a solution, The National Rural Electrification Programme (NREP) had set to a master plan for the use of renewable energy-based solutions for off-grid areas. Within the master plan, off-grid areas were selected, and viability study was conducted to identify their economic viability for grid connection; thus, further off-grid solutions for those areas were assessed.

6.3 Case study area description

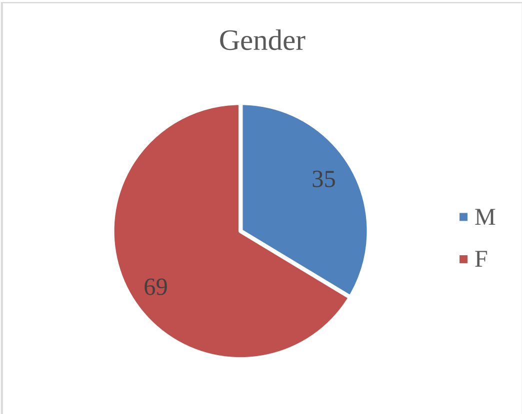
Revon C (Okarevona) is an area located in Oniipa, Namibia. It is an informal settlement within Oniipa town with over 700 residents and covering around 862 629m^2. It's densely populated area mainly comprises of residential houses that are made from conventional building material and zinc structures. Most of the residents are low-income groups which are dependent on informal small businesses. Electricity access is one of the infrastructural challenges in the area. Only a few of the residents have access to electricity, and also the cost of electricity is reported to be quite high for those who have access.

The Oniipa Town Council recently drafted urban planning to make Revon C a formal settlement. Hence, with the request of the council, the Revon C was selected as a pilot site for Fusion Grid research project.

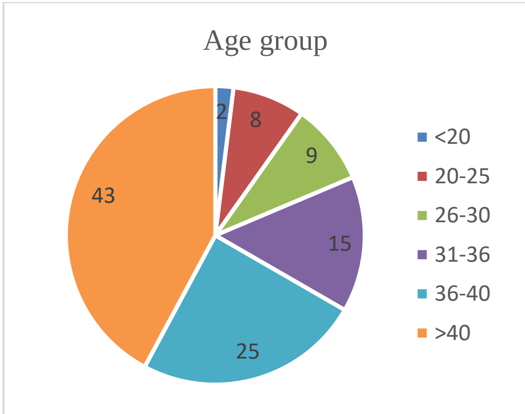
6.3.1 Preliminary data analysis

Before detail studies made, a survey was conducted regarding demographics, electricity, network, appliances, and service satisfaction were conducted. The data were presented and analysed in the following section. There were 107 respondents for the survey.

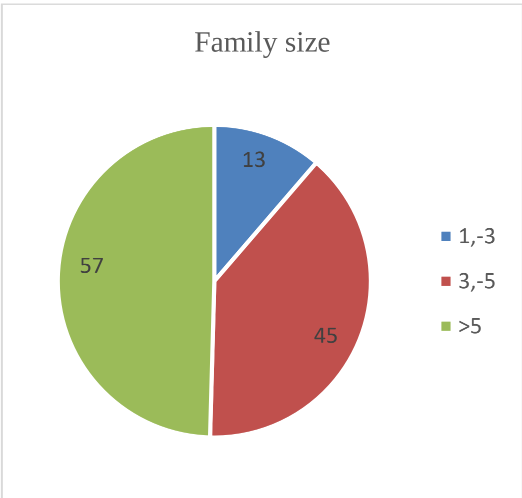
The survey involves mostly age groups above 20 years old, where 42% of participants were above age 40, followed by 25% in the age 36-40. Among the participants, Females account for 66% of the survey. Most of the households have a family size of above 3 members. Educational qualifications show that high school graduates and Diploma holders are higher in number accounting for 28% and 23%, respectively. (See figure 30)



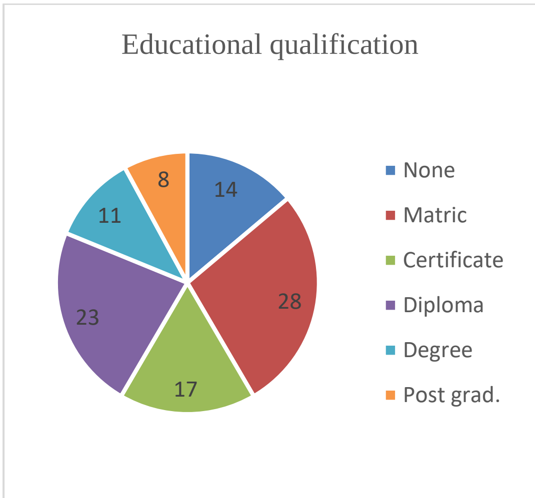
(a)



(b)



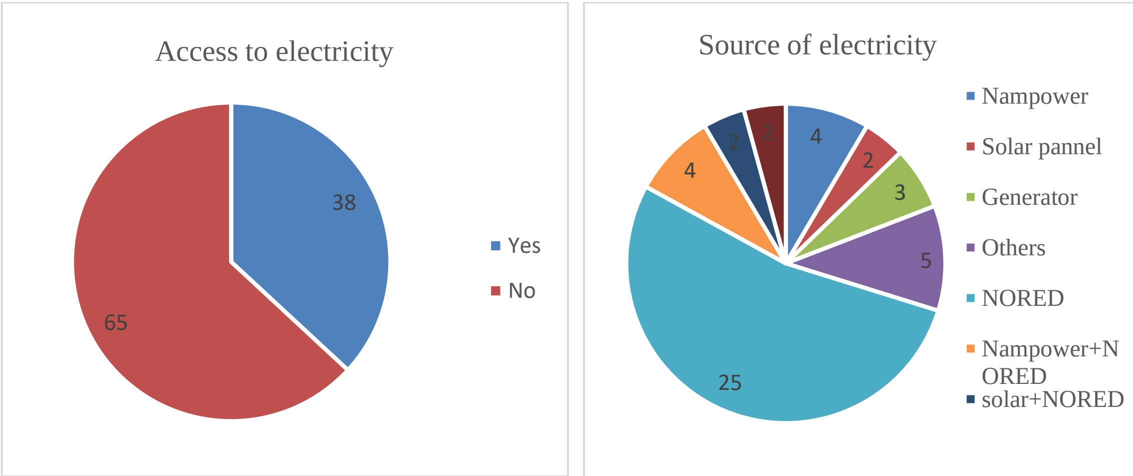
(c)



(d)

Figure 28: Demographical makeup. (a) gender, (b) age group, (c) family size, and (d) educational level.

According to the survey, the community´s access to electricity is 37% with a slight number of power outages. More than 90% of the community' s residences are not happy with the service in either not having access or with the quality of the service. For those who have access to electricity, more than 60% of the users get their supply from NORED – A Regional Electricity Distributors (REDs). Also, nearly 10% of customers use NamPower – a state-owned power generation and transmission entity which is also a shareholder of all REDs. The rest of the customers uses solar panels and diesel generators to power their households. (See figure 31)



(a) (b)

Figure 29 : Energy status of Revon C. (a) access to electricity, and (b) sources of electricity

Households with power access use diffenent electrical and electronics appliances. The types and numbers of the electrical appliance are presented the figure 32 below.

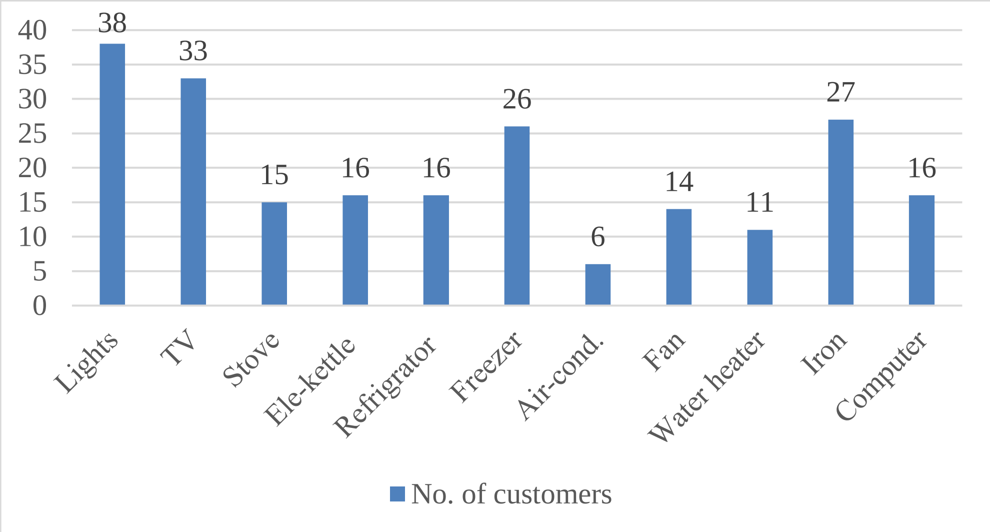


Figure 30: Household appliance availability.

Accordingly, using the average number of electrical units per household and consumption hours per day, the total energy consumption per annum is estimated. The power consumptions of electrical units were taken from (Reber, et al., 2018) and universal standards. (See table 4)

Table 4: Power consumption for household appliances.

	Lights	**TV**	**Stove**	**Ele-kettle**	**Refrigrator**	**Freezer**	**Air-cond.**	**Fan**	**Water heater**	**Iron**	**Computer**	**Total**
No. of customers	38	33	15	16	16	26	6	14	11	27	16	
Electrical unit consumption (W)	9	150	7,000	1,433	50	50	2,500	75	5,000	1,000	80	
Total consumption (Kw)	1.026	4.95	105	23	0.8	1.3	15	1.05	55	27	1.28	
Total time of consumption (hr/year)	2,190	1,460	730	365	4,380	4,380	1,460	2,190	365	91	1,095	
Total energy consumption per year (KWh/year)	2,134	7,227	76,650	8,368	3,504	5,694	21,900	2,299	20,075	2,463	1,401	**150 MWh/a**

As can be seen from table 4, some of the survey participants in Revon C uses different high wattage appliance such as stove (40% of participants), air-conditioner (15% of participants), water heater (28% of participants), and iron (40% of participants). The average energy consumption per household is estimated to be around 600 KWh/year; which is higher than the average SSA´s household consumption.

Furthermore, the average monthly income from the survey shows that people earn around 4,040 Namibian dollars (N$) or 240 € - which is lower than the country's average wedge of 6,626 N$ (397€). As can be seen in figure 31, around 40% of the residents that were in the survey income lies between the range of 500-2,000 N$ (30-120 €). Incomes above the average wedge account for 26%, while 10% of the survey participants were destitute with an income of 100-500 N$ (6-30 €) per month.

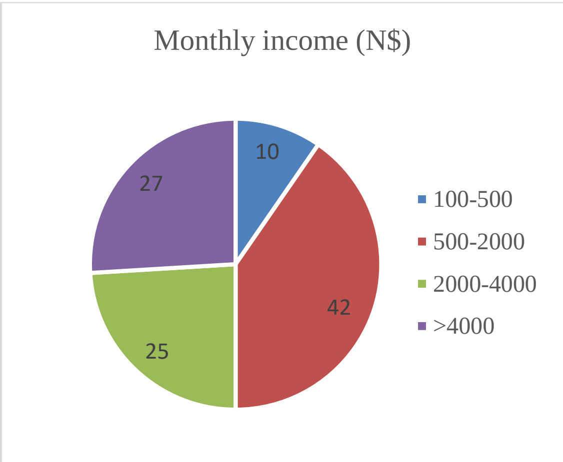
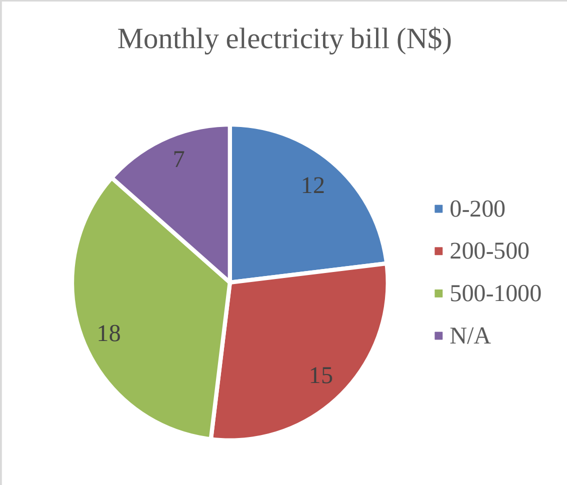
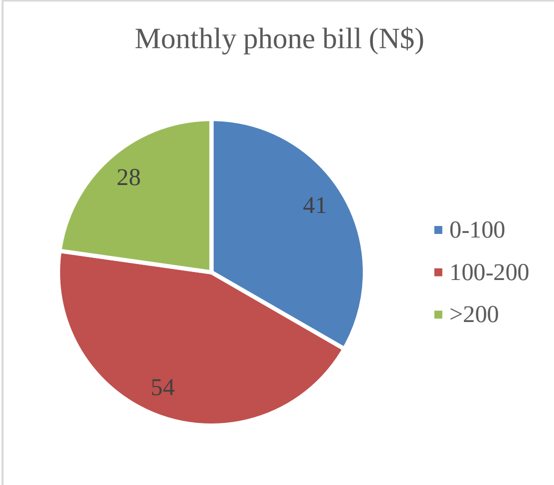


Figure 31: Monthly income form survey.

In Revon C the average monthly electricity and phone bills are around 499 N$ (26,96€) and 170 N$ (10,21€), respectively. (See figure 34) Based on the average energy consuption (table 4) and electricity bill, the average energy cost is 0.07 €/KWh. According to the survey question regarding whether electricity and phone services are expensive, 67% for electricity and 73% for phone service replied to being expensive.





(a) (b)

Figure 32: Monthly electricity and phone bills.

6.4 Energy business model consideration

Developing microgrids business model for Revon C requires a holistic approach that comprises financial, technical, and ownership roles. Also, microgrid´s competence in the area can be further strengthened using added services and payment schemes. As discussed in Chapter 5, several business model considerations are required before deploying a microgrid project.

In this section, some of the significant features and considerations for a business model in Revon C are discussed.

6.4.1 Technical features

Technical consideration for microgrids' primary places upon the type of energy resource and conversion technology. Furthermore, the reliability of power can be maximized with battery storage and optimal power technologies.

Revon C comprises mainly residential and small business shops. Accordingly, customer´s behaviours can be establishing using the demand variation in different time of the day. As discussed in Chapter 5.2, in most SSA's rural residential homes demand steadily develops through the daytime reaching a peak during the night-time; which is also similar in the case of small shops.

Revon C (also in many parts of Namibia) receives high solar irradiance throughout the year, which makes solar power a preferable renewable energy resource. Thus, a suitable solar power option comprising battery storage and optimization systems can be taken as a primary option. And, the option of utilizing AC and DC power in the distribution network is possible using inverters.

One alternative layout for power systems can be made with a modified Anchor load model. Small businesses, productive use, and health centres can be used as anchor customers followed by residential customers according to their income level and willingness-to-pay.

6.4.2 Customer segment and pricing mechanisms

As previously described, Revon C village is a semi-rural area adjacent to a well-planned town of Oniipa. The village is intertwined with the town in socio-economic activities with Oniipa town. Most of the people are low-income with a small share of destitute. Also, there are a considerable number of residents with higher incomes (above the country's average wedge).

Customer segmentation for Revon C can be established based on income and service uses. Different tire can be assembled in a package according to their income levels and consumption. Within the package, power usage and appliances, connectivity, and other additional services can be included.

A proposed customer segmentation is presented in table 2. Accordingly, higher-income customers with higher demand can benefit from payment options that encourage consumption by a flexible payment, and higher connectivity; likewise, for lower-income customers tariffs systems that suitable power tariff with basic connectivity can be provided.

Table 5:Proposed customer segmentation, payment systems, and connectivity.

Income Tire	**Tariff/ Payment system**	**Connectivity tire**
Upper middle income	Stepped progressive tariff, post payment	Higher
Lower income	Stepped regressive tariff, day/ night tariff, PAYG	Basic
Destitute	Power tariff (Solar home system package)	Basic

In addition, loads can be distributed according to demand and sales share of customer groups. Hence, residents and small businesses with higher incomes and demand can be taken as anchor customers followed by lower-income households. This is mainly due to the fact predictable and long-term revenue can be secured with higher-income customers.

For lower-income customers stepped regressive tariff systems or day/night tariff alongside a basic connectivity can be assembled in the service package. Destitute customers groups with lower willingness to pay, and income level, can use power from the microgrids with power appliance which are equipped regulating instruments such as a timer and load limiters.

6.4.3 Ownership and operational roles

As discussed in the previous Chapter 5.5, ownership of the microgrid project can be among government, private, and community. This can be carried out using ownership options such as Public-Private-Partnerships (PPP), joint ownership, and government-owned model.

In case of Revon C, ownership and operational role can be among Oniipa town council, private investors, and the community. Also, the ownership share can be fully taken by the national power utility as a part of the rural electrification program. Furthermore, financial vehicles such as Lease-To-Own can also be implemented to transfer ownership to the local community, which can create a sense of ownership among in the community.

6.4.4 Source of financial support and financial mechanisms

Financial supports for the microgrid project can be raised from the government, private investors, donors, and the community.

In the case of Revon C, lack of electricity access and higher willingness-to-pay can be a drive for private investment in electrification projects in the area. Besides, concessional loans and loan guarantees facilitated by the government can further encourage investment initiatives for developing microgrid projects. Moreover, government support, grants, donor and loans can also be used as financial mechanisms in developing projects; and, Result-based financing (RBF) also can be implemented to ensure the subsidies are adequately aligned with the target project.

6.4.5 Customer relations

As discussed in the previous Chapters 5.3, introducing customer agreement is one way to establish better customer relationships. These agreements are essential to enhance relations by providing different packages of service which gives customers to choose in power usage, connectivity, and other services. They also become more critical, especially when microgrids are deployed in semi-urban areas where customers are already connected to power grids or have other power generating options such as diesel generators.

In case of Revon C, customer relations are a crucial part of creating and maintaining a convenient business model. Dealing with inquiries from different customer groups requires to establish an interactive customer connection. One crucial way to build a strong relationship with the local community is by introducing a suitable business model that attends to resolve requests from different customer groups.

6.5 Financial viability of Fusion Grid for Revon C

In this section, financial viability of fusion grid is assessed using Net Present Value (NPV). As previously mentioned, Revon C is selected as a fusion gird research pilot site.

Thus, the input values were retrieved from the entry-level load one of the (Huoman, et al., 2019) power cell specification (See appendix 1 & 2). The power cell provides electricity up to five customers and assumed to provide 24/7 power supply with day-time generation and night-time battery supply. Similarly, assumptions were taken for ownership shares of the microgrid. The interest rate and capital cost of equity were assumed to be 7% and 5%, respectively. Also, the tax rate is assumed to be 15% for energy generation. (See table 6)

Table 6:Initial data and assumptions for NPV evaluations.

1	Capital expenditure (€)	11, 627.00 €
4	Income tax rate	15 %
5	Interest rate	7 %
6	Capital cost of equity	5 %
7	Lifetime of the system	20
8	Annual hours	8760
9	Power cell house generation capacity (KW)	2
10	Energy produced and stored (KWh/a)	17520
11	Availability rate	0.95
12	Depreciation of assets	581.35 €/a
13	Operating & maintenance cost (1.5%CAPex)	174.41 €/a
14	Insurance(1%CAPex)	116.27 €/a
15	Capital cost of debt	232.54 €/a
16	Capital cost of equity	406.95 €/a
17	Spare parts (2%CAPex)	232.54 €/a

Base on the above input values, the NPV becomes positive with a tariff of 0.26 €/KWh and high with an ownership share of 50% debt and 50% equity. This is attained by altering the tariff and ownership shares to find the least values that show a positive NPV. (See figure 33)

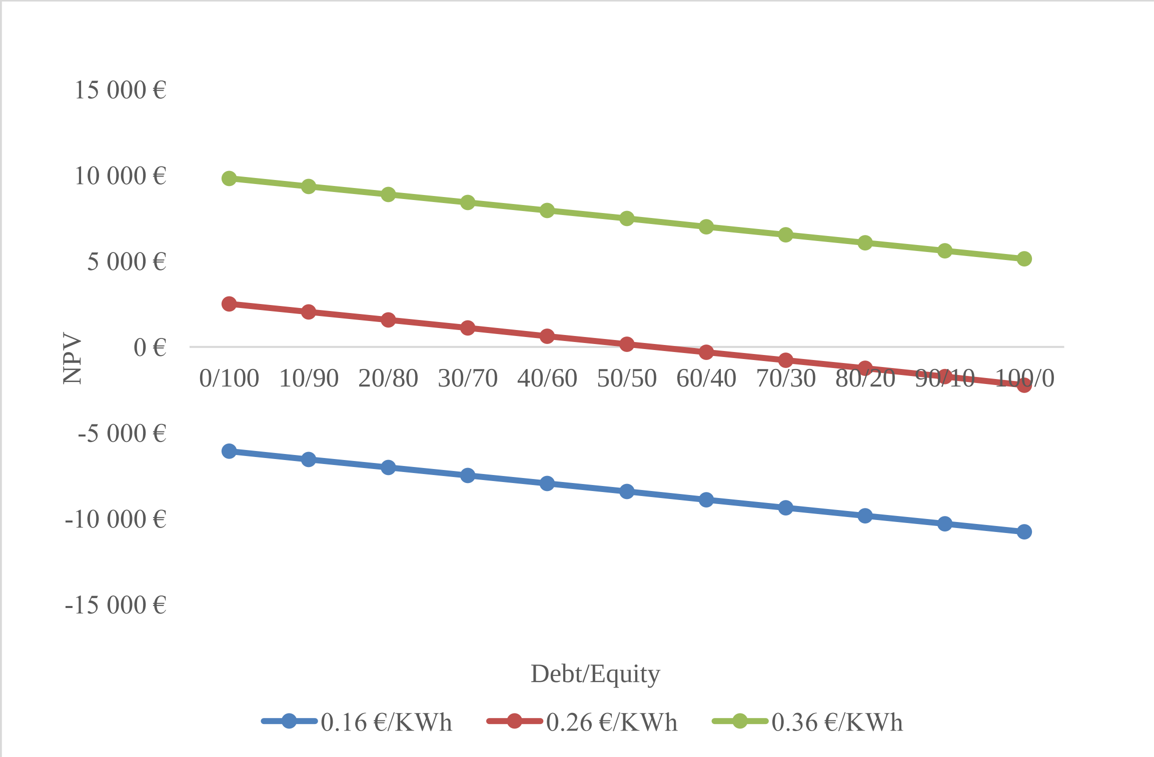


Figure 33: Sensitivity analysis of energy tariffs.

Also, the payback period for the system is estimated to be 7 years with suggested energy tariff and ownership shares. (See figure 34)

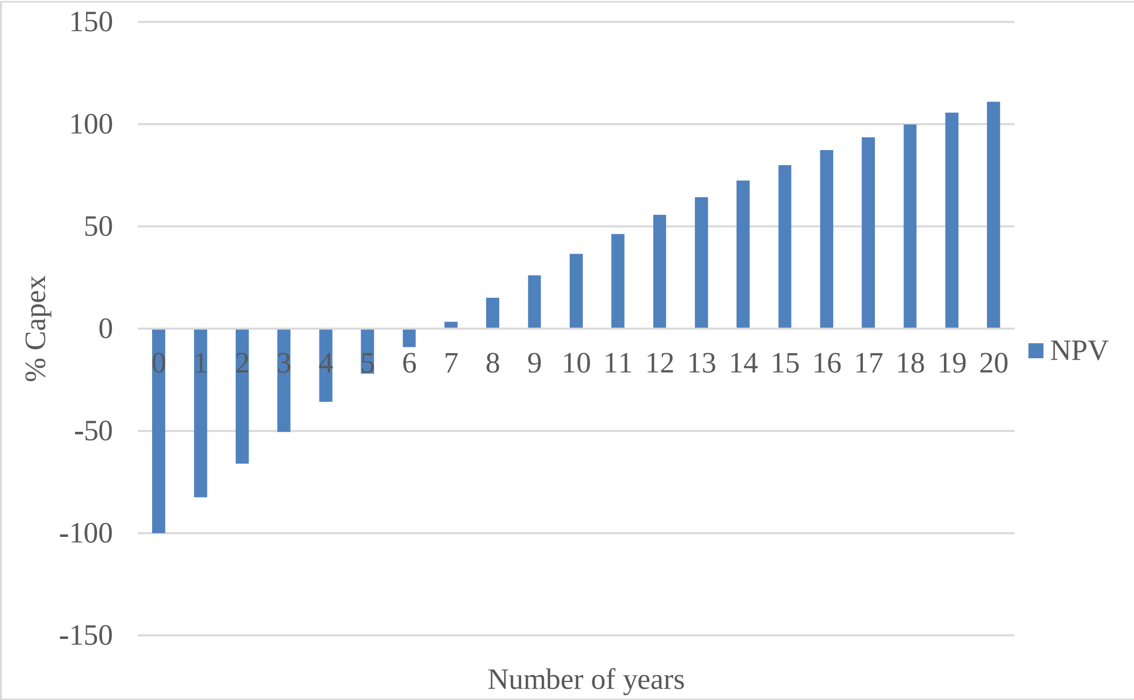


Figure 344: NPV result for FG power cell with energy tariff of 0.26 €/KWh (50% debt and 50% equity)

The above evaluation is mainly considered the microgrid solution as power unit than of both power and network connection provider. Therefore, the digital market revenues created by added service can further reduce the payback period. Also, tax exemption and cost incentives for renewable power generation can further lower the tariff and payback period of the power cells.

However, the electricity tariff offer of the regional electricity distributer NORED shows a range of 0.096-0.13 €/KWh tariff excluding the connection fees (NORED, 2019).This shows that the suggested microgrid solution is more expensive than of the NORED´s power purchase offer. Hence, this calls for further studies in pricing and cost structure for the power cells, thus, affordable and reliable supply of power is attained.

6.6 Chapter summary

Overall, based on the country´s current energy status and electrification rate, DERs incorporated by microgrids can be a suitable solution. Besides, the growing demand for energy and the country´s critical dependence on import power can further raise the energy cost in the coming future. This become crucial since the regional power-pool supply capacities are becoming fully utilized.

In the case of Revon C, the result showed that Fusion Grid tariff is higher than tariffs of local energy provider, therefore, further studies are needed regarding the actual energy demand and creating appropriate microgrid business model, which can also further underline the value creation of Fusion Grid concept. Also, innovative pricing structures and demand side management options are required to be further assess.

Nonetheless, Fusion Grid concept is still applicable to places where grid extension is expensive, and the network connection is unavailable. Also, other customer segments such as tourist lodges and parks, campus areas, military bases, schools, and health centers can use the fusion grid for its reliable power supply and high-speed network connection.

7 DISCUSSIONS

In this chapter, the overall outlook of the thesis is discussed. major themes regarding SSA´s energy status, microgrids and their business models and business model evaluation standards were overviewed.

1. DERs for SSA rural electrification

DERs have the potential to satisfy SSA’s rural power demand and have advantages over traditional grids by reducing the excessive infrastructural cost for transmission systems, power losses and suitable for renewable sources, which can be scalable to satisfy small communities demand. Most importantly, DERs lessens the social inequalities that centralized grids create. Notably, in SSA where the grid connection is limited for rural areas, DERs development in forms such as microgrids can narrow the power gap and makes developments much ease. Furthermore, with new technologies like smart grids, SSA’s grid systems can be receptive to DERs, thereby lifting pressure from the centralized generation system and increasing overall grid reliability. Similarly, Information and Communication Technologies (ICTs) can bring remote accesses for smart metering, maintenance, and data analytics, of DERs systems.

There are arguments that are raised regarding whether centralized or decentralized solutions are preferable for SSA power systems, in which some argues decentralized solutions are seen as incapable of supplying reliable energy service while on the other hand, others argue that centralized systems and grid extensions are too slow, expensive and less reliable to reach people without access to electricity.

Nonetheless, both arguments are mainly based on outdated assumptions, which excludes recent and future technological advancements for both solutions. Today’s centralized power systems primarily depend on embedded and often an overlaid system of sensors, computation, communication, control, and optimization - which enables intermittent sources to penetrate to gird systems smoothly. Also, for DERs solutions, advent smart grid and ICTs technologies are making transmission and distribution controls more efficient. Besides, recent developments in generation and storage technologies are making DERs technologies more reliable.

Hence, both solutions can be interwind and made to be complementary, that is, decentralized solutions become first-hand solutions for rural electrification until grid extensions reach. Subsequently, with the economic development of rural areas, the late-extended grids can fill the electric gap. Also, by interconnecting both solutions, electricity markets can be created, in which surplus and shortages can be traded according to the supply and demand of the grid.

2. SSA's energy resources and technologies

As mentioned, SSA has a vast untapped energy resource that can be utilized to satisfy its growing energy demand. Nonetheless, determining whether fossil-based or renewable resources should be appropriate for new generation building can be debatable. The main challenges of using fossil fuel as a major power supply are pollution, price volatility, and climate change. Similarly, it is worth noting that fossil fuel subsidies can largely influence rural electrification expansion options. Fossil fuel subsidies in some SSA countries create a barrier for sustainable energy developments by trapping energy investments in carbon-intensive technologies. In fact, in some parts of SSA regions, the optimal option for off-grid electrification is found to be fossil-based fuel rather than solar PV. Although the possibilities of 100% renewable energy resource - mix scenarios were proven for the year 2030 & 2050, moving away from fossil fuel in the recent future seems unlikely and requires policy-wise actions.

Similarly, in the case of renewables, the main challenges for capacity expansion are intermittency and variability for solar and wind powers and risks related to climate change hindering hydropower. In fact, the challenges for renewable-based capacity expansion are mainly in the system flexibility towards intermittency and variability, rather than economic costs. In the case of a high renewable power system shift, battery storages, demand response, improved forecasts, and other necessary strategies should be considered. Furthermore, since baseload demand can be challenging to meet with intermittent and variable sources capacity relies on generation mix – which comprises dispatchable and variable sources with known demand profile. Hence, it is very essential to SSA energy systems to be more flexible to accommodate renewable penetration into the grid systems, which can also promote the increasing share of renewables in the energy mixes.

3. Microgrids project development and sustainability

Developing microgrids project requires thoroughly design considerations. Some of the important development requirements are:

1. Secure power supply with adequate quality,
2. Better price for local power supply,
3. aligning with regulatory and obligations,
4. technical aspects for effective operation,
5. proportionated cost reflecting the with benefit it brings,
6. added values to stockholder by creating local employment, elevating local wealth through employment and ownership, reducing electricity cost, accounting for reducing carbon footprints and pollutions,
7. lifecycle consideration including operation and maintenance and end of lifetime (what is required to maintain the microgrids and its components) and grid constraints.

It is also worth noting that, sustainable actions are need for the long-term viability of microgrid systems in SSA rural area. Besides, most of the previous failed attempts of microgrids give a negative view and poor reputation among communities, donors, and philanthropists. Thus, it is necessary to thoroughly consider and act on issues that linked with the social, technical, economic, environmental, and policy of the region.

Socially, effective community engagement and participation are necessary to achieve microgrid's viability. This can be done through educating the communities and stakeholders in a topic such as the necessity of routine maintenance of the energy infrastructure. Besides, by clearly defining the ownership of the systems, roles and responsibilities can be specified and expected. Moreover, conducting a useful pre-design survey - which comprises energy status, loads and consumptions patterns, resource availability and amount- project that can be award to a qualified contractor. It is also worth note that, security and protection related to microgrids infrastructures are necessary; thus, the long-term operation is viable.

Technically, designing microgrid systems requires an appropriate and realistic design that involves concerned stakeholders and which also follows the international standards for design, planning, and development. Subsequently, adequate project supervision is also required; thus, system failure is prevented. In addition, materials that are used for the energy systems components should fulfil the quality standards placed by the system designers. After commissioning, remote monitoring systems that provide real-time information and status of the system can assist the operation and maintenance process.

Economically, government financial assistance plays a majorly for microgrid development. These supports can be through financial means such as grants, loans, and other financial mechanisms. On the community side, with higher willingness-to-pay and readiness, potential developers and investors can be drawn. Also, with appropriate business models, entrepreneurs can be attracted to microgrids business with different ownership shares and ventures.

Similarly, environmental-related aspects should be addressed in developing microgrids projects. Practical environmental impact assessment (EIA) can disclose unseen environmental impacts that can affect the sustainability of the surrounding environment. Furthermore, life cycle assessment and evaluation of the energy systems using the global environmental performance parameters.

Most importantly, policy support for microgrid development for achieving long term viability. These imply consolidation of the existing energy policies in promoting microgrids, establishing, regulating and strengthening PPPs, markets in the country. Besides, quality control measures and standards should be established; thus, the sustainability of microgrid is assured.

4. Microgrids business models and evaluation methods

Defining and creating the right business model requires similar earnestness as of designing innovative products. A business model describes means of delivering value to customers, and also how it captures value from the created values. In the case of energy systems services, business model value proposition encompasses in delivering affordable energy and services; value creation covers the means of delivering power and services to match demand, and values capturing comprises creating revenue and return in investments.

As discussed in Chapter 4, currently, there are numerous types of energy business models for power utilities and microgrids systems. In addition, there are also new innovative types of models that are designed and altered to create value according to the energy system and customer needs. This helps to propose different values for customers, while values are captured by energy systems developers. Moreover, the emergence of smart meters and DERs create additional value proposition such as smart loads, and demand response.

Designing microgrid business models requires to take several considerations into account; thus, the created value is captured. This is particularly crucial in rural SSA, where various socio-economic factors play a significant role in electrification. Thus, business model evaluations in the context of the SSA´s rural area are necessary to assess accordingly. Based on that, a specific business model can be created which can deliver affordable energy and services for rural customers.

8 CONCLUSIONS

The purpose of this thesis is to assess the current energy status the SSA and the possible use of microgrids as energy solutions for rural areas.

Microgrids can solve successfully SSA´s rural electrification requirements incorporated with efficient energy technologies and innovative business models. The efficient design of components, energy management, and storage systems are necessary to utilize the variable and intermittent energy resources as a reliable and continuous power supply. Besides, microgrids are required to be financially viable by yielding an adequate return on the investment and creating suitable energy costs for customers. Thus, business models consider technical, financial, and social factors for creating values.

Furthermore, microgrid´s long-term sustainability relays on the human factor and social aspects. The project viability requires a suitable managing structure for operating and ownership of the microgrids from the initial stages. Parallelly, rural communities must have a minimum organizational structure and well-defined leadership; thus, financial, operational, and maintenance of the systems is created.

Based on the research work presented and discussed in this thesis, further researches may be needed in subjects such as price incentives for use of PV generated power; price comparison of electricity and other digital services, and value creation in fusion grid concept.

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APPENDIX 1: POWER CELL CONFIGURATION

The power cell comprises photo-voltaic (PV) solar panels, Lithium-ion based battery, battery charger and inverters. There are five consumers including the primary (anchor) consumer. The systems voltage is selected to be 48 VDC so that the inverters convert to the standard 230 VAC. Also, weather forecast, consumer behaviour, load profiles are included in the control system parameters.

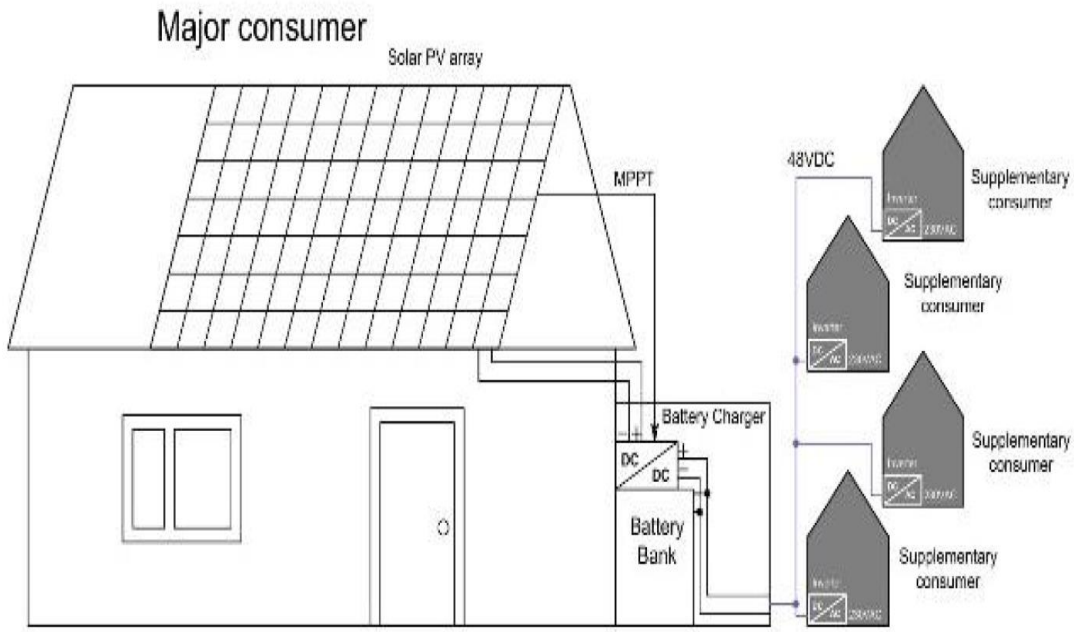

Figure 35: power cell configuration (Huoman, et al., 2019)

APPENDIX 2: POWER CELL COMPONENTS AND COST SPECIFICATIONS

The power cell system has six solar panels, one Lithium -ion battery and five inverters. The energy prices are calculated using the power cell total cost and energy battery capacity within the life cycles.

Table 7: Components and cost specifications

	6 panels, 1 battery	
	Entry level loads	Advanced loads
Number of panels	6	6
Number of strings	2	2
Number of batteries	1	1
Battery capacity	4000 Wh	4000 Wh
Number of cycles	8000	8000
Number of inverters	5	5
Inverter output power		
Power cell house	2 kW	2 kW
Basic customer	400W	2 kW
Power cell price	**11627 € ***	**15350 € ***
Energy price	**0,454 €/kWh**	**0,60 €/kWh**