Co-Supplying the National Grid: An assessment of private electricity generation and the potential of solar Photovoltaic (PV) integration in Juba-South Sudan.

A thesis submitted to the Department of Environmental Sciences and Policy of Central European University in part fulfilment of the Degree of Master of Science

Ladu David Morris LEMI

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Ladu D. M., LEMI

CENTRAL EUROPEAN UNIVERSITY

ABSTRACT OF THESIS

Submitted by: Ladu David Morris Lemi

for the degree of Master of Science and entitled:

Co-Supplying the National Grid: An assessment of private electricity generation and the potential of solar Photovoltaic (PV) integration in Juba-South Sudan

July 2017.

Despite the importance of electricity in improving people's quality of life and the global campaign for energy transition to renewable sources, South Sudan's electricity generation is exclusively from diesel generators with an installed and functioning capacity of 12 MW in Juba against a demand of 154 MW. Persistent power outages has led to a rise in Off-grid electricity self-generation by both households and commercial firms using captive diesel generators. This research aims to explore the generation options, quantify the amount of the Off-grid electricity in Juba and establish how such amount can be connected to the grid system by conducting a survey study involving 44 companies, 2 government institutions and 2 solar energy retailers. The study found that the current Off-grid installed generation capacity in Juba is higher than On-grid with a total of 28.93 MW from 142 generators. 98% of this amount is diesel-fired electricity and only 2% is from solar. However, to keep these generators running, the companies spend US$ 533,204 monthly to procure 589,760 litres of diesel, which emit 1553.8 tCO_2. Adoption of solar energy by the companies is very low and showed a mixed perception with majority of companies having no or limited knowledge on solar. Besides, the governance of the electricity market is under the monopoly of a government parastatal utility company and run without a single legal framework. The study recommends restructuring of the electricity market to attract private players by developing legal frameworks and creation of awareness for the promotion of solar energy.

Keywords: Diesel generators, Electricity market, Governance, Solar energy, Juba, South Sudan, Off-grid, Diesel-fired electricity, Legal framework, Self-generation.

DEDICATION

Dedicated to my beloved daughter and wife Emily and Norah for the unwavering support and motivation throughout my study. Your love and care has led into credible accomplishments in this study.

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"Blessed are those who give without remembering and take without forgetting" Elizabeth Bibesco.

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Lastly, I wish to acknowledge the courage of the respondents who despite the sensitivity of research in Juba at the time when global sanctions were sweeping businesses in the country, they were able to provide crucial data without which the pursuance of my research project would have futile.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	Alternating currents
AfDB	African Development Bank
bbl/d	billions of barrels per day
CIA	Central Intelligence Agency
CNPC	China National Petroleum Corporation
CPA	Comprehensive Peace Agreement
DC	Direct Current
DRC	Democratic Republic of Congo
EE	Energy Efficiency
ERA	Electricity Regulatory Authority
ERC	Energy Regulatory Commission
ESI	Electricity supply institutions
ESIA	Environmental social impact assessment
FAO	Food and Agriculture Organization of the United Nations
FIT	Feed-in-tariff
GCF	Green Climate Fund
GDC	Geothermal Development Company
GDP	Gross Domestic Product
GHG	Green House Gas
GoSS	Government of South Sudan
GW	Giga Watt
GWEC	Global Wind Energy Council
ICSHP	International Center on Small Hydro Power
IEA	International Energy Agency
INDC	Intended nationally determined contribution
IPP	Independent Power Producers
IMF	International Monetary Fund
IPC	Integrated Food Security Phase Classification
JEPP	Juba emergency power project
LED	Light-emitting diode
kVA	kilovolt-amps
kW	kilo Watt
kWh	Kilo Watt hours
MENA	Middle East and North Africa
MoCII	Ministry of Commerce, Industry and Investment
MoE	Ministry of Environment
MoED	Ministry of Electricity and Dams
MoFEP	Ministry of Finance and Economic Planning
MoH	Ministry of Health
MoP	Ministry of Petroleum
MPPT	Maximum Power Point Tracking

MSW	Municipal Solid Wastes
Mtce	Metric Tons Carbon Equivalent
$MtCO_2$	Metrix tons of CO_2
MW	Mega Watt
Mwh	Mega Watt hours
NAPA	National Adaptation Plan of Action
NGO	Non-Governmental Organizations
ONGC	Oil and Natural Gas Corporation
PF	Power Factor
PPA	Power Purchase Agreement
PPP	Public-private partnership
PV	Photovoltaic
REA	Rural Electrification Authority
RETs	Renewable energy technologies
SEDC	State Electricity Distribution Companies
SHS	Solar Home System
SSA	Sub-Sahara African
SSBS	South Sudan National Bureau of Statistics
SSEC	South Sudan Electricity Corporation
SSERA	South Sudan Electricity Regulatory Authority
SSNEP	South Sudan National Electricity Policy
TandD	Transmission and Distribution
UN	United Nations
UNDP	United Nations Development Programme
UNECA	United Nations Economic Commission for Africa
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations Children's Fund
UNIDO	United Nations Industrial Development Organization
USAID	United States Agency for International Development
VAT	Value Added Tax
WEC	World Energy Centre
WEO	World Energy Outlook
WFP	World Food Programme of the United Nations

1.0. INTRODUCTION

1.1. Background

Previously known as the southern part of the Republic of Sudan, perhaps the most interesting global narrative and memories of the Sudan is its history of horrific civil wars, which unfortunately, culminated into state fragmentation. South Sudan is the world's newest country, which gained its independence from the Republic of Sudan on July 9th, 2011, after decades of what was known as Africa's longest civil war. It has a geographical location in the northeast Africa and bordered by Ethiopia to the East, Kenya to the Southeast, Uganda to the South, the Democratic Republic of Congo to the Southwest, Central Africa Republic to the West and Sudan to the North. The country has a total area of 644329 km^2 and a wealth of natural resources including conventional and renewable energy resources, fertile agricultural lands, water and animal resources among other minerals of global importance like uranium. This resource-based wealth makes observers to describe South Sudan, as a middle-income country should its resources be well managed and translated into social services for the citizens.

Initially, South Sudan comprised of three regions and regional capitals, which included, Equatoria, Bahr el Ghazal, Upper Nile and Juba, Wau, Malakal respectively. However, prior to independence, the regional system was abolished, and a state system was adopted which divided the three regions into 10 states with each being administered by a state governor, state ministerial cabinet and a state parliament. Three years after the independence, the ten states were further fragmented into 32 states and the national government that sits in Juba, the capital of the country, supervised the state governments. This political dispensation although has worked well in developed countries like the United States, it appears to be problematic for countries emerging from decades of conflicts like South Sudan. Resources ownership and management between state and national governments has been contentious and, in most instance, leads to lethal conflicts at local or national levels (Cascão 2013).

According to the World Bank (2016) and the Central Intelligence Agency-CIA (2017), South Sudan has a population of about 12.23 million and an annual growth rate of 3%. When this population is contrasted to the geographical size of the country, it indicates that there are only 19 people per km^2 in South Sudan, making it one of the least populated countries in Sub-Sahara Africa. The South Sudan National Bureau of Statistics (SSBS) report of 2009 states that, most people (83%) in South Sudan live in the rural areas and subsistence agriculture is the main source of their livelihoods compared to the market dependent urban population. Despite its agricultural potentials, poverty and food insecurity remains so high in South Sudan. SSBS (2012) observes that, 51%of South Sudan's population lives below the World Bank's poverty line threshold of $1.5 per day and about 20% of the population requires humanitarian food aid. In 2017, this percentage rose to more 40% with others facing starvation (IPC 2017).

1.2. Energy and climate change

The energy sector of South Sudan as a country emerging from prolong period of conflicts presents a unique case in the region. Primarily, the economy of the country depends heavily on crude oil exports, which account for 60% of total revenue for the country in 2015 compared to 98% in 2008 (UNEP 2017). It is estimated that between 2005 and 2011 for instance, the country fetched 13 billion dollars revenue from its oil export (Mozersky and Cammen 2018). However, due to the volatility of oil prices in the international markets, oil dependent economies like South Sudan remains vulnerable to economic collapse (MoE 2013). The price volatility, coupled with political instability and internal conflicts in and around its oil fields, has reduced daily oil production to 130000 barrels per day from 390000 in 2011. Today, South Sudan struggles with a worse economic crisis having an influential rate of more than 104.12% (Statista 2018).

Despite being the seventh oil producer in Africa, South Sudan has the lowest electricity consumption per capita in Sub-Saharan Africa[1]. Like any other Sub-Sahara African (SSA) country with a large rural population, majority of people in South Sudan derive their energy from biomass such as charcoal, wood fuel or grass (SSBS 2012). Electricity generation is exclusively from thermal diesel generators. According to World Bank (2013) and UNDP/MoED (2013), the electricity demand for South Sudan is 300 MW and expected to rise to 1400 MW by 2030. Yet the installed capacity for the whole country is 30 MW in isolated locations covering only a total of 15 km. Of this capacity, only 22 MW was erratically operational and provided electricity to an estimated 22000 customers which empirically indicates that only 1% of the population have access to electricity with a per capita consumption rate of 1-3 kWh compared to 80 kWh in the Sub-Sahara region (UNDP/MoED 2013).

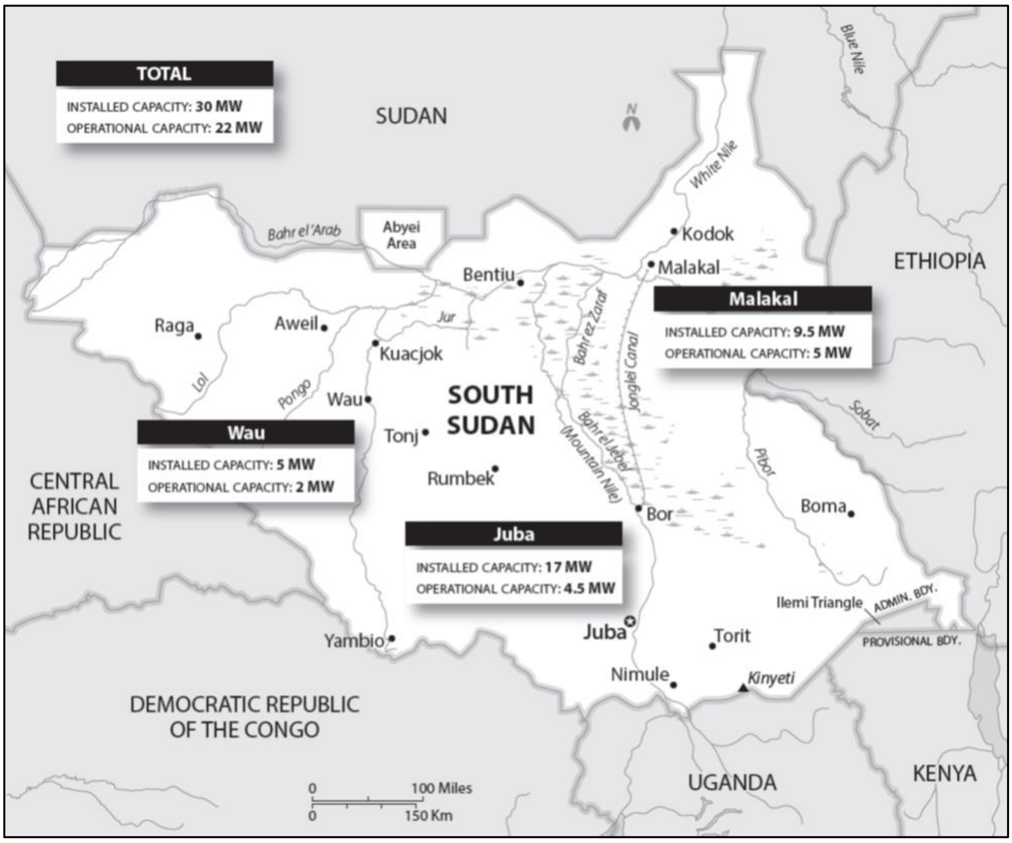


Figure 1- 1: Figure 1- 1: The distribution of South Sudan's electricity installed capacity
Sources. Mozersky and Cammen (2018).

[1] https://www.usaid.gov/powerafrica/south-sudan

Climate change has been identified as a major threat to the economic development of South Sudan. Studies have shown that South Sudan is one of the most rapidly warming places on earth with temperatures increasing by 0.4^{0}C per decade; a rise that is two and half times higher than the global average (USAID 2016a). The total carbon emissions for the country stood at 1.33 $MtCO_2$ that is mainly driven by the reliance of the population on wood fuel and fossil (diesel) combustion for electric power (USAID 2016b). In 2014, South Sudan acceded to the United Nations Framework Convention on Climate Change (UNFCCC) and ratified the Paris Agreement on climate change. South Sudan has also submitted to this global body its Intended Nationally Determined Contribution (INDC) and National Adaptation Plan of Action (NAPA). Both the INDC and NAPA outline national emissions reduction measures and priority sectors to achieve such targets. In the electricity generation and energy use, for example, the country aims to exploit its renewable energy resources potential to achieve a low carbon and climate resilient development outcome (USAID 2016b) as well as generating its projected energy demand. Unfortunately, exploiting these renewable energy resources to supply electricity requires a huge external funding or investment that the South Sudanese government has not been able to attract since its independence in 2011.

Despite rectifying and committing to global conventions on greenhouse gases reduction, UNDP/MoED (2013) observes that, the government of South Sudan has planned to elevate its electricity customers' portfolio and generation capacity to 48,000 and 96 MW respectively by 2020 through the installation of more thermal diesel generators to supply electricity. Electrical generation from diesel generators is insufficient, unreliable, expensive to operate and maintain and can be disruptive to economic development due to variabilities in oil and spare parts prices. For sustainable economic and social development of South Sudan, reliable power supply from environmentally friendly sources is paramount.

The supply of electricity to the public to boost both social and economic development can be made sustainable if it is diversified not only in terms of generation sources, but also in terms of suppliers. In this context, private electricity generation can make a significant contribution to the On-grid system if it is sustainably operated, managed and documented. In the developing countries where the supply of electricity is met using diesel generators like in South Sudan, the sustainability of these diesel generators could be enhanced by integrating with renewable technologies like solar photovoltaic (PV), and establish a hybrid system that is reliable, environmentally and economically sustainable (Sopian *et al.*, 2005; Ani 2016).

1.3. Problem statement

Juba is the commercial and administrative centre with several business opportunities in South Sudan and has the highest population compared with other towns in the country. According to the World Bank report of 2014 on easiness of doing business in South Sudan, there are currently more than 6000 commercial enterprises in Juba (World Bank 2014a). Additionally, all South Sudan government's institutions, foreign diplomatic missions, hundreds of humanitarian organizations including several UN agencies have bases in Juba. The existence of these institutions and companies in Juba indicates a growing demand for electric power in the city.

Despite the potentials for renewable energy generation from hydropower, wind, solar, geothermal and biomass, South Sudan's electricity generation is exclusively diesel-fired. Of the 30 MW installed capacity in the country, 17 MW is installed in Juba of which only 12 MW is operational against a growing demand of 154 MW (Deng 2009). In 2005, following the end of the long civil war, the government recognized the growing business opportunities and electricity demand in Juba. In response to that, it established the Juba emergency power project (JEPP) in which some 5 MW diesel generators were first installed by Electrowatts and later an additional 12 MW generators were installed by Finland's Watsilla following fast-growing power load in Juba. However, after few years of operation, the 5 MW generator broke down leaving only the 12 MW capacity in operational condition in Juba.

Given the fact that diesel-fired electricity generation is notoriously expensive to maintain, generation capacity in Juba declined rapidly which resulted in supply constraints, forced blackouts and load shedding (AfDB 3013a). Since 2014, the electricity generation capacity of Juba power went from 12 MW to 0.0 MW due to rapid variabilities in fuel prices and lack of spare parts for the thermal power plants. In response to the prevalent unreliability of On-grid electricity supply, electricity consumers in Juba opted for Off-grid self-electricity generation using privately owned thermal diesel generators. This practice of own electricity generation is increasingly becoming an important source of electricity in Juba city despite the economic, social and environmental impacts it causes.

As the government continues to face investment challenges into its mega-electricity generation from hydropower for the On-grid system, thermal diesel generators will undoubtedly continue to be the primary source of electricity generation in Juba. Moreover, the current amount of privately generated Off-grid electricity from private diesel generators and the potential of solar energy in Juba as well as its contribution to the Off-grid power is undocumented and the possibility for establishing solar energy hybrid system for sustainable electricity generation remains undetermined.

1.4. Aim of the research

The overall aim of the study was to explore and understand the potential of involving private companies in the generation and supply of electricity to the national electricity grid in Juba city.

1.5. Specific objectives

The objectives of the study are to:

1. Assess the generation options and quantify the Off-grid electricity generation in Juba.
2. Understand the current state of electricity market design and governance in South Sudan.
3. Determine possible mechanisms on how private electricity generators can become electricity traders and contribute to the national on-grid system.
4. Analyze the social, economic and environmental impact of private owned diesel generators.
5. Explore the potential of solar energy and the understanding of the various actors regarding its integration with diesel generators as a step towards energy transition.

1.6.Thesis outline

This thesis is divided into six parts denoted as "chapters" including the introduction, which provided a general overview and the research aim and objectives. Chapter 2 gives a description of the state of energy resource, electricity generation practices and how these resources and practices are governed. Chapter 3 demonstrates the methodology followed in this research; highlighting the processes for data collection and analysis. Chapter 4 presents the research findings in connection with the research objectives. Chapter 5 is devoted for the discussion of the research findings and establishes the linkage with overall literature. It also provides attempts to seal any gap identified in the findings using the knowledge in the literature. Chapter 6 draws the largest picture of the study into a conclusion and provides recommendations for action at both national and state level for sustainable development of the electricity sector.

2.0. LITERATURE REVIEW

2.1. Energy resources and development in South Sudan

One of the most important indicators for a country's development lies on the amount of energy the country produces or consume. Despite being rich in energy resources, the Sub-Saharan Africa (SSA) is very poor in energy supply yet reliable and affordable energy is critical for its development (Blechinger *et al.,* 2016). Energy plays a significant role in improving people's livelihoods, thereby contributing to development and poverty reduction (UNDP/MoED 2013). For instance, since the year 2000, Sub-Saharan Africa has witnessed rapid economic growth and its energy use rose by 45% (IEA 2014a) which indicates the link between energy and development. However, ensuring sufficient energy for such economic growth is also determined by the availability of local energy resources that can be utilized to provide the needed energy.

South Sudan is among the few countries in Sub-Saharan Africa with abundance of both conventional and renewable energy resources. Today, a substantial literature exists on the energy resources of South Sudan (Whiting *et al.,* 2015; UNDP/MoED 2013, AfDB 2013a, World Bank 2013 and Deng 2009), although their potential to drive the country's socio-economic development through energy provision is not fully utilized. Currently, conventional energy resource mainly oil, dominates South Sudan's energy and economic sectors. The country has the capacity of exporting refined as well as crude petroleum products (REEEP 2012). However, as a post-conflict fragile country, Mozersky and Cammen (2018) assess its renewable energy potential and conclude that if attention is properly invested into their development; renewable energy could become a leading driver for sustaining peace in the country by creating green jobs for the youth who can easily be absorbed into various forms of conflicts.

This section of the review, therefore, provides a descriptive outline of the available study reports on South Sudan energy resources and their perceived potentials for the economic development of this country starting first with the conventional and then the renewable sources.

2.1.1. Oil and Gas

The discovery of oil in the united Sudan began in the 1980s by the United States company Chevron, but explorations started in the 1990s (AfDB 2013a; Shankleman 2011). Before 2011, Sudan was the second largest non-OPEC oil producer in Africa with an export revenue earning of US$11 billion in 2010 (EIA 2014a). However, following the independence of South Sudan in 2011, South Sudan took control of the three quarters of the oil production making it the seventh and third largest oil producer in Africa and Sub-Saharan Africa respectively with an output of 360,000 barrel/day (EIA 2014a; AfDB 2013a). Figure 2-1 compares South Sudan's crude oil export to that of Sudan between 2012 and 2016. Although having such resource-based wealth, South Sudan still needs Sudan and vice-versa for two important reasons. The first is the fact that the oil resources are located at their common borders and extend to each other territory. The second is their economic developments. South Sudan depends on Sudan to transport, process and export its crude oil, while the transit and processing fees South Sudan pays makes a significant contribution to Sudan's economy (IMF 2016).

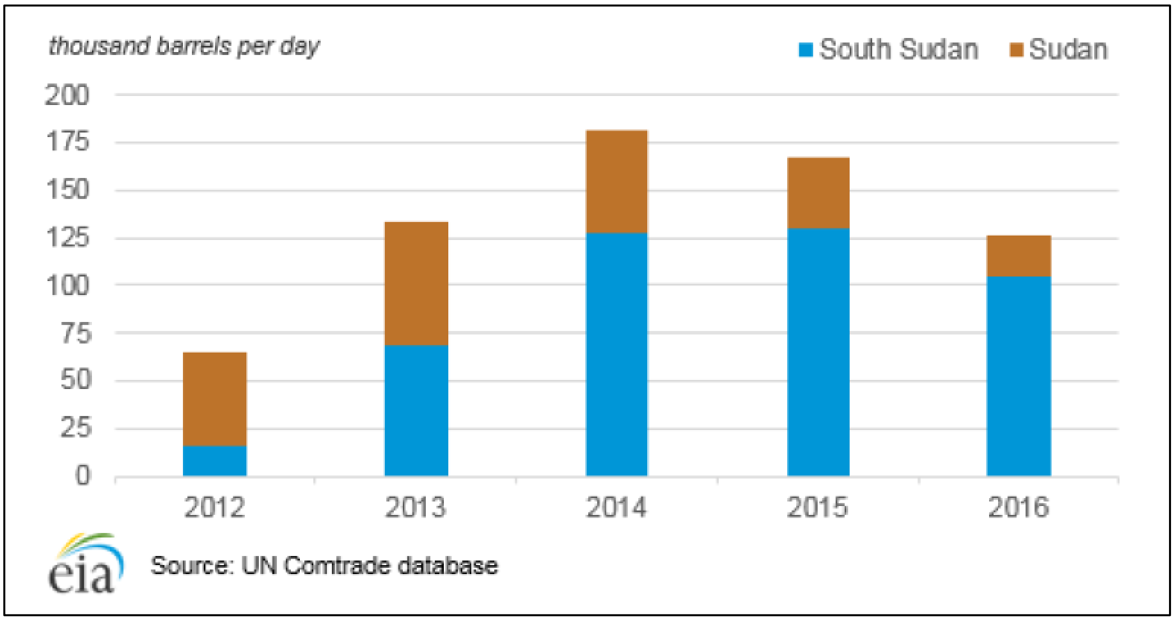


Figure 2- 1: Sudan and South Sudan oil exports
Source: US Energy Information Administration (2018)

The total proved oil and gas reserves for South Sudan stands at 3.5 billion barrels and 3 trillion cubic feet respectively according to both BP's 2017 Statistical Review of World Energy and the Africa Energy Series (2017 p9). However, this does not represent a comprehensive documentation of the available reverses because much of the country is yet to be explored for significant discoveries of reserves outside the known Muglad and Melut basins (US Energy Information Administration 2018). The current oil discoveries are concentrated around Bentiu in Unity state and Melut in Upper Nile state (Figure 2-2) which are demarcated in a number of blocks. Additional areas in Jonglei, Warrap and Lake States have been reported to have potential reserves and if proven, South Sudan will progress as a leading producer of crude oil in Sub-Saharan Africa.

Today, oil plays a leading role in the economic development of South Sudan with a GDP share contribution of as much as 98% that makes it the most oil dependent state in the world (Shankleman 2011; Mager *et al.*, 2016). Exports of petroleum crude is the main source of foreign exchange earnings for South Sudan and as a new landlocked country, the crude oil is transported to the international markets using pipeline passing through Sudan (AfDB 2013a).

South Sudan's crude oil has been categorized into three blends or types namely Nile, Thar and the Dar blends based on their chemical composition (UNDP/MoED 2013). The Nile blend is depicted as of high quality and attracts high market price due to its high fuel and gasoil yields while the Dar blend has low price because it requires more processing before transportation and it also produces more pollutants; thus, endangering the environment around the oil fields. Little is known internationally about the Thar blends found in South Sudan Thar Jath oil field.

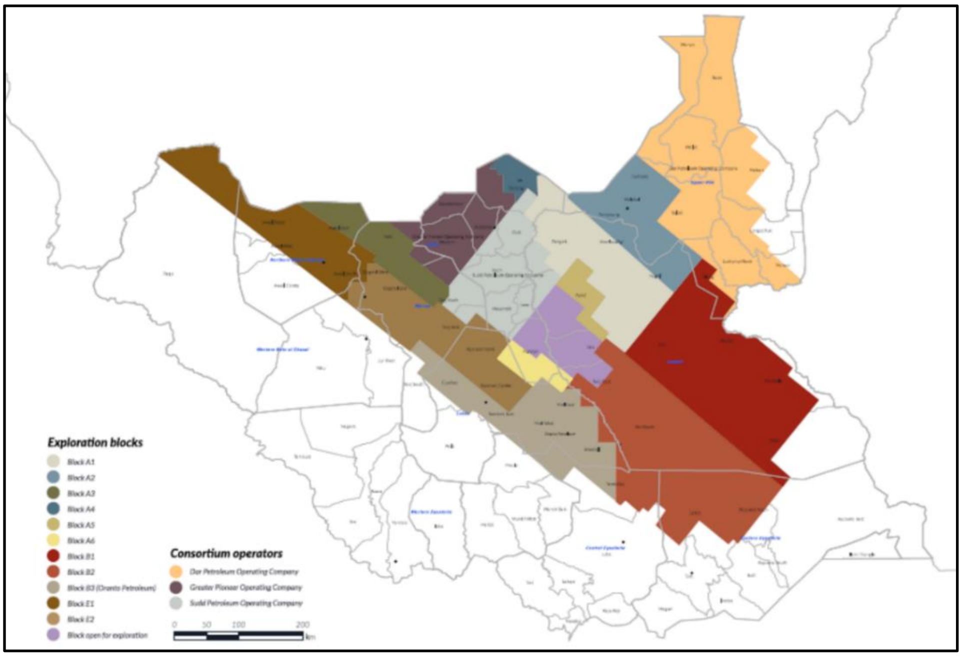


Figure 2- 2: South Sudan Oil and Gas Blocks
Source: Africa energy series (2017)

The management of the oil and gas resources in South Sudan has been described as a natural resource curse (Okwaroh 2012). Right from its independence, recurrent external and internal conflicts coupled with sanctions have prevented the country from attracting potential European and American investors into the sectors. This has given chance to the Asian national oil companies like China National Petroleum Corporation (CNPC), Oil and Natural Gas Corporation (ONGC) of India and Petronas of Malaysia, which operate in large consortia (*i.e. Dar Petroleum Operating Company, Sudd Petroleum Operating Company and the Greater Pioneer Operating Company*) to dominate South Sudan's oil sector. In March 2018 however, the US department of commerce sanctioned all oil firms operating in South Sudan for their alleged role in fuelling brutal civil war using oil money (Reuters 2018).

Additionally, continued conflict resulting into oil infrastructure damages coupled with high degree of negligence among the oil companies have led to big-scale environmental problems. Cordaid, a Dutch organization providing humanitarian aid to communities living around South Sudan's oil-fields observes that "produced water, drilling muds, oil spills and chemicals have seriously polluted the environment in and around the oil fields" (Cordaid 2014) and have resulted into a number of health-related problems. These findings were supported by Pragst *et al.,* (2017) who observe in the Thar Jath oilfields areas an increase of salinity in drinking water with severe human discomfort and rise in livestock morbidity and mortalities due to excessive presence of heavy metals and other chemical substances in the environment. Tiitmamer (2015) further notes that despite the existence of environmental management provisions in the petroleum Act, none of them have been implemented by the oil companies or enforced by the government.

The presence oil and gas deposits can boost a country's energy generation potentials. However, South Sudan has not developed its natural gas potential. WEC (2013) observes that natural gas, which is being produced during oil extraction, is mostly flared or reinjected into the wells for the purpose of oil recovery; hence, there is neither production nor consumption of dry natural gas to meet domestic demand for energy. Additionally, the crude oil is used only for export and in turn, the government has to procure refined petroleum products for thermal electricity production. The government had started building two oil refineries with a total capacity of 13000 b/d in Unity and Upper Nile regions of the country (US energy information administration 2018). It was expected that the completion of the construction would cut down the government's high expenditure on importing about 25-30 million litres of refined heavy fuel oil, diesel, petrol and kerosene per month from foreign markets for its power generators and transport sector, but the emergence of conflicts in the country affected the construction process.

Nevertheless, South Sudan should have explored other avenues to utilize its crude for direct electricity generation. Deng (2009) observes that, with stable production, crude oil will be utilized as a thermal fuel for most of the Watsila Generator sets for electricity generation across South Sudan. The conversion of fossil crude to electricity has a well-documented literature. Saudi Arabia for example generates electricity directly from crude oil and during the period from 2009 to 2013, it used about 0.7 million bbl/d of crude oil for electricity generation to electrify the kingdom (Demirbas *et al.*, 2017; US Energy Information Administration 2014). This option (i.e. crude-electricity) can even be very costly for South Sudan because a pipeline will need to be built between the oil field and Juba where the electricity generation power plants will be stationed or a long transmission line will be needed. Additionally, South Sudan could also undermine its commitment to the international treaties to combat climate change through carbon emission reduction if the option of crude to electricity is to be taken so seriously in the electricity sector.

2.1.2. Hydropower

In the quest for sustainable development and the pursue for clean energy sources as the global climate change discourse increases, hydropower has been considered as a potential source of clean and renewable energy to play an important role in global clean energy supply (UNIDO and ICSHP 2016). Klunne (2013) pointed out that, the African continent possess 10% of world's hydropower potential and majority of which are found in sub-Sahara Africa. Yet only between 4-7% of this potential has been developed to provide electricity to the region for most of the past decades. In the recent years, the SSA region has seen a surge in the development of hydropower and of the total installed electricity generation in the region today, about 20.2% is from hydropower while in other countries in the region like Zambia, Ethiopia, the Democratic

Republic of Congo (DRC), Namibia and Malawi for instance, up to 90% of their electricity supply is hydro powered due to the availability of water resources (Conway *et al.,* 2017).

South Sudan with a proximate location within the Nile Basin is one of the SSA countries endowed with abundant water resources, which constitutes 5% of the total area of the country (AfDB 2013a). The most important feature of South Sudan's water resources is the White Nile that flows through the country and established a number of important hydropower sites. Some scholars including Johnson (2003) have argued that the prospects for the future socio-economic development of South Sudan lies on its water resources potential not on oil as claimed by the government. This is attributed to the fact that water can support electricity generation, livelihoods and also ensures food security for the people which in the moment is a major challenge.

As a potential contributor to global sustainable development through clean energy, South Sudan has vast untapped hydropower potential to generate electricity from large plants to small-scale hydropower plants that can be exploited in an efficient manner that is both profitable and sustainable for the country's development (World Bank 2013; UNEP 2017). The climate and the topography of South Sudan make it a future supplier of hydroelectric power for domestic consumption as well as electricity export. Deng (2009) notes that, throughout the year, South Sudan receives consistent rainfall for almost 9 months with an annual mean ranging from 1mm in the semi-desert north of the country to more than 1600 mm in the equatorial region south and west of the country. Given the mountainous and hilly landscape of the country in those areas experiencing excessive rainfall, natural waterfalls have developed, which radiate water from the upper reaches of mountains and hills to the lower catchment offering South Sudan enormous power supply potentials.

Nevertheless, the development of hydropower in South Sudan face many challenges of political, economic and technical dimensions for several decades of instability. Following the signing of the Comprehensive Peace Agreement (CPA) in 2005 that ended Africa's longest civil war and the establishment of an autonomous government in the Southern Sudan, a number of feasibility studies to determine the actual potential of hydropower were undertaken by the government. Although some sources state that South Sudan has an estimated hydropower potential ranging between 3000 MW to 5583 MW (ESI-Africa 2016; Amogpai 2007; Liu *et al.*, 2013), the government records indicates that the known exploitable hydropower potential for the country is 2105 MW and other sites are still under studies (World Bank 2013). Yet, none of these potentials have been exploited for electricity generation and as a result, the country continues to primarily derive its electricity from diesel generation.

The African Development Bank (AfDB) and the government of South Sudan (GoSS) have found that, South Sudan has 5 mega hydropower sites along the Nile River with a cumulative capacity of 2,590 MW and 18 small hydropower sites on different streams and small rivers across the country with a generation capacity ranging from 1- 40 MW (AfDB 2013a; GoSS, 2014). Figure 2-3 shows the map of South Sudan indicating the location of all mega and small hydropower sites while Table 2-1 presents the known capacities of each of the sites.

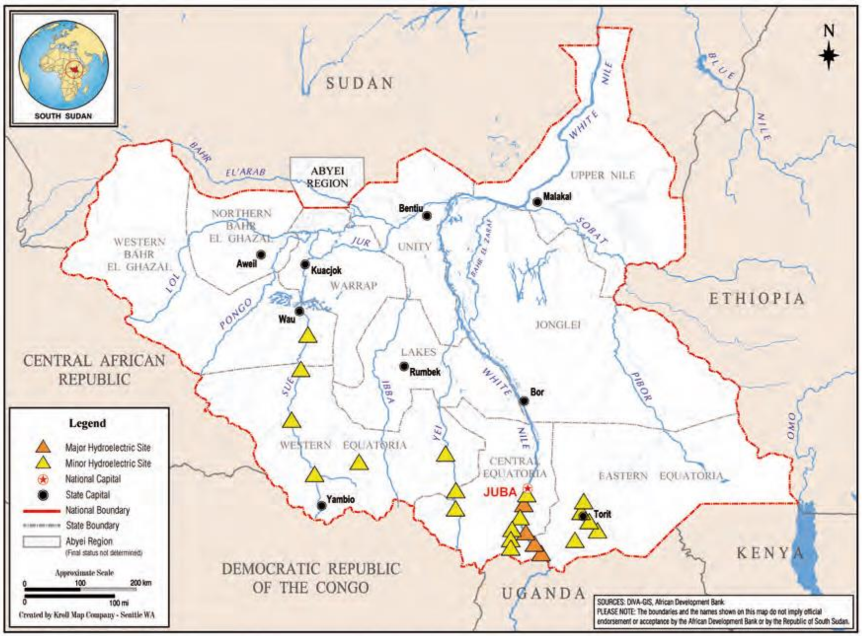


Figure 2-3: Locations of hydropower potential sites in South Sudan
Source: *AfDB, 2013a*

Hydropower sites	Capacity (MW)
Bedden	720
Grand Fula	1080
Lekki	420
Shukoli	250
Juba barrage	120
Sue	12
Yei 1	3
Yei 2, 3,4	0.3
Kinyeti 1-4	3.5
Kaya	13.5
Fula	40

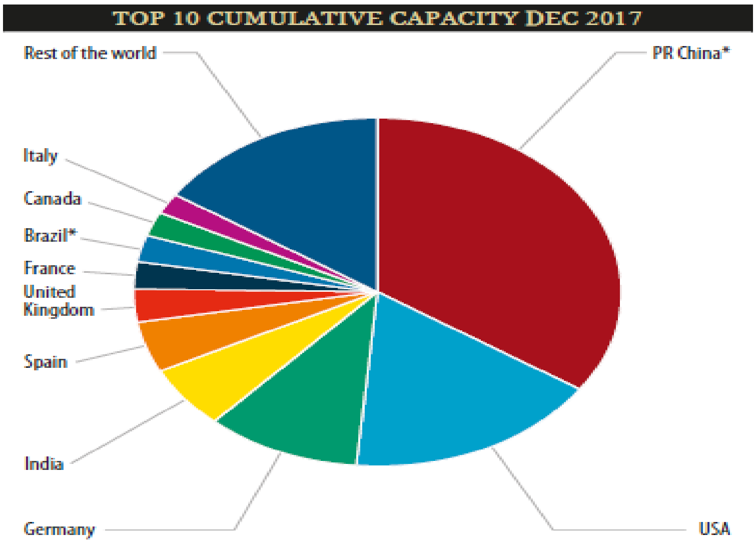
Table 2- 1: Capacities of the potential hydropower sites in South Sudan
Sources: Data modification of Deng (2009).

Despite having limited resources and unattractive investment environment, the government always focus on the development and construction of mega hydropower dams particularly the Fulla rapid and expansion of national grid to electrify the country. According to Mozersky and Kammen (2018) such ambitions are years away even in the best-case scenario, due to the country's state of conflict, economic meltdown and limited institutional capacity. However, it is important to note that, it is not the construction of mega hydropower dams that can solve South Sudan's electricity poverty. As suggested by Klunne (2013) and supported by Ahlborg and Sjöstedt (2015), small-scale hydropower plants can play a significant role in improving access to electricity either through a rural mini-grid system, or as a distributed connection to the national grid system in the country because it does not require the multimillion dollar investment that the country is now unable to attract.

Furthermore, Liu *et al.,* (2013) attest that the construction of large hydropower along the Nile River from the South Sudan-Ugandan border at Nimule to Juba without doubt will take long time to complete; thus, small hydropower plants can prove economically feasible to counter the current electricity deficit in the country and Juba city in particular. Yet, as a post-conflict fragile country, implementing small hydropower plants can even prove practically difficult as South Sudan struggles with institutional, social and political challenges deterring all external supports for the electrifications of the country.

2.1.3. Wind power development

The development and use of wind power dates back to the 19th and 20th centuries. Since early 1980s, wind power has been considered as a clean and green energy source to be exploited for both electricity generation and job creation. Today, Germany, USA, China, UK, India, France, Brazil and Spain (Figure 2-4) are some of the countries with a combined installed capacity of 81% of the total wind energy capacity in the world (Global wind energy council (GWEC), 2017). Prior to the session of South Sudan from Sudan, wind power was mainly used in the agriculture sector having been introduced in the 1950s by the Australian government to El Gezira Agricultural scheme for grain grinding and irrigation (Omar 2015). However, there is no existing historical data of any use of wind power in South Sudan.



Country	MW	% Share
PR China*	188,232	35
USA	89,077	17
Germany	56,132	10
India	32,848	6
Spain	23,170	4
United Kingdom	18,872	3
France	13,759	3
Brazil*	12,763	2
Canada	12,239	2
Italy	9,479	2
Rest of the world	83,008	15
Total TOP 10	**456,572**	**85**
World Total	**539,581**	**100**

Figure 2- 4: Highest cumulative installed capacity in 2017.
Source: GWEC, 2017.

Ackermann (2000), Amogpai (2007), Deng (2009), REEP (2012) and Whiting *et al.*, (2015) all report that wind power density in South Sudan ranges from 2.5-3.8 m/s compared to standard wind velocity of 5 m/s and the highest of which is found in the Upper Nile region of the country. This wind density suggests that large-scale commercial installations of wind turbines in South Sudan is neither attractive for large investment nor economically unviable. Therefore, small turbine installations have a huge opportunity to generate energy for pumping water and irrigation particularly in Renk where there is a form of mechanized commercial farming as well as for rural electrification initiatives.

The installation of small wind turbines can be a promising sustainable energy trajectory for South Sudan's rural electrification program or for Off-grid stand-alone system important for lighting Juba streets as well as transitioning the agriculture sector from rain-dependent to a modern irrigation system (REEEP 2012). The government of South Sudan has therefore focused on future development of the wind power for rural electrification as an approach for electricity decentralization. Tummala *et al.,* (2016) argue that establishing large-scale wind turbines farms are not sustainable renewable energy options for power generation particularly in areas experiencing low wind velocity like in most parts of South Sudan; and that, small scale wind turbines with generation capacity ranging from 1.4-20 kW are the best options to produce sustainable and sufficient energy for domestic needs. The socio-economic viability of small-scale wind turbines make them so attractive for a decentralized Off-grid energy production particularly in low-income developing countries like South Sudan where financing mega electricity power generation remains elusive (Mishnaevskt Jr *et al.*, 2011).

However, wind proponents should also be mindful that wind-based electricity generation is unreliable as it depends on unpredictable weather. The contemporary advancement in energy technologies has amalgamated sustainability into renewable energy generation. For instance, Where the wind speed is low to generate sufficient energy due to weather variabilities, wind turbines can now be integrated with a diesel generator, batteries and solar PV (Fig. 2-5); thus, making electricity generation sustainable (Gan *et al.*, 2015; Uğurlu and Gökçöl 2017; Ullah, 2013).

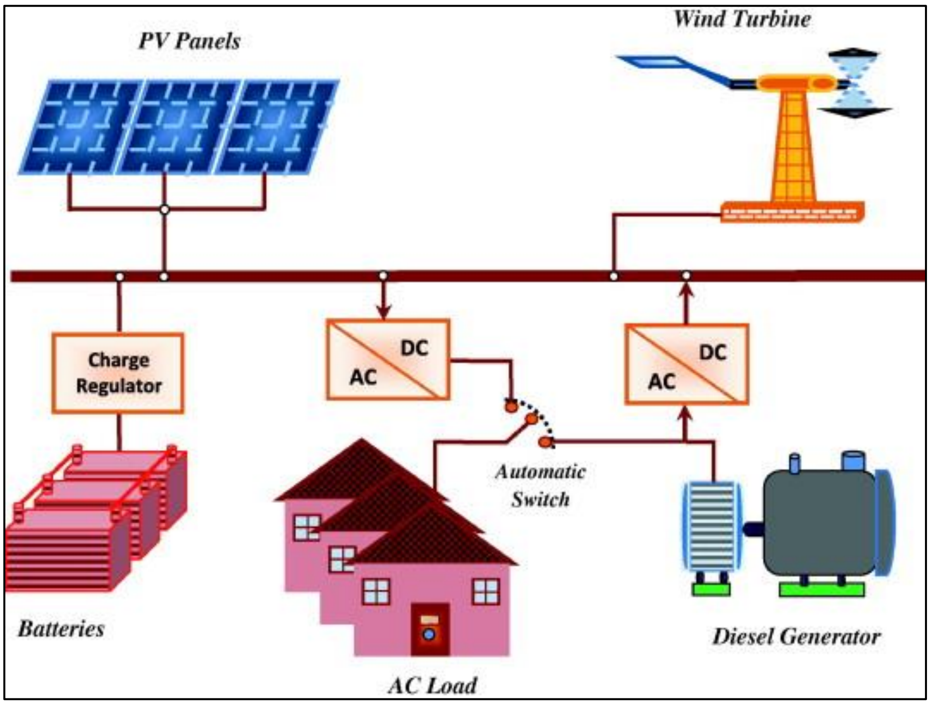


Figure 2-5: Schematic illustration of stand-alone PV/wind/diesel hybrid system with battery storage.
Source. (Kaabeche and Ibtiouen 2014).

2.1.4. Solar energy

Solar energy is one of the highly penetrating renewable energy technologies in the world followed by hydropower (Mozersky and Kammen 2018). Solar energy is categorized into photovoltaic (PV) and solar energy thermal systems based on their final energy output. For example, PV converts sunlight directly into electricity while solar thermal converts sunlight into heat energy that can be utilized at household levels for heating (Amogpai 2007).

South Sudan's solar energy potential at a horizontal surface radiation is estimated to be approximately 6.9 GJm2/year or 436 W/m^2/year and a daily sunshine of more than 8 hours throughout the year (REEEP 2012; Deng 2009;). Although the whole country has ample sun radiations, Northern and Western Bahr el Ghazel states and Renk are particularly attractive locations for solar investment. Figure 2-6 shows the map of South Sudan and the potential for solar energy exploitation. This potential presents an important niche for renewable energy generation either as a connected grid system or a stand-alone Off-grid PV system particularly for rural remote areas where grid extension will not be feasible.

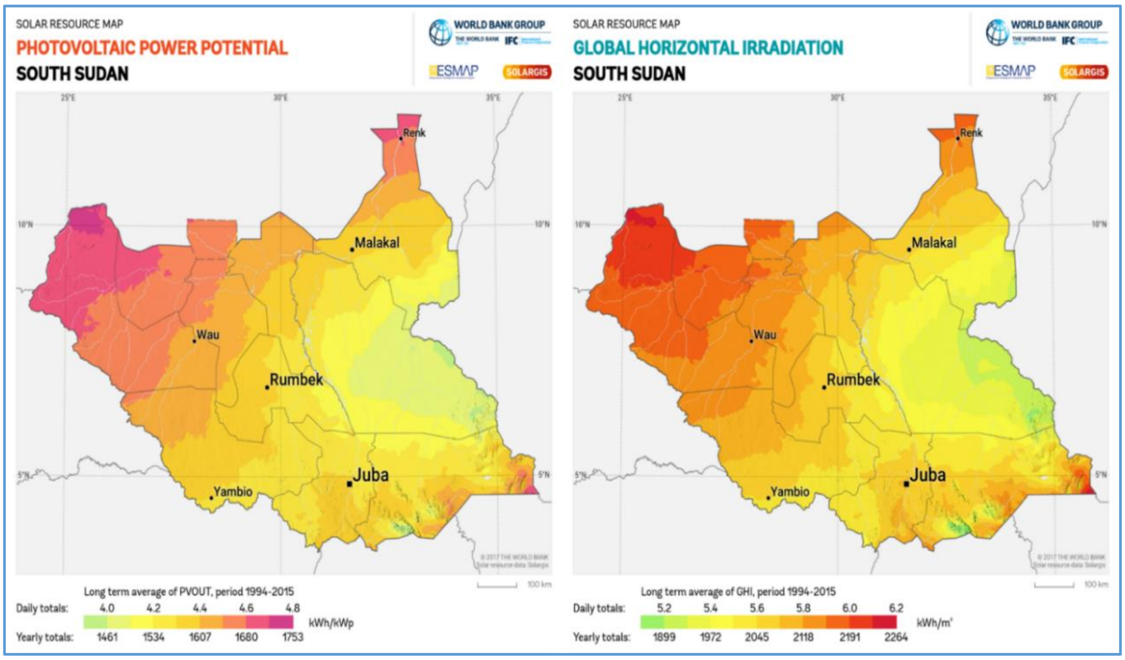


Figure 2- 6: South Sudan's solar energy potential

Source: SolarGis *(2017)*

Solar energy is a promising solution for energy poverty in South Sudan. There is currently a substantial body of literature that elucidates successful implementation of solar technology to improve isolated communities' access to energy in many rural areas in Sub-Sahara Africa (Quansah et al., 2016; Amankwah-Amoah, 2015; Rahut et al., 2017). In South Sudan, the government has recognized the use of solar in the rural electrification program particularly in lighting through a light-emitting diode (LED) in households, schools, administrative units and health centres. For instance, in collaboration with national and international non-governmental organizations (NGOs), different forms of solar devices have been introduced into South Sudan and more than 54,000 households are currently using them for various purposes. Specifically, solar is currently being used for streets lighting in Juba and Maridi, powering radio stations, telecommunication network stations, pumping and heating water, phone charging, refrigeration as well as electricity for watching TV-set (UNDP/MoED 2013; Whiting *et al.*, 2015; REEEP 2012).

In recent years, there has been an explosion of the Solar market in the East Africa region that is either publicly or privately driven. Several companies now offer a variety of solar systems ranging from small appliances such as solar lanterns and small mobile-phone chargers of 0-300 watts peak that are attractively pro-poor to mini-grids at village level as well as utility-scale, grid-connected plants.

However, in South Sudan, Whiting *et al.*, (2015) observe that there is neither a national solar technology producer nor a company although there are few solar energy retailers in Juba selling products probably originating from Asia via Kenya. Altai consulting commissioned by the joint IFC and World Bank Lighting Africa program, conducted solar lighting products supply chain mapping in South Sudan and concluded that although the market opportunities for solar lighting products is huge and untapped, it is disorganized, ungoverned, lacking financing modalities and NGOs are the current major clients with purchasing power of up to 70% of the total products (World Bank, 2014b).

2.1.5. Biomass

In 2014, the World Energy Outlook (WEO) assesses household's energy poverty levels using two important indicators: lack of access to electricity and reliance on traditional forms of biomass. Sadly, SSA popped out with devastating results of only 31% electrification rate and as much as 80% reliance on biomass (Toklu 2017). Again, among the various sources of renewable energy in the green growth discourse today, biomass is the most widely used renewable energy source in the world. For the SSA's rural poor who perceive modern electricity as a form of luxury for the minority rich class, thanks for the continued abundance of biomass that they can still derive their energy needs from it for cooking, drying, lighting and heating despite the health-related risks.

Like the rest of the SSA countries lacking access to electricity, more than 96% of South Sudan's population depends directly on traditional biomass fuel in the form of firewood, charcoal, crop residue and animal wastes (i.e. dung) for all their energy needs (SSNBS 2012; REEEP 2012). The potential of biomass in South Sudan is exceptionally huge. Forest resource is one of the features of South Sudan. Omer (2005) and REEEP (2012) observe that the total forested area in the country is about 75 million hectares and 29.3 cubic meters are the standard international allowable cut limit. Additionally, being rich in livestock, animal waste (i.e. cow dung) is estimated to be 4.5 million tonnes per year; and with 46% of the total land being arable, agricultural residues can add significant potential (Whiting *et al.*, 2015).

Furthermore, in the Municipal Solid Wastes (MSW) sector, South Sudan's cities generate tonnes of wastes. In Juba, for example, a municipal solid waste composition analysis study showed that an average household waste generation rate within Juba city is 1.11 kg/cap/day (UNEP 2013) which seem to be higher than the regional average as shown in Table 2-2.

No.	Water Component	% Juba	% Eastern Africa media
1	Organics	31	60.9
2	Plastics	20	5.5
3	Paper & Carboard	12	7.7
4	Soil/ash	12	Not available
5	Metal	7	1.8
6	Glass	5	2.3
7	Textiles	4	1.7
8	Special care water	2	Not available
9	Other waste	7	12.7
-	Total	100	100

Table 1-2: Comparison of waste composition between Juba and other cities in Eastern Africa
Sources. Adopted from Whiting *et al.*, (2015).

Despite these potentials, the utilization of biomass for electricity generation in South Sudan has not been established. Other than the traditional way of using biomass for rural energy needs, biomass residues are an important source of electricity and other forms of energy like biogas and heat generation. Dasappa (2011) for example assesses the potential of biomass energy for electricity generation in sub-Sahara Africa using gasification technology and conclude that, by using only 30% of the available Agro-processing residues and 10% forest residues from wood processing industry, a power generation potential of 5000 MW and 10000 MW would be derived from the waste respectively.

Through efficient MSW management system, solid waste could also be a potential energy resource via the waste to energy approach. Gashaw (2013) reports the establishment of the first Sub-Sahara African waste to electricity plant of 50 MW capacity in the neighbouring Ethiopian capital Addis Ababa, with a daily load of 500 tonnes of municipal urban wastes. This waste load is less than the one generated in Juba every day. This is an important signal for South Sudan to further investigate in its quest for energy while at the same time fulfilling its international obligations for reduced greenhouse gas emissions.

Furthermore still, South Sudan has the seventh largest livestock population in Africa, which comprise of 11.7 million heads of cattle, 12.5 million goats and 12.1 million sheep (FAO/ WFP 2013). This population indicates yet another potential for biogas generation as a clean energy for rural communities. Organic wastes including agricultural residues, cow dung, human wastes etc. are main constituents of solid biomass, which have a high potential for biogas generation. The use of biomass to generate biogas has been well studied and documented with several successful projects implemented at community levels (Omer 2016; Begum and Nazri 2013; Cioablă and Ionel 2011). In South Sudan, this technology was introduced to Rumbek secondary school in 2001 by UNICEF as a pilot project to demonstrate the potential of biogas for rural sustainable energy needs. However, being a donor-led project, its subsequent development was not possible but the potential for future biogas generation from biomass remains unexploited in South Sudan.

2.1.6. Geothermal energy

Geothermal energy is one of the renewable energy sources that is expected to play an important role in an energy future where the emphasis is no longer on fossil fuels, but on energy resources that are at least semi-renewable and environmentally friendly (Georgsson 2014. According to the US Energy Information Administration, geothermal energy derived its name from two Greek words *geo* (earth) and *therme* (heat). Thus, geothermal energy is heat inside the earth which can be used as steam to heat buildings or to generate electricity. Demirbas *et al.,* (2016) and Kaitano (2016) explain that, geothermal energy has two usage pathways as in electricity generation and direct use in space heating, greenhouse heating in horticultural farming and industries.

In the East Africa region, more than 45% of Kenya's installed electricity capacity, for example, comes from geothermal resource. With approximate location in the Great East Africa rift valley like Kenya, South Sudan has potential geothermal energy resources. Prior to independence, UNESCO took a fact-finding study in 2001 and found a high temperature gradient in oil wells along the Bahr el Arab area indicating the existence of geothermal energy (Blinker and Grassi 2001). Currently, three potential sites have been identified and the government of South Sudan has prioritized geothermal development in partnership with Kenya’s Geothermal Development Company (GDC), which has the necessary expertise, and experience in conducting surface exploration to ascertain the actual reserve.

2.2. Electricity generation and supply

2.2.1. An overview.

Electricity is one of the modern drivers of a nation's economy as well as improvement in the quality of people's lives by increasing the level of health, education and technological advancement. Reliable supply of electricity opens up national economy to many opportunities thereby achieving socio-economic growth and development and when electricity reliability is interrupted, it causes outages that create unfavourable environment for economic growth (Javadi *et al.,* 2012; Kolawole *et al.,* 2017). This therefore shows that a consistent flow of electricity is paramount for strong economic development.

Yet, despite the significance of electricity to humanity, there are as many as 1.3 billion people without access to electricity and 3.5 billion mostly in the developing world rely on solid fuel like biomass as their primary source of energy which not only endanger their health but also severely damaging the environment (Langbein, *et al.,* 2017). Examining the limitation to modern energy access reveals that of those who do have access to electricity, majority are concentrated in the Sub-Sahara Africa (65%) compared to 20% in South Asia, 3.5% in East Asia and Specific, 3% in Latin America and 3% in the Middle East and North Africa (MENA). This is a clear indication that, electricity generation in SSA is low when compared with the rest of the world. This made Rosnes and Vennemo (2008) to asserts that, there is no place in the world that the gap between available energy resources and access to electricity is greater except in Sub-Saharan Africa.

Reliable supply of electricity is determined by the availability of energy resources. In this context, Sub-Sahara Africa has the potential to dominate global power supply, but power continues to remain the largest bottleneck faced by many countries in this region. According to the International Energy Agency (IEA), 30% of the global oil and gas discoveries are in

SSA. Coal production stood at 220 Mtce in 2012 and there are several potential renewable energy sources including solar and wind that are not fully exploited. Additionally, the hydropower potential for the region represents 10% of the global hydropower. The East Africa rift valley is also another energy hotspot for its geothermal potential. Interestingly, 18% of the world uranium supply is in SSA but nuclear energy is not in the energy debate of the region. The challenge of SSA according to the IEA is lack of capacity to turn these resources into electricity production to drive the region's socio-economic development (IEA 2014a).

2.2.2. Electricity generation

As stated earlier, the majority of South Sudan population obtain their energy needs from biomass with over 96% of the households in Juba use firewood or charcoal as their primary fuel for cooking. Electricity generation capacity is only 22 MW from thermal diesel generators for the whole country and 1% of the 12 million people have access to the electricity. Most of these people with access to electricity live in Juba and the remainder in Malakal and Wau towns where there is electricity grid (World Bank 2013). This energy poverty just represents the snapshot of the big picture of energy insecurity in the whole of Sub-Saharan Africa.

In 2012, the total installed generation capacity of Sub-Sahara Africa was one of the world's lowest with a capacity of 90 gigawatts (GW) compared to 2,192 GW in Asia. One country (South Africa) accounts for more than half of the existing installed capacity in the region. The electricity generation has a heavy dependency on fossil than renewables, which are so abundant in the region. Coal, natural gas and oil dominates the electricity production sector with exception of hydro, which has a significant contribution (see Figure 2-7). At individual country levels, the focus and the installed capacities differ substantially. For example, in South Africa coal is the main generator (85%), in Nigeria natural gas (71%), Uganda, hydro (76%), Kenya, geothermal (47%) and in South Sudan, oil (100%). Other countries have more than one resources hence; they diversify their generation (US Energy Information 2015; IEA 2014a; EXIM Bank 2017).

The disparities in the electricity mix in the SSA region can be attributed to each country's resource base and the available national technological knowhow. Taking the five countries above, one can see a wide difference in their installed capacities, which in some countries may require decades to be able to electrify the country when viewed in contrast to population and country size as follow. South Africa has installed capacity of 45820 MW against a population of 56 million and land area of 1219090 km^2; Nigeria's installed capacity is 12500 MW, population of 186 million and area of 923768km^2; Uganda with 850 MW, population of 41.5 million and area of 241038km^2; Kenya with 2370 MW, population of 48.5 million and area of 580367km^2. Meanwhile South Sudan has the lowest installed capacity of 22 MW against a population of 12.2 million and area of 644329km^2 (Eberhard *et al.,* 2016; CIA n.d.). According to Mozersky and Kammen (2018), South Sudan's total installed capacity meant to supply power to tens of thousands of customers is just the equivalent of the amount of electricity needed to power 3600 houses in the United States. The above country's demographic data have an impact on electricity demand, transmission/distribution and accessibility including rural electrification programs planning.

Production per capita of electricity is very low in SSA compared to the world regional scale. The whole Africa has a per capita generation of 123 MW/million population compare to 1,078 for Eastern Europe and Central Asia, 3,600 for Asia and 515 for Latin America (United Nations Economic Commission for Africa-UNECA 2014). Most of the existing installed electricity generation in SSA is grid-based. IEA (2014a) partition the whole of Sub-Sahara Africa into four sub-regions and highlighted that Southern Africa has the highest installed grid-based capacity compared to the other sub-regions (fig. 2-7). In its detailed analysis, Southern Africa sub-region has 58 GW of which about 79% mainly from coal is in South Africa leaving the rest of the member countries with 21% mainly from hydropower. South Africa's portion of the sub-regional grid capacity is attributed to the fact that 45% of coal in sub-Sahara African is in South Africa. The West Africa has 20 GW mostly gas-fired in Nigeria because of its natural gas wealth and only 30% of the capacity is in the rest of the member countries.

Unlike in the case of Nigeria where most of the electricity came from natural gas which is regarded as a clean form, the rest of the west Africa sub-region generate most of their electricity from oil. The East Africa where South Sudan sits has 8.1 GW mainly from hydropower and 45% oil-fired, which points to the potential of the Nile waters and the large-scale hydropower development in Ethiopia as well as the 6.2 billion proved oil reserves in both Sudan and South Sudan. However, the Central Africa sub-region, which account for 12% of the total population of SSA has only 4GW about 4% of the total installed capacity in the region. Most of the 4GW is hydro generated (65%) and oil-fired (20%).

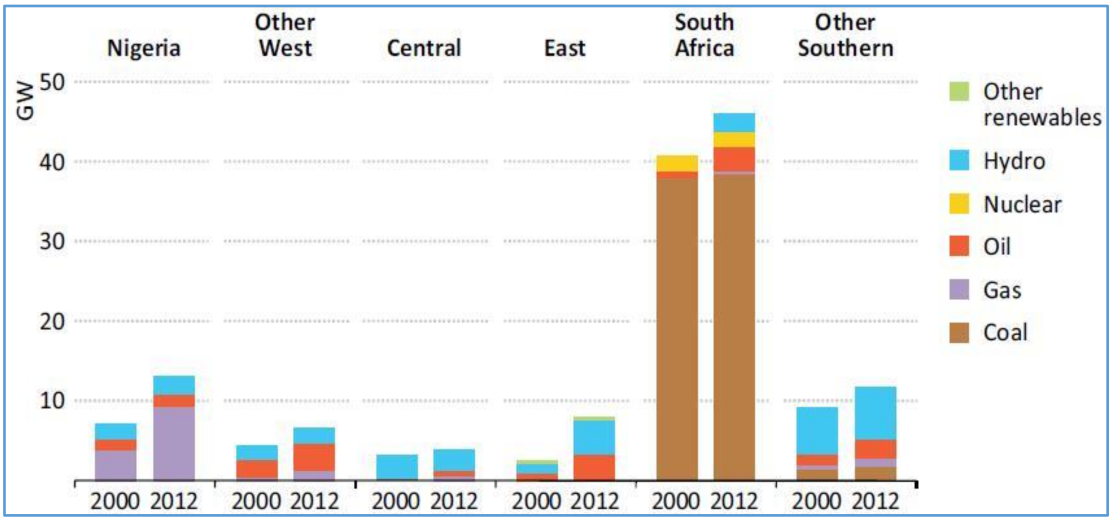


Figure 2- 7: Installed grid-based capacity by type and sub-region
Source. IEA (2014a)

2.2.3. Electricity supply and accessibility

When diagnosing the possible mechanism for electricity generation and people's access to electricity services, it is important to note that, there is no direct proportionality between installed electricity generation capacity of a country and the real amount of final electricity that is available for the consumers. Many factors contribute to this fact by constraining electricity generation, supply and accessibility in SSA. In addition to having low electricity generation capacities in most countries in SSA region with exception of South Africa, the transmission and distribution networks also pose a challenge as it lacks efficiency thus, resulting in severe losses and reduction in the amount of power available for the end-users.

As a point of reference, in 2014 the total power losses in Africa stood at 21.1% and in some countries, it is even much higher beyond imaginations with an average between 30% and 50% in Sub-Sahara Africa (Baurzhan and Jenkins 2017). UNECA (2014) observes that, the Eastern Africa sub-region has the least access rate in SSA, which is characterized by exceptionally high transmission and distribution losses. In Tanzania, losses exceed 20% of the generated amount, DRC has between 20% and 30%, and Uganda has 38% only from distribution apart from cases of theft, technical knowhow and illegal connections.

The disparities in generation and transmission/distribution capacities have a lot to inform any energy sector analysis. In this context, it may be presumed that the rate of electricity transmission and distribution losses is directly proportional to the installed generation capacity. This claim is fully supported by IEA (2014a) which states that transmission and distribution losses reduce the supply of the available electricity to end-user in SSA by more than 20% but drops to an average of 18% when South Africa, which account for almost half of the installed capacity, is removed. Further, when South Africa is compared to North Africa which has the highest electricity access in the continent, the transmission and distribution losses for South Africa stands at 10% compared to 14% for North Africa which confirms the conclusion that, the higher the generation capacity, the higher the transmission and distribution losses.

Low per capita electricity generation equals low per capita electricity consumption. Over the past years, demand for electricity in SSA grew rapidly, yet electricity consumption has stagnated as world lowest. Although it is widely known that the per capita electricity consumption in SSA is one-third of the world average making it the highest in the world with people without access to modern electricity, there is large discrepancies within and between countries (EXIM Bank 2017; Kolawole *et al.*, 2017).

Rural areas have the lowest consumption per capita ranging from 50-100kWh and other countries particularly South Africa exceeds world average (IEA 2014b). Nevertheless, other countries like South Sudan with heavy reliance on biomass energy, which accounts for over 96% of total energy consumption, have a per capita electricity consumption rate that is the lowest in comparison with its neighbouring countries (Fig. 2-8). Of the five neighbouring countries excluding Central Africa Republic, South Sudan has the lowest per capita consumption rate of just about 10kWh followed by Ethiopia while Kenya has the highest per capita consumption among South Sudan's neighbours (World Bank 2013).

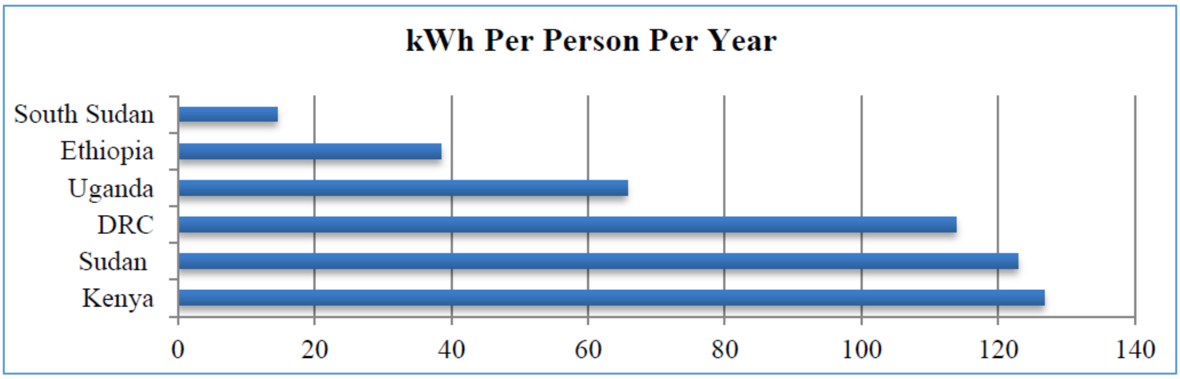


Figure 2- 8: Per Capita Electricity Consumption Highlighting South Sudan
Source. *World Bank (2013)*

At a country level within the Sub-Sahara Africa, there is even great disproportion in the degree of access to electricity with South Sudan being the least country in electricity access. UNECA observes that while some countries are in total access deficit, others are better off which ranges from 1% in South Sudan to 99.8% in Seychelles (UNECA 2014). Figure 2-9 indicates access to electricity in South Sudan and how it compares to the Eastern Africa sub-region. It is of no doubt however that the combination of low level of electricity generation coupled with heavy dependence on biomass, low per capita electricity consumption and the lack of adequate energy infrastructure represent a handful of some of the main energy challenges South Sudan need to confront in its electricity sector.

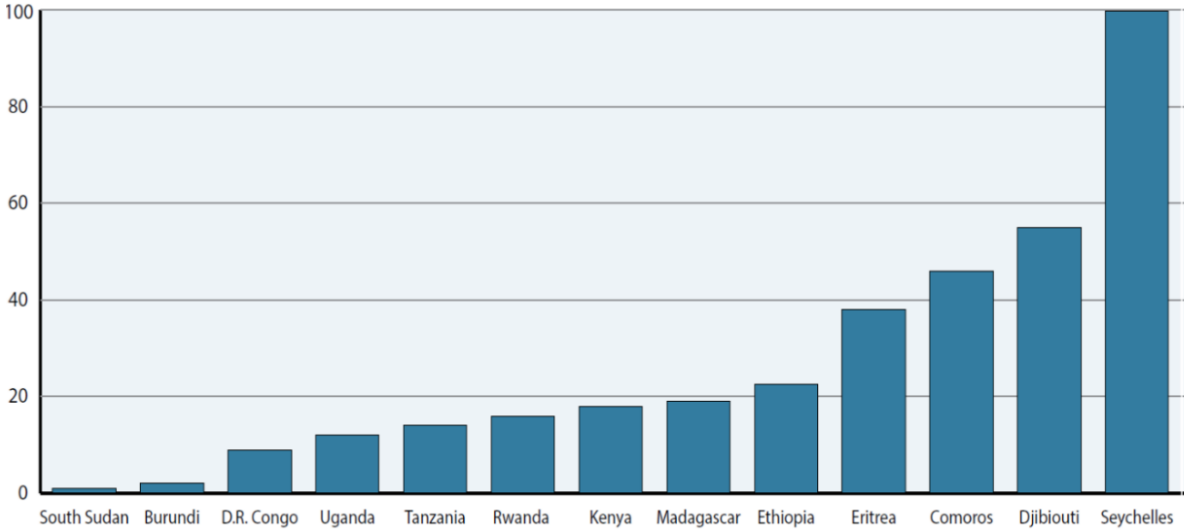


Figure 2- 9: Percentage of population in Eastern African Member states with access to electricity.
Source. UNECA (2014).

Furthermore, in an analysis on the level of access to electricity in 13 countries in the Eastern Africa sub-region including South Sudan, UNECA found that, although the average access to electricity in these countries is 27% or 21% without Seychelles which has a 99.8% access rate in the sub-region, there is a huge gap at country levels. Comoros, Eritrea, Seychelles and Djibouti are above average by 19%, 11%, 72% and 28% respectively. Yet on the dark side of it, the rest of the countries fall below the sub-regional average with a significant sub-regional access gap of 26% in South Sudan and Burundi while others range from 4.5% in Ethiopia to 18% in the Democratic Republic of Congo (DRC). Figure 2-10 shows the discrepancies in access to electricity level while further indicting the level at which South Sudan's access rate compares to both the sub-region and the Sub-Sahara Africa.

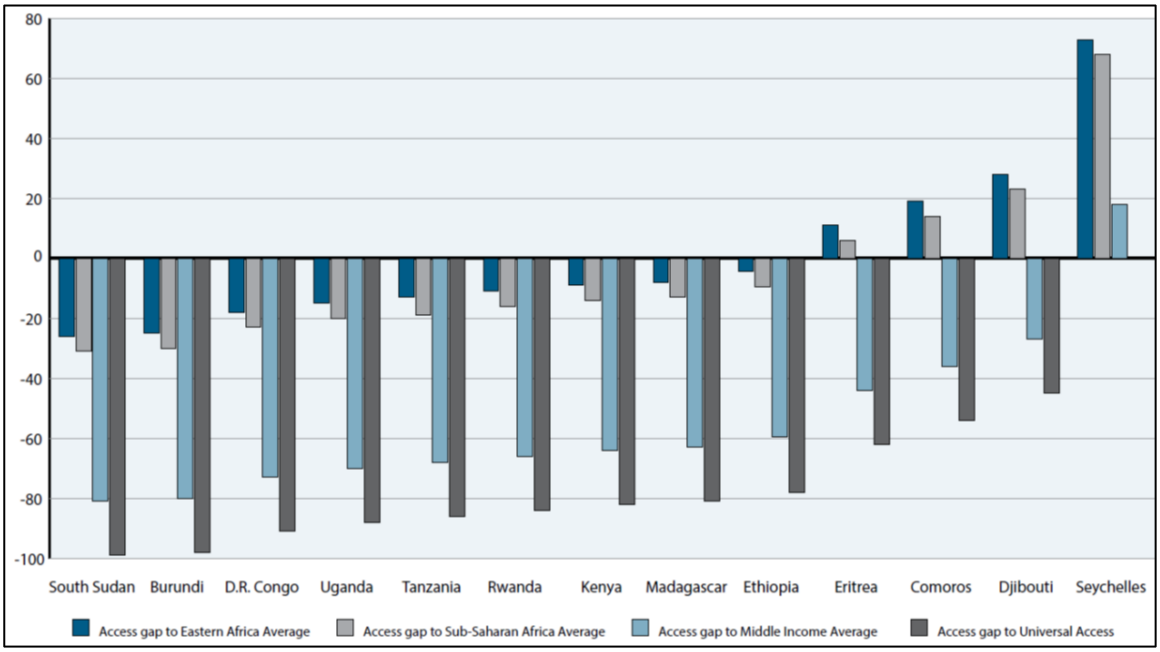


Figure 2- 10: Electricity access gap in Eastern African countries relative to sub-regional, sub-Saharan, middle-income and universal access levels

Source. UNECA 2014

In most of the countries in the region including South Sudan, utilities are government parastatals with direct influence of specific government institution on their functioning. These utilities are subjected to deal with government bureaucratic procurement procedures which unfortunately prolongs the installations or maintenance of the generation infrastructure that eventually result into low production and supply. Factors such as: (i) limited development of the available renewable energy resources, (ii) energy infrastructure inadequacy (iii) limited investment in electricity generation capacity (iv) household income levels and (v) the nature of energy policy reform and market governance can be responsible for constraining people's access to electricity. Additionally, non-decentralized energy systems particularly to the rural areas where the majority of people live is yet another challenge because the available grid connections have only concentrated in urban and peri-urban centers leaving out the largest portion of the population without access to electricity (Chhetri 2007).

With fossil fuels being the main sources for electricity generation coupled with poor T&D network, it is inevitable that the costs to produce one unit of electricity can be very high, and for the consumers to be connected to the electricity network, utility companies reflect all incurred costs in the final consumer price. IEA (2014a) and EXIM Bank (2017) report that the average cost of electricity generation in 2012 was $115 per Mwh. But when an estimated 18% losses, transmission/distribution infrastructure costs and retail services are added, the cost goes to $205 per Mwh or higher in some countries which logically means that a region with more than 65% of its population living below the poverty line cannot afford to connect even when the electricity is heavily subsidize by the local governments.

2.2.4. Self-Generation

Rising electricity demand coupled with inadequate generation capacity, high T&D losses and several electricity outages causing massive economic losses to firms has made the performance of Africa's electricity sector to be notoriously unsatisfactory, inefficient and unreliable (Steinbuks and Foster 2010). Castellano *et al.*, (2015) further assert that erratic electricity supply in the Sub-Sahara Africa has resulted to 20% and 5% economic losses of GDP and sales respectively. In the past few years however, the inability to provide reliable electricity in SSA has grossly encourage the prolific growth of inefficient and expensive on-site self-generation of electricity which account for 6-10% of the region's generation capacity (Foster and Steinbuks 2009; Avila *et al.*, 2017). Figure 2-11 shows the percentage of firms owning back-up generators in selected countries in Sub-Sahara Africa, while Figure 2-12 shows the share of own electricity generation of some African countries in the national installed capacity as of 2005. Today, self-generated electricity from small to medium-sized thermal diesel generators has become an increasingly important source of power for many end-users ranging from households to large enterprises.

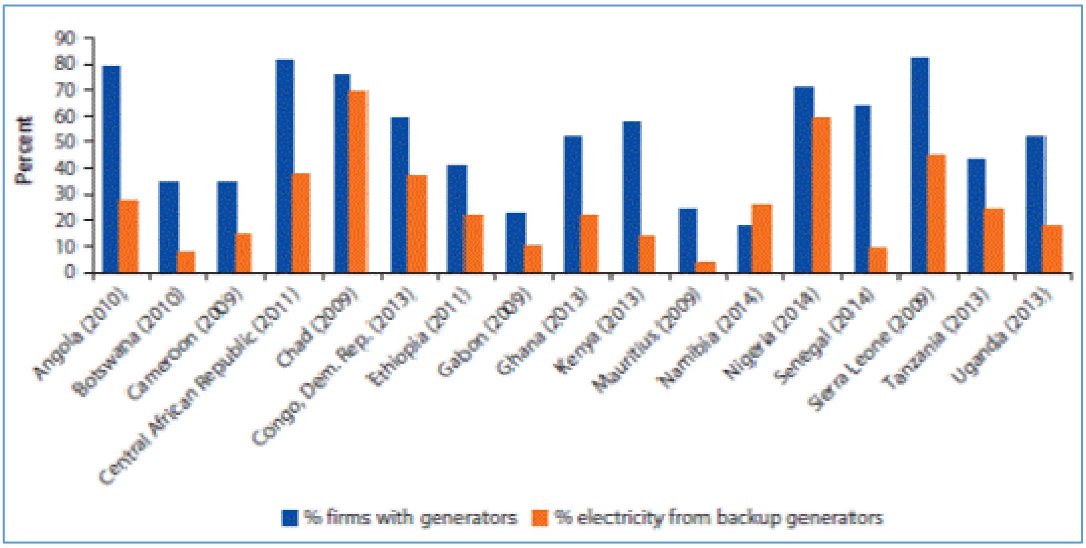


Figure 2- 11: Percentage of firms in selected Sub-Saharan African countries relying on back-up generators.
Source: Eberhard *et al.*, 2016.

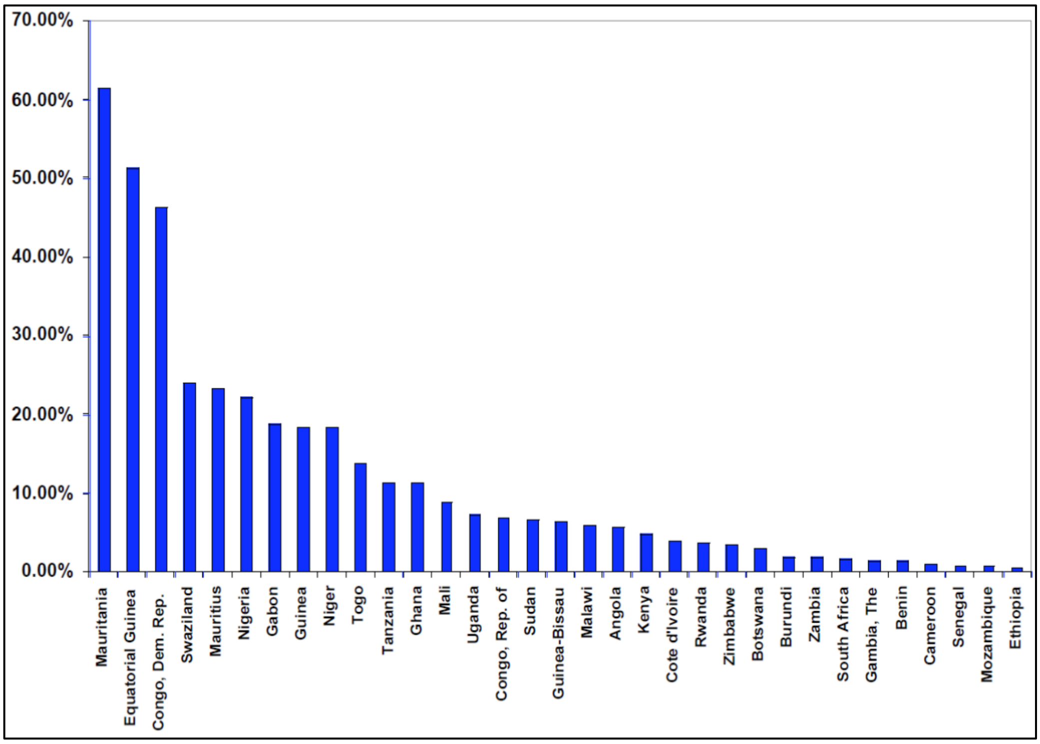


Figure 2- 12: Own-generated electricity as a share of installed generating capacity in Africa, 2005
Source: Foster and Steinbuks 2009

Self-generated electricity using diesel generators is perceived as an alternative to the continuous outages of the public utilities or during emergency; yet, it is generally more expensive than electricity from the public grid since the generation cost for one kilowatts hour (kWh) varies between US$0.3 and US$0.7 (Baurzhan and Jenkins 2017). With the global volatility of oil prices, it can even be insufficient and unreliable leave alone the accompanied health, social and environmental issues (Azodo 2014). Even with back-up own generations, there is still unmet demand for electricity and in most cases, households or enterprises without generators are left in darkness during short or long outages while those with private generator installations are left to struggle with significant additional costs associated with running their generators.

Steinbuks and Foster (2010) claim in their study that firms which own a back-up generator incur outages related losses of less than US$50/hour compared with more than US$150/hour incurred by companies lacking back-up generators. Nonetheless, this finding is a narrow comparison of the fact surrounding diesel-based electricity generation because it is not based on cost-benefit analysis, which could have indicated the cost of generating the electricity utilized during the outage(s). Oketola (2014) and the World Bank (2013) in their separate analyses reveal the real burden of electricity generation based on diesel generators. In each of the studies, they observe that Nigeria and South Sudan spent US$455 and US$71 million in 2011 on running generators and for the case of South Sudan, the utility company made a significant loss of US$ 54 million about 76% of the total investment.

The wide spread substitution of public for private provision of electricity explains why the role of private utilities or individual entrepreneurs in boosting electricity generation and supply within a given geographical location. However, as stated earlier, self-generation based of diesel can create a multifaceted problem relating from fossil fuel price volatility and variability couple with expensive maintenance costs. Thus, self-generation can be sustainably managed by integrating with renewable energy sources.

2.3. Solar as model for energy transition

In the contemporary global development sphere, climate change has emerged as one of the most impediments to development, and the fact that development is directly linked with energy; energy processes are therefore responsible for up to 80% of the global climate change issues due to emission of greenhouse gases (IEA 2015a). Yet, in the developing countries where electricity provision is insufficient and disruptive, the rate of self-generation, using fossil sources like diesel generators have risen spontaneously.

Electrical transmission and distribution grids do not cover many remote areas in Sub-Saharan Africa. Hence, isolated diesel generators have become the predominant standard to produce electricity because diesel generators have comparably low investment costs and easy operational and maintenance structure when compared to the expansion of the electricity grid system to scattered small settlements in rural areas (Platts 2009; Chaurey and Kandpal 2010). Nevertheless, the over reliance on local diesel generators leads to a high dependence on the imports of fossil fuels which make institutions and countries on one hand vulnerable to volatile crude oil prices and environmental degradation due to carbon emissions on the other. Thus, the adoption of this approach for addressing energy poverty is not appealing for future scalability (Cader *et al.,* 2023; Ulsrud *et al.,* 2015).

According to IEA, “the current trends in energy supply and use are unsustainable economically, environmentally and socially and without decisive actions, energy related greenhouse gases (GHG) emission would lead to a considerable climate change degradation with an average of 6^0C global warming” (IEA 2015b p1). This leads to the quest for sustainable energy solutions that are able to fulfil the present energy demand while preserving the environment and natural resources for the future generations. Renewable energy (RE) particularly solar photovoltaic (PV) is one of the most promising emerging technologies that can offer beneficial solutions to ensure energy access, decarbonization of the power sector and sustainable energy supply thus, leading the way towards energy transition (Breyer *et al.,* 2017).

2.3.1. Photovoltaic (PV) technology

The idea of using sun for heating and lighting dates back to the ancient Greek history; but its extensive use and commercialization began in the 1970s first in the space satellite industry and then following the 1973 oil crisis, western governments began the transition from oil dependency to alternative sustainable energy sources (El-Zein 2017). Solar PV is one of the renewable energy technologies that operates by direct conversion of sunlight into electricity in a more efficient process without any gas or noise. The conversion of light to electricity takes place in a solar PV cell constructed of a special semiconductor material like silicon or thin film cells made from a photosensitive material (Mundo-Hemandez *et al.,* 2014; Hosford and Cole 2015).

When the sunlight falls on the PV cells, direct electric currents (DC) are produced, which ideally means that only loads comfortable with such units can utilize PV power. However, the system has been well refined to ensure that it is applicable to all loads by the inclusion of an inverter into the system that coverts the DC to alternating currents (AC) output for AC loads/consumption. Given its simplicity and efficiency of about 6-15%, solar energy supply represents a promising potential for increasing access to electricity services by forming an amazing and sustainable power system. Depending on how the system is installed and set-up, solar photovoltaic technology can be utilized as a standalone/off-grid system in remote areas without electricity grid to give rural communities access to electricity or used as a grid-connected installation system in which the electric power generated is fitted directly to the public grid for distribution (Mundo-Hernandez *et al*., 2014).

Although Africa as a continent has, the best solar energy potentials ranging from less than 1600 to more than 2400 kWh/m^2 capable to produce on average twice as much electricity than in most European countries, solar PV installed capacities and electricity generation remain lower than the rest of the world (Baurzhan and Jenkins 2016; Jäger-Waldau 2017). Solar PV electricity is in fact the most preferred energy technology for more than 40% of the population particularly in the rural setting and the market is mostly dominated with Solar Home System (SHS). As of 2016 global statistics, China has emerged has world number one in terms of solar power installed capacity (i.e. 77.5 GW) followed by German with 48.3 GW that is approximately 63% of its power demand. Meanwhile only South Africa in the entire African continent has the largest installed capacity of 1.5 GW and world's twentieth (PV Magazine 2017; Morris and Pehnt 2016).

Even interestingly enough, the total installed solar power capacity of German for instance is greater than that for the whole Sub-Sahara Africa without South Africa but the incentive for future development guarantees Africa's potential. Figure 13 below shows global solar energy potential of the various regions of the world in which Africa and the Middle East have the best solar power potential and to some extent Australia. Meanwhile figure 14 shows the top 10 countries in the world for solar power total installed capacity with China has world's number one despite having less potential than some countries in Africa.

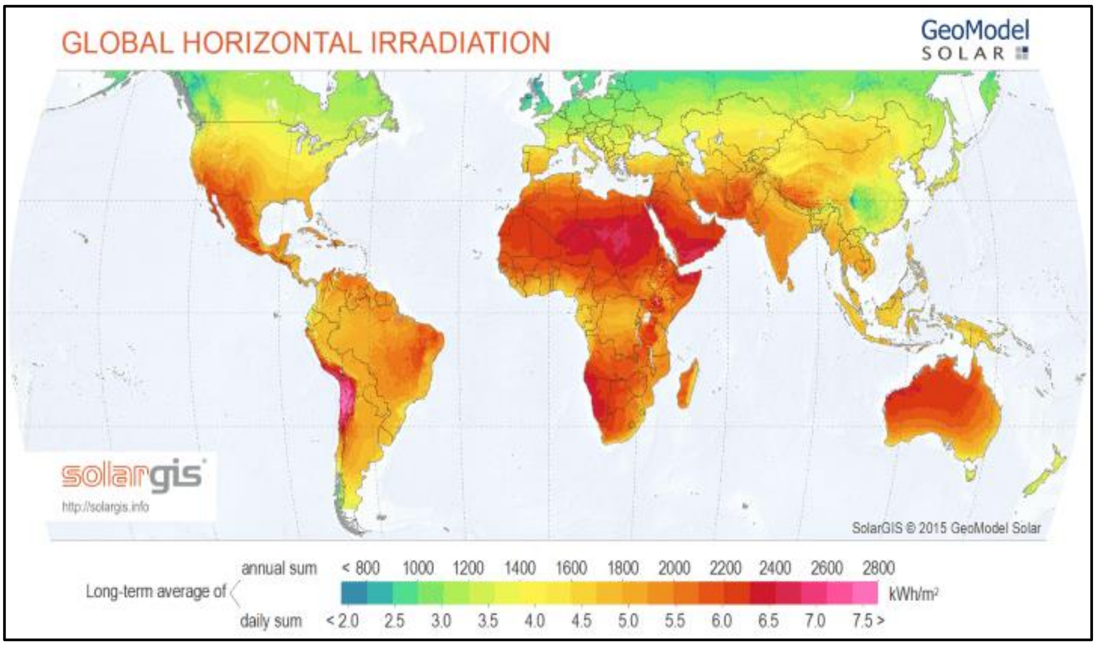


Figure 2- 13: World Solar PV Energy Potential Maps
Sources: British Business Energy 2016.

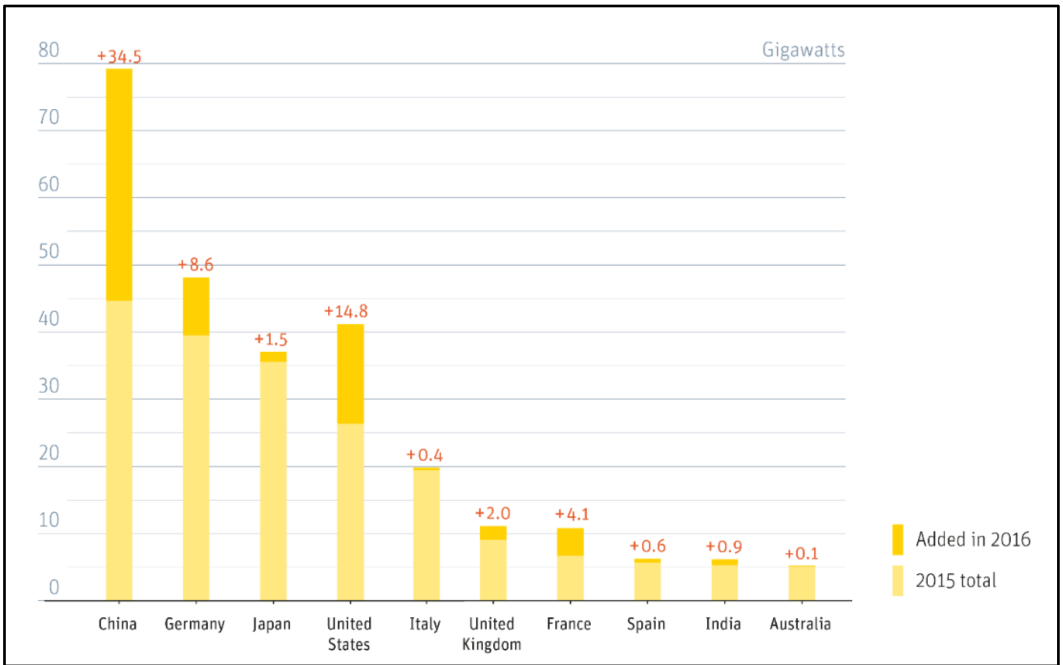


Figure 2- 14: The top 10 countries in the world for solar power total installed capacity
Sources: Morris (2016)

2.3.2. Grid-connected solar PV system

Solar PV system can be in a form of a mini-grid system that generate electricity and the electricity is directly transferred to the grid network connecting several households to the system. Grid-connected solar PV can either be as a decentralized with solar PV panels mostly installed on rooftop buildings or centralized (Small or large-scale solar power plant). A typical set up of the PV system comprises of pieces of solar PV panels, electricity grid system, grid-inverters and may or may not include batteries for energy storage. In the case where batteries are not used, the grid serves as the energy storage facility thus, keeping the cost of installation and electricity consumption low and make it very attractive. Since solar PV generates direct currents (DC), the inverters connected to the network help in the regulation of voltages and the frequency of the electricity produced to meet the requirements of the grid. Figure 2-15 shows a schematic representation of a grid-connected system in isolated residential.

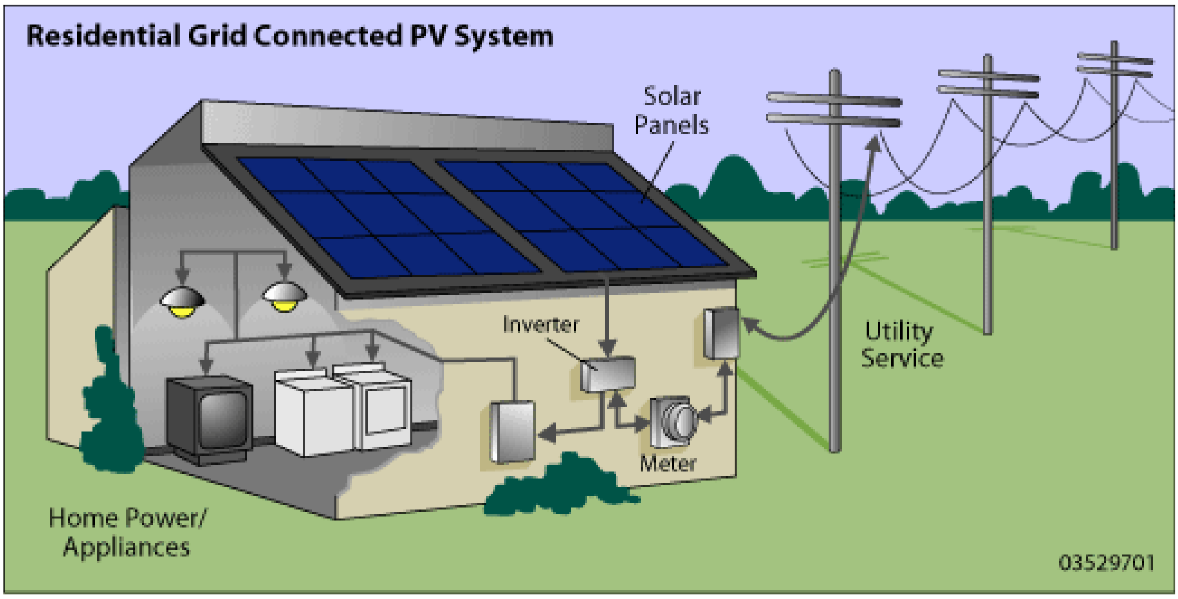


Figure 2- 15: Schematic representation of a Grid-Connected PV System.
Sources: Quansah *et al.*, (2016).

Quansh *et al.*, (2016) and Hosford (2015) state that in the grid-connected solar PV system, when the solar PV produces more electricity in sunny days than needed for the house consumption, the excess is exported to the electricity grid and supplied to surrounding households, and during days of bad weather and night hours, electricity is taken from the grid and used to power the house. This phenomena of supplying the grid system by individual private generators is the core issue of this thesis. However, it is important to note that the growth of solar PV power supply by small-scale prosumers in countries like German and others has been incentivized by local regimes that act as attractors of Independent Power Producers (IPPs).

In the context of Africa, Baurzhan and Jenkins (2017) has reported a number of successfully built utility scale Solar PV power plants in Africa with varying capacities that include a 15MW plant in Mauritania, 96MW in South Africa and 50MW in Ghana. In the Eastern Africa sub-region, Kenya is planning to become a regional leader in Solar PV installed capacity as stated in its energy plan to increase Solar PV in the mix to a capacity of 100MW in 2016, 200MW in 2022 and 500MW in 2030 (UNEP 2014). This is feasible given the fact that there is currently a drastic decline in Solar PV prices and the availability of multilateral corporations like the World Bank, Africa Development Bank, the Green Climate Fund (GCF) among other financial entities that are willing to fund sustainable energy transition trajectories.

2.3.3. Off-grid/Stand-alone solar PV system

Off-grid power generation system is a conventional stand-alone unit that is independent of the distribution network. Diesel generators have been the sole sources for power generation for the Off-grid system despite continuous imposition of environmental, health and economic risks (Buarzhan and Jenkins 2016). However, Solar PV systems for Off-grid power generation is now the most appropriate option for increasing access to electricity in rural and isolated areas in a more sustainable and democratic way. The Off-grid solar PV system approach is well documented with a substantial body of literature already available as a solution for rural electrification programs where the grid network is not available and its extension from the central system is economically unviable due to the economic status and the settlement patterns of the rural inhabitants (Sandwell *et al.,* 2016; Mandelli *et al.,* 2016).

Unlike the case of On-grid system, the Off-grid solar PV systems do not dependence on the public utilities for their power supply during night hours, but instead the electricity generated by the PV panels is stored in a set of batteries for later use and like in the case of the On-grid, an inverter is also important for currents adjustment. Figure 2-16 shows a schematic illustration of an Off-grid solar PV system for a residential house. Apart from being an alternative for electricity supply, Off-grid system can also act as an awareness step in the electrification process to promote rural transition to modern energy sources and as a steppingstone for future development of grid system. IEA (2010) observe that about 60% of the expected electricity generation to promote the universal access will come through Off-grid system of which, about 90% will be from renewable like solar PV.

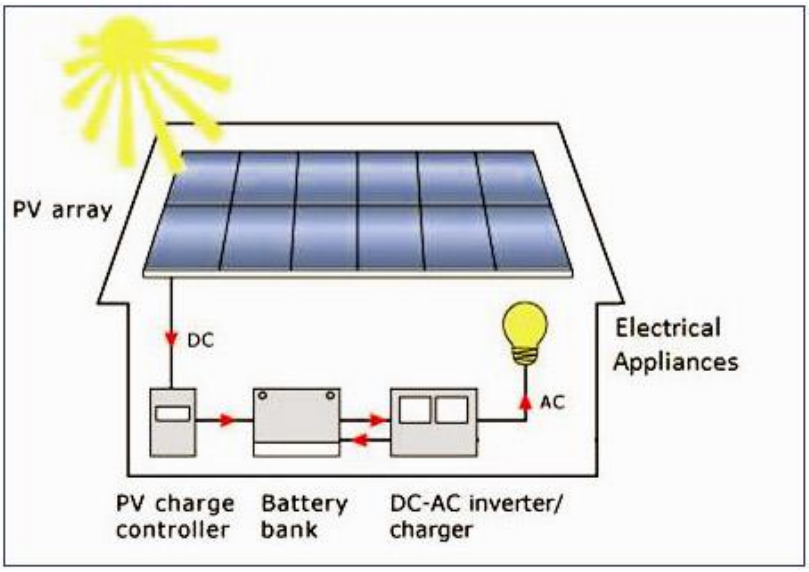


Figure 2- 16: A schematic representation of a residential Off-grid solar PV system
Source: *Ace Technologies (*http://www.myace.in/pv-systems.html)

Despite having solar energy potential, there is currently no available literature on solar PV diffusion in South Sudan. However, there is a clear evidence for the significance of Off-grid system in the region. In Kenya for example, several innovative approaches for Off-grid solar PV utilization have emerged like Off-grid solar PV Kiosk used as knowledge and enterprise hub for recharging batteries, powering TV/radio or phone charging (Njogu *et al.*, 2015). Modern advancement in solar technological over the years has resulted to a drastic drop in the costs of solar panel, inverter, and the LED technology which has successfully eliminated all barriers in solar deployment. Thus, Rawn and Louie (2017) states that over 40 million solar lanterns and solar home systems have already been deployed in Sub-Saharan Africa with a market share exceeding US$500 million in 2015.

2.3.4. Solar PV hybrid system

The current discourse on energy transition aims at making a shift away from fossil fuel-based electricity generation like using diesel generators. Yet countries that rely on diesel generators such as South Sudan with 100% diesel-fired electricity for both On-grid and Off-grid can find it extremely difficult to make any drastic move away from the usual practice. Hence, a gradual transition in which diesel generators are integrated with one or more form of renewable would have a meaningful transitional path for such countries.

While solar energy is the highly recommended energy technology for transition particularly in Africa, a solar-based stand-alone system can suffer heavy from intermittent issues resulting from unpredicted weather that affects sunshine. Hence ensuring system reliability is paramount. In this context, Noguera *et al.*, (2017) point out that to increase the reliability of a renewable-based electricity supply and to have continuity in the service provision, hybrid systems that integrates more than one form of energy technology presents better options for maintaining stable energy supply when there are shortages by one of the energy resources. These systems integrate diesel generators with renewable resources such as photovoltaic solar energy, micro/mini-hydropower, biomass or energy storage system (batteries) thus, providing greater system reliability, maximizing performance and reducing costs that could have been incurred when diesel generators were the sole providers of electricity.

A solar hybrid system is built in such a way that it combines solar PV with battery bank and diesel generator, a bi-directional inverter that facilitates a D.C-A.C conversion for load handling and A.C-D.C conversion for charging the battery bank by the generator set. The efficiency of the system can also be expanded to include wind power as showed in Figure 2-5 previously. As an Off-grid power generation, it offers clean and efficient power with less emission of gases and noise. Figure 2-17 shows a Schematic diagram of a PV-Diesel hybrid system.

The solar hybrid power system utilizes solar PV to generate electricity that can be supplemented by diesel generators over issues of intermittence. During configuration design of the system, the solar panel sizes are critically considered with respect to a diesel generator that operate in tandem with the battery system. The power and charger controllers determine the AC conversion of the DC power and charge the batteries with energy from both the solar panels and the diesel generator respectively. This approach is an important step towards transition to a clean and sustainable energy generation in countries with an absolute diesel-based power generation because the generators are only run to recharge the battery and once they are fully charged, they can be shut down hence reducing costs and GHG emissions.

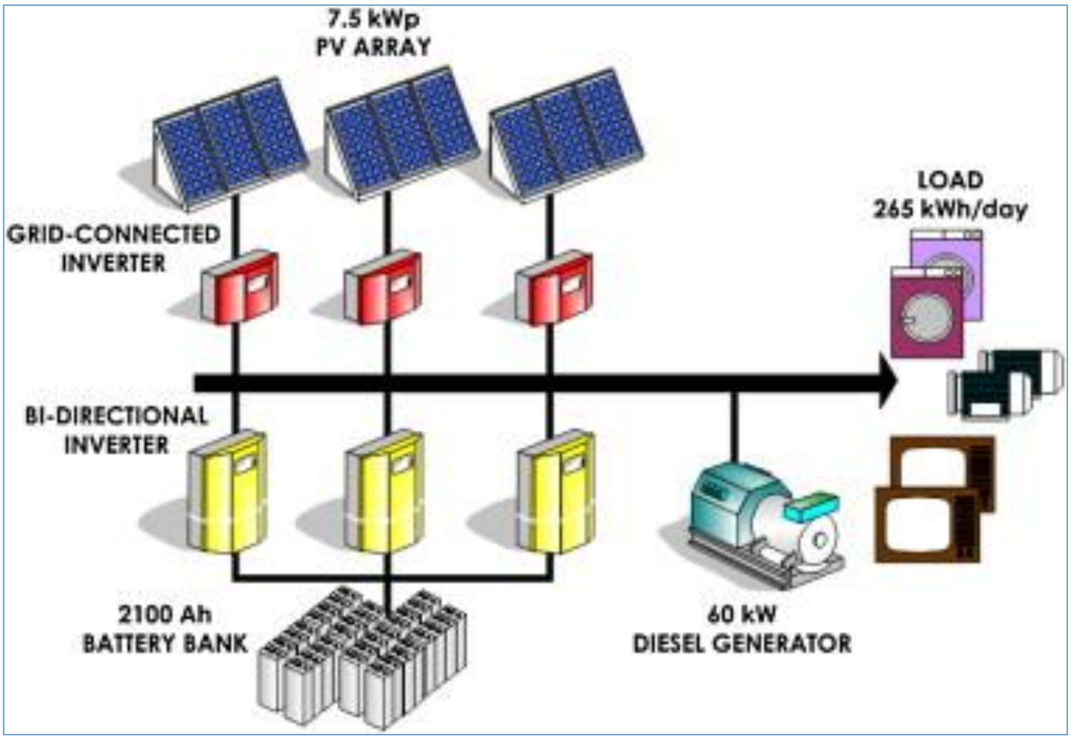


Figure 2- 17: Schematic diagram of the PV hybrid system installed
Source: Phuangpornpitak and Kumar (2011)

Sopian *et al.,* (2005) describes a simple set up of a hybrid system involving an inverter module, diesel engine, a battery storage system and a solar PV which operates under three different phases (i.e. day time, night time and shortfall). During daytime, the solar PV generates all the power and charges the battery(ies), during night hours the stored energy in the battery is then discharged to provide the needed power and during shortfall like nights or cloudy days the diesel generator is operated to generate the power and the excess is used to charge the battery. Sopian and colleagues then conclude that, the use of hybrid system give so many benefits such as: improved power reliability, improved energy services, reduced emission and noise pollution, continuous power supply, increased operational life, reduced costs and efficient use of energy. Kalembe (2017) and Hrayshat (2009) also analyse the techno-economic and environmental impact of a similar PV-Diesel-Battery hybrid system for a rural area involving a 23% PV penetration rate. They found that the hybrid system is suitable to achieve ecological and socio-economic objectives related to power availability because hybrid systems are able to decrease the operational hours of the diesel generators by 19.3% and diesel consumption by 18.5% equating to about 18% of GHG emission compared to pure diesel generation hence, it makes the whole system environment friendly technology.

Furthermore, Yilmaz *et al.,* (2015) perform a dynamic simulation of a PV-Diesel-Battery hybrid plant for Off-grid electricity supply in a remote mountain house in Turkey. They used 6 Sentech 250W poly crystal panels, 12 Concorde 12W 99Ah batteries, 1 generic 1.5kW inverter with a Maximum Power Point Tracking (MPPT) and 1 Datsu 1.5kVA single phase diesel generator. The results indicate that of the total 3700kWh electricity required to power basic house appliances (i.e. refrigerator, TV, washing machine, dishwasher, computer and other small devices) for a year, 74% of the energy was generated by the PV system, while the surplus energy in the batteries and the diesel generator generated 25 and 1% respectively. The cost and emission analysis showed that the unit cost of energy for 30 years is 0.24 Euros and CO_2

emission is reduced by 42.53 tons. These findings provide a substantial justification for solar hybrid system as a solution not only for the rural households' electricity demands but also for energy transition in diesel fuel dependent countries.

2.3.5. Solar PV market

Globally, solar PV systems uses have expanded and the market is rapidly increasing despite being previously regarded as an expensive technology. Solar PV system price has decreased by over 80% in most global markets due to modern advancement in technology and as the price continue to decrease while that for electricity increases, the market is steadily increasing as well and other new emerging markets are coming up. It has been observed that in 2016 for instance, the total investment attraction of solar energy was worth US$113.7 billion approximately 55% of all renewables and the PV industrial production grew by 30% worldwide reaching a total volume of 80GW of PV modules (Jäger-Waldau 2017 p1). Yet in developing countries like Sub-Saharan Africa, the global decrease in solar PV is minimally felt among the rural communities as the cost of energy for solar PV system stands at US$0.83/kWh much higher than the world average (Baurzhan and Jenkins 2016).

As stated earlier, China is world's largest solar market in 2016 after adding about 34.5 GW to the 2015 figure followed by the United States. It is further expected that by 2024, the global market for solar PV combine with energy storage will hit US$23.1 billion, up from US$1.2 billion in 2015 and as the costs continue to drop and an exceptionally high number of customers turn away from the conventional power utilities to adopt solar PV sets, the revenue will reach US$49.1 billion by 2026. While Asia Pacific and Western Europe regions will dominate the market, Africa will continue to be a minor player in the solar market despite having ample solar resources. This portrays the fact that solar market in Africa as a whole has many barriers ranging from lack of access to financial support to absence of enabling regulations and policies that would guide the development of the markets (Hill, 2015; Colthorpe, 2017; *Kronsbein,* *2017*; *Quansah et al.*, 2016*).* Figure 2-18 indicates the global major solar market shareholders (A) and the forecasted market growth from 2017 through 2026 (B).

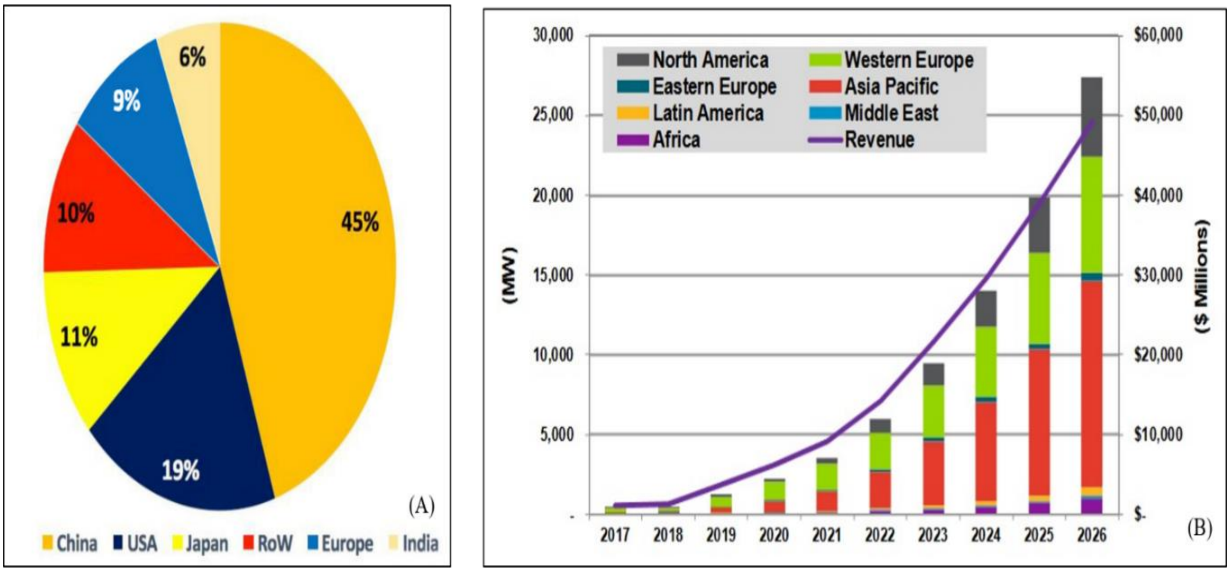


Figure 2- 18: Global major solar market shareholders and 2026 forecasted market growth
Source: Kronsbein (2017) and Colthorpe (2017).

In the Sub-Sahara Africa, governments have begun addressing most of the regional market impediments at national levels through the development of policies and regulatory systems. Despite having overall low market performance however, some market niches in the region have greater contribution than other countries. For instance, based on the various sets of solar PV, Kenya has a strong and rapidly growing market with a significant contribution to the global figure. It has been reported that in terms of SHS, Kenya's market in 2007 for instance was 10% higher than the rest of the world but only below China that had 16% market share at the time.

Hansen, *et al.*, (2014) studied the development of solar PV markets in East Africa specifically focusing on Kenya, Tanzania and Uganda and found that, although the markets in Tanzania and Uganda are rapidly expanding, Kenya is solar energy giant, not only in terms of installed solar PV capacity but also in terms of market volume in the region. When compared to the rest of the African countries, Kenya holds the lion share in terms of installed SHS accounting for 40% of the total capacity of the entire continent (Ondraczek 2013). Adding to the lever Ethiopia and Tanzania, these three countries account for 66% of the total African solar market (Global

2016) that is not only being used for domestic markets, but also as a gateway to other neighbouring countries' markets.

2.4. Energy Governance Systems

The governance of energy is one of the strategic issues in the politics of energy security that has dominated the contemporary sustainable energy debates (Smith 2009). Governance can be defined as the act or state of controlling/governing and when energy is embedded to governance, then energy governance can be interpreted as the mechanisms to control or govern stability and sustainability of energy systems which encompass the protection of energy security, energy markets and addressing climate change and related environmental issues (Koyama 2017). Most countries and global energy institutions have designed their energy governance objectives although with different priority targets towards achieving the trilemma of energy policy (i.e. energy security, affordability and climate migration).

According to IEA (2016), there has been a tremendous development in energy technologies in recent years. Yet energy infrastructure and regulatory frameworks continue to lag behind at a rate, if not addressed, may undermine the achievement of energy security and climate change mitigation targets due to lack of strong government intervention with enabling policies and institutions.

Governance is very crucial particularly in establishing the guiding rules, incentives, and institutions that drive and shape sustainable energy transition. Energy governance is responsible for the design and implementation of regulations, markets, and institutions as well as influencing the kind of actors, energy technologies and mechanisms that can be encouraged or discourage from the system (Mitchell 2014). Kuzemko *et al.,* (2016) claim that institutionalism has over the last 30 years come to play a pivotal role in the politics of governing for energy systems transformations with regards to energy and climate governance decisions makings and practices. Additionally, in the transition towards delivering sustainable energy solutions for all using renewable technologies, government policies are key development drivers because they put in place the mechanisms for the dissemination and mobilization of the necessary resources for the private sector to invest in renewable energy technologies (Karekezi and Kithyoma 2003).

Furthermore, energy governance has also been a ticking political manoeuvre in several developing countries with both internal and external politicking by political elites who use energy as an election-winning manifesto and international powers who use financial support as a tool to advance their interest into national energy policymaking. These practices tend to influence energy policy instruments. In Kenya, Newell and Phillips (2016) observe that determining who sets the terms of energy transition attracts questions about the role of actors, interests, and institutions as they seek to advance competing energy pathways and associated technologies. Hoggett (2017) also note that transition in energy systems meant to achieve clean, affordable and secured energy requires institutional reforms and tackling a number of challenges thus, strengthening the governance framework. Figure 2-19 illustrates the various factors of transition that need to be tackled during the governance of energy systems.

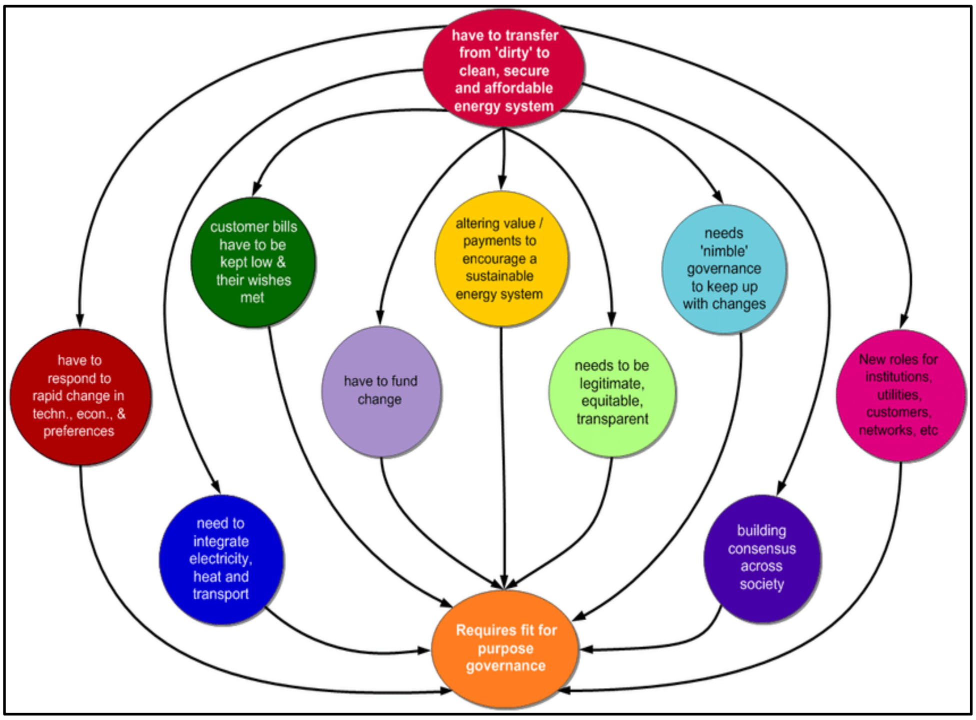


Figure 2- 19: Challenges of transforming energy systems
Source: (Hoggett 2017)

Unlike the case in the developed world, the regulatory frameworks for the governance of the energy sectors in the developing countries is affected by poor institutional capacity, political instability, technical and financial performance defaults, budgetary constraints, subsidy burden, and donor-dominated investments (Zaman and Brudermann 2017). In the Sub-Saharan African countries, the lack of access to modern energy sources mirrors the effectiveness of their systems of governance. Governance shortcomings such as corruption, inadequate regulatory and legal frameworks, weak institutions and lack of transparency and accountability, which cumulatively culminate in poor governance, are not exceptional to Sub-Saharan Africa (Birol 2014). These governance challenges go further to affect the energy sector that needs to attract a large foreign investment in energy development.

Nonetheless, most Sub-Saharan countries have recently made a substantial progress in improving their energy sector governance by establishing and developing different institutions, energy policies and legislation. These reforms include establishment of institutions like the Electricity Regulatory Authority (ERA) in Uganda, Rural Electrification Authority (REA) in

Kenya and the development of policies and regulations such as the feed-in-tariff (FIT), Tax holiday/VAT exemption, tenders and auctions, fuel subsidies removal, international partnerships as well as mechanisms for transparency which are meant to attract private investment in energy production, transmission and distribution (Mwangi, *et al.*, 2013.

Market liberalization and decentralization of energy systems are important aspects of good energy governance. Kenya for example reformed its energy systems through market liberalization in which institutions and policies such as the 2004 Sessional Paper No. 4, 2006 Energy Act No. 12 and the Energy Regulatory Commission (ERC), as well as REA were established to align the energy sector with national goals. To further attract private investment in renewable energy generation, Kenya introduced FIT and VAT exemption policies (Newell and Phillips 2016).

Zaman and Brudermann (2017) applied a systematic review approach in analysing the energy governance of the electricity sector in Bangladesh in the context of a resource poverty developing country to develop an elaborate conceptual framework for energy governance. Using three criteria (i.e. quality of national governance, political landscape and integration into international governance) and seven attributes (i.e. market reforms and institutional settings, energy policy and legislation, information disclosure, political acceptance and (in)stability, corruption, international development assistance and external influences in energy policy), they showed that the market reforms and institutional settings within the sector, for example, can transform a once monopolized sector into a liberalized one where several actors competitively participate in the delivery of improved energy services in an accountable manner. This suggests that well-established institutions are important for effective coordination and implementation of energy policies to ensure smooth functioning of the energy systems; and above all, ensuring that there is a political will to create the necessary coalition within and beyond border for international investment in local energy resources.

3.0. METHODOLOGY

3.1. Introduction

This study was primarily intended to assess private electricity generation in Juba city, South Sudan. It was assumed that there was a high amount of electricity being privately generated in the city that has not been reflected in the total installed generation capacity of the city. In this regard, the assessment was essential to establish an insight in to the parallel private generation. This chapter, therefore, presents a brief description of the methodology that was used to investigate the aim and objectives of the study. It describes the target area, the sampling method, data collection procedure, data analysis and limitation of the research method.

3.2.Target area

This study was conducted in Juba the capital of the Republic of South Sudan. Juba is located at 4°51'05.9"N 31°34'56.9"E and lies along the White Nile. It also functions as the seat and metropolis of Jubek one of the 32 states in the country. Juba covers a total area of 52 km^2 and has an estimated population of 450000 people according to the World population review website, which makes it the largest and highly populated city in the Republic of South Sudan.

Juba is divided into three administrative units (Payams): Kator, Munuki, and Juba and it is administered by the city council Mayor who oversees all socio-economic and development activities. Like any other city in Africa where the economic development is mostly stationed, Juba is the economic and business hub for South Sudan with more than 6000 commercial enterprises ranging from small to large firms (World Bank 2014a; AfDB 2013a). The study was carried out in Juba Payam based on the concentration of commercial firms and business centers. Both Munuki and Kator Payams are mainly residential settlements with fewer business activities compared to Juba which comprises mainly of commercial firms with significant used of generators to supply own electricity. Figure 3-1 shows the map of Juba city and Juba Payam where the study was carried out marked with red colour.

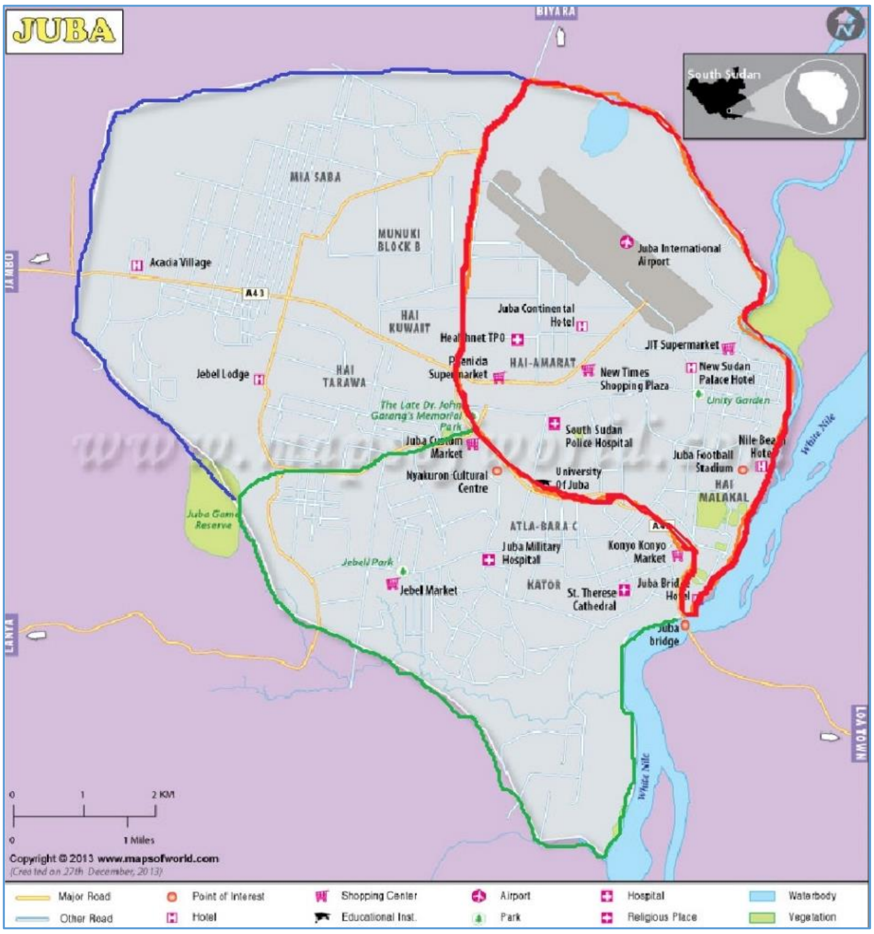


Figure 3- 1: Map of Juba and its three Payams.
Source: Maps of the world (2013) with modification.

3.3. Sampling method and sample size

Prior to deciding on the sampling procedure for the study, two days were spent moving through and identifying companies present in the area. Additionally, an online hotel-booking website (Jumia travel) was consulted and a list of hotels was drawn based on the address provided. A total of 136 companies was documented and categorized as Hotels, Banks and Manufacturing companies based on their operation lines. Manufacturing companies comprised of companies that use electricity to make products as opposed to hotels and banks that use electricity for services.

Kadam and Bhalerao (2010) state that it is naturally neither practical nor feasible to study the whole population in any research study given the complexity, time consumption and the logistical requirement attached to it. In this regard, a small portion "Sample" can be derived from of the population. To derive the sample for this study, a simple random sampling procedure was chosen according to Lindgren (1981) who suggests that a random sample provides a good chance of having a sample that represents the population in every characteristic. David and Dodd (2002) further stated that randomness is the basic principle of a sample being representative of characteristics of the population, and this is because every individual in the chosen population has an equal chance of inclusion in the sample.

However, since the companies appear to be heterogeneous in regard to their operational line and use of energy, this study researcher decided to apply a stratified sampling method. According to Meng (2013), this method helps make it possible to partition the population into several homogeneous subsets, called strata and that for a better representation, applying simple random sampling within each stratum is preferable than applying it to the entire population. The sample size of each stratum in this study is proportional to the size of the stratum in the entire population.

The sample size for the study was then calculated using an online calculator[2] using a 90% confidence level and a confidence interval of 8%. The calculated results are presented in T**able 3-1** below.

[2] http://www.raosoft.com/samplesize.html

Strata	Population	Proportion	Sample size
Hotels	95	70%	42
Banks	29	21%	13
Manufacturing	12	9%	5
Total Population	136		
Total percentage		100%	
Total sample size			60

Table 3- 1: Population and Sample size Frame

Table 3-1 above presents the firms/companies identified in Juba Payam which comprised of three categories or strata namely: Hotels, Banks, and manufacturing. The hotels, banks, and manufacturing have a total of 95, 29 and 12 respectively. Based on a proportional stratification, the sampled size for each stratum came to a total of 42, 13 and 5 from hotels, banks and manufacturing respectively. The sample sizes were selected by means of a stratified random sampling as stated earlier. To select the participating companies, all the firms in each stratum were assigned a number ranging from 1 for the first firm to last firm in the order of (1, 2, 3,…n). Using a mobile phone random number generator app (R) available in google store, the participating companies in each stratum were randomly selected. Figure 3-2 below shows the stratified sample size of each stratum against its proportional population. The total sample size of companies selected to participate in the study was 60, which represents about 44% of the entire population.

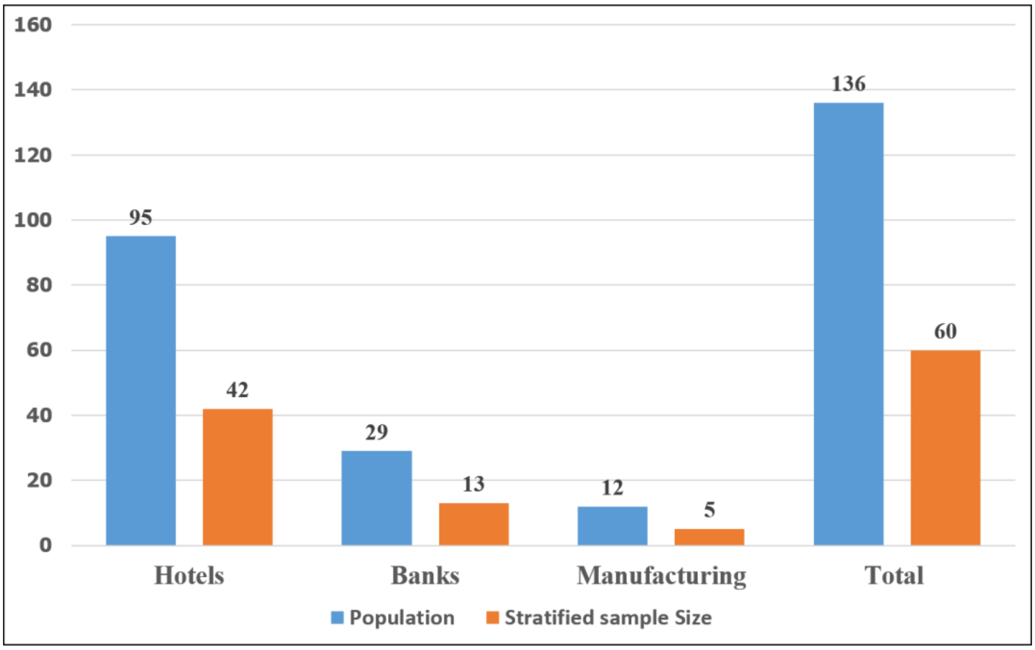


Figure 3- 2: Sample size distribution of each participating companies

In addition, three government officials belonging to South Sudan Electricity Corporation (SSEC) and the Ministry of Electricity and Dams (MoED) as well as two private solar energy retailing companies operating in Juba were contacted. Being the national bodies responsible for electricity in South Sudan, no specific sampling method was used to select the two institutions. There are currently no many private solar energy companies in Juba. Those who participated in the study were based on their willingness to provide information.

3.4. Data collection procedure

The study employed the combination of both quantitative and qualitative data collection approaches in addition to relevant literature search from online sources. The use of both quantitative and qualitative methods in social science research is rapidly growing with high adoption rate due to the fact while quantitative research captures the structure, qualitative research the process, hence facilitating each other (Kelle 2006; Niglas 2000).

The quantitative data were collected from the stratified sampled companies that were selected to participate in the study using a detailed self-administered questionnaire that captures key questions of the research (Appendix 1). This approach was chosen because the researcher thought that the respondents might not have enough time for face-to-face interviews. Additionally, self-administered questionnaire gives the respondents ample time to check their business records and give accurate figures as required by the questions. Stewards and Cash Jr, (2008) note that to achieve an effective research data with a high response rate from a target population, a self-administered questionnaire is the best option because of the comfort the respondent enjoys while answering.

The questionnaire was designed using both close-end question for minor queries and open-ended questions so that the respondents have the chance to provide their thoughts regarding the research subject. This has also been supported by Reja *et al.,* (2003) who observe that open-ended questions avoid the bias that may result from suggesting responses to the respondents by allowing them to express their opinion without being influenced by the researcher as opposed to close-ended ones that limit the respondent to the set of alternatives being offered by the researcher. In the process of delivering the questionnaires to the respondents for completion, the company managers were first met and then briefed about the purpose of the study. At this point, the document was either taken or the researcher was referred to the right person within the company. The filled copies of the questionnaires were collected by the researcher from the respondents on the agreed days, which range from 5-7 days on average.

While on the other hand, the qualitative data were collected through a formal discussion with the key stakeholders from MoED and SSEC and representatives of private solar energy companies. The discussions with the government and private companies' representatives were guided by five (5) and six (6) key questions respectively. Appendix 2 shows the list of the questions that were used in the discussions. Both the quantitative and qualitative data were collected between May 7th and 25th 2018 in Juba city Republic of South Sudan.

3.5. Data analysis

Data analysis is the most important component of any research study. Regardless of how accurate the design and the fieldwork were conducted; the analysis of the data will determine whether or not proper inferences can be made. Schwandt (2007) states that data analysis involves breaking down the bigger picture of the subject matter into smaller units and in the process of putting the units together, one will understand clearly the entirety of the subject under study.

After gathering all the data from the fieldwork, they were coded and then converted into MS Excel to form a working database. They were then analyzed using a descriptive statistical method with the help of tables, charts, and graphs to visualize trends that underlie the research subject. The amount of electricity generated was calculated according to the formula:

$S_{(\mathrm{kVA})} = P_{(\mathrm{kW})} / PF$…………………. *(i).*

Where ***S*** is the power in kilovolt-amps (kVA), P is the actual power in kilowatts (kW) and PF the power factor.

The qualitative data from the formal discussion with the government institutions were analyzed based on governance themes and key findings were used for addressing relevant questions of the study. The data collected from the solar companies were also analyzed and integrated into the findings of the other coded data to strengthen the discussion. Key findings were properly interpreted and described in line with the research aim and objectives. Based on these findings, several recommendations were formulated for the concerned authorities to act on them.

3.6. Limitations of the research method

The conduct of this research faced two main limitations. Firstly, the sampling procedure used to identify the hotels in the area did not match well. The locations for some of the hotels drawn from the Jumia website could not be established on the ground although the online address clearly specified the target area for the study. Furthermore, due to the current economic crisis and conflict in South Sudan, some of the selected hotels to participate in the study had already ceased operations in Juba thus affecting the sample size and the researcher opted not to replace them to avoid biasness of the sampling method.

Secondly, there was a collision between the research period and the United States imposition of sanctions on several companies in South Sudan for their alleged meddling with or fuelling South Sudan conflict. These sanctions made doing research and being provided information by companies very sensitive in Juba for the fear of spying. Thus, some of the respondents declined from participating in the study by stating that they can only provide information to students studying in the country. Table 3-2 compares the intended number of selected stratified samples and the actual number that fully participated in the study and the researcher received their responses for analysis.

Strata	Population	Intended sample	Actual sample	% Participation
Hotels	95	42	29	69
Banks	29	13	11	84.6
Manufacturing	12	5	4	80
Total	136	60	44	**73**

Table 3- 2: Participants' actual participation rate as compared to the intended sample size

From table 3-2 above, it can be summarized that the participation rate of each stratum, Hotels, Banks and Manufacturing was 69%, 84.6% and 80% respectively and the overall participation rate against the intended sample was 73%, less by 27%.

4.0. RESULTS

4.1. Introduction

This chapter presents the results of the study and establish a links to the objectives. The research had sought to:

1. Assess the generation options and quantify the Off-grid electricity generation in Juba.
2. Understand the current state of electricity market design and governance in South Sudan.
3. Determine possible mechanisms on how private electricity generators can become electricity traders and contribute to the national on-grid system.
4. Analyze the social, economic and environmental impact of private owned diesel generators.
5. Explore the potential of solar energy and the understanding of the various actors regarding its integration with diesel generators as a step towards energy transition.

4.2. Private electricity generation in Juba

Juba is both the capital city of the Republic of South Sudan and the business hub for the country. Previous studies indicate that there are more than six thousand companies operating in Juba. As one of the most growing cities in the region following the independence, electricity is one of the drivers for the socio-economic growth of the country. The On-grid electricity generation capacity in Juba lag behind the demand leading to severe outages.

Large and medium scale private companies have resorted to expensive self-generation of electricity using standby diesel generators. The capacity of the Off-grid electricity in Juba was therefore assessed in this study. The kVA rating of the generators and the power factor (PF) were taken into consideration to estimate the Off-grid power capacity in MW available in Juba. Table 4-1 below summarizes the results of private Off-grid electricity generation in Juba.

Companies Types/Strata	No of Companies Covered	Total No of Diesel Genset Identified	No of Hours Run	Self-installed Generating Capacity (KVA)	Electricity Generated/Month (kWh)
Hotels	29	83	17790	22,034	313,587,888
Banks	11	39	3925	5,749	18,051,860
Manufacturing	4	20	2520	7,675	15,472,800
Total	**44**	**142**	**24235**	**35,458**	**347,112,548**

Table 4- 1: Table 4-1. Summary of the different parameters of private electricity generation in Juba

As shown in Table 4-1 above, the 44 companies surveyed during this study own a total of 142 diesel generators of which the hotel industry has 58.5% followed by the banking (27.5%) and the manufacturing (14%). Similarly, the hotels also have the highest installed generation capacity compared to both banking and manufacturing. However, unlike the banking industry despite having more diesel generator sets than the manufacturing, its installed generation capacity is less than that of the manufacturing sector.

The total installed capacity of the Off-grid electricity generation in megawatts (MW) found in this study was calculated using the formulae:

- $S_{(\text{kVA})} = P_{(\text{kW})} / PF$ ………………*(i).*

Where ***S*** is the power in kilovolt-amps (kVA), P is the actual power in kilowatts (kW) and PF the power factor.

Electrical power factor (PF) is defined as the ratio of real power (kW) to apparent power (kVA) in an AC electrical power system that is always a number between 0 and 1. Therefore,

- $PF = kW/kVA$………………………. *(ii).*

However, the recommended power factor for most of the modern diesel engine generators is 0.8 and this was the power factor used in this study.

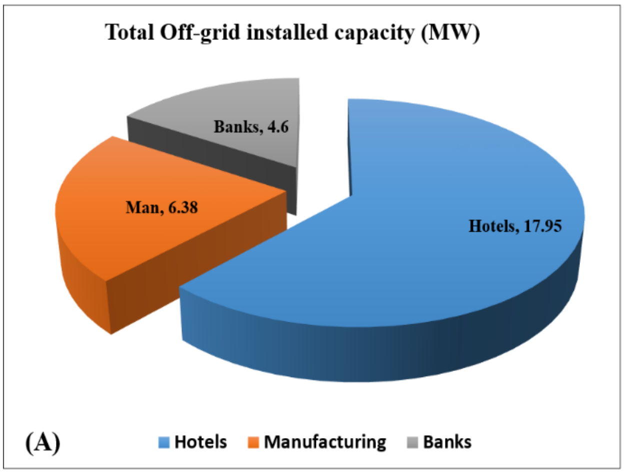
Then,

- $P_{(MW)} = P_{(kW)} / 1000$………………. *(iii).*

The actual electricity generated in kilowatts hours (kWh) was then calculated as:

- kWh = kW * h………………………. *(iv).*

Based on the above calculations, the study found that the total installed capacity of the Off-grid privately generated electricity in Juba is 28.93 MW, of which, 98% is diesel-fired and only 2% is renewable. Additionally, if this capacity were to be run all at the same time without alternation of one generator after the other, the capacity would generate as much as 347.1 million kWh of electricity per month with a percentage distribution of 90, 5 and 4.5 for hotels, manufacturing, and banks respectively. Figure 4-1A and B show the breakdown of the total installed capacity by sector or stratum and sources of generation respectively.



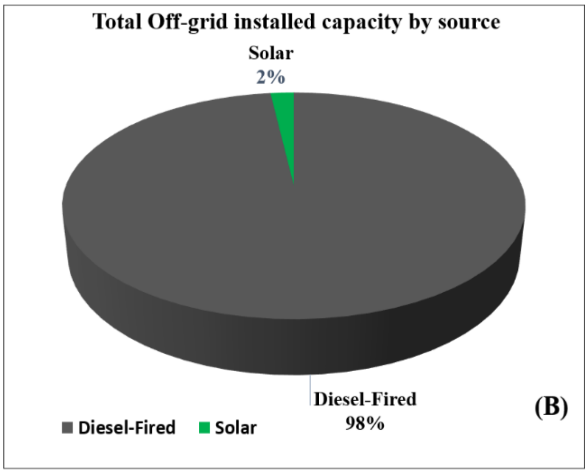


Figure 4- 1: (A). Total installed capacity by stratum. (B). Installed capacity by source of generation.

Figure 4-1 (a) indicates the dominance of the hotel industries in the Off-grid electricity generation while (b) provides an overall representation of the renewable energy penetration in the Off-grid system. A close dissection analysis of the different strata/sectors under this study further revealed that of the two percent installed solar system, 57% is in hotel sector and utilized for lighting and heating water, while 43% is in the manufacturing sector. The banking sector utilizes 100% diesel-fired electricity for all their operations. Figure 4-2 below shows the breakdown of the total installed capacity by sector and energy source respectively.

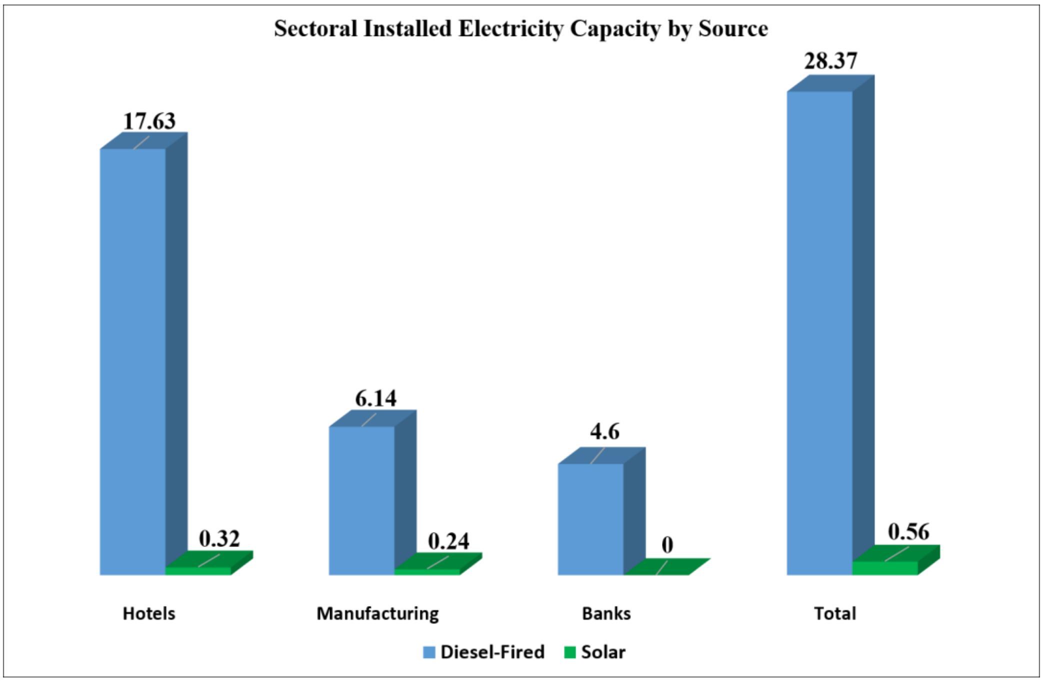


Figure 4- 2: Total Off-grid electricity by source of generation

4.3. Electricity market governance systems

As explained earlier in the literature, governance refers to how governments exercise their political, economic, and administrative authority, which include the mechanisms, processes, and institutions to manage their national affairs. In the context of energy governance, Goldthau (2014), outlines three features of the energy system that encompasses: (i) "its embeddedness within, and its coevolution with the socioeconomic institutions, regulatory agencies, incumbent market actors and social norms; (ii) the multiple scales of sustainable infrastructure solutions and (iii) the existence of elements of common pool resource problems."

The research study found that governance of the electricity sector in South Sudan can best be described at two levels that include institutional and policy and regulatory framework.

4.3.1. Institutional Arrangement

Regarding the institutional governance of electricity, South Sudan's intuitions are still at their embryonic stage. MoED is the main institution responsible for governing the electricity sector. It formulates policies and strategies that relate to the management and development of the electricity sector. The government parastatal utility, SSEC is the immediate institution whose mandate is centred on electricity generation, transmission, and distribution as well as revenue collections. However, MoED has the mandate to regulate the performance of SSEC and in close understanding sets tariffs for the electricity distribution.

Other institutions directly or indirectly involved in the management of the electricity sector include the State Electricity Distribution Companies (SEDC), the Ministry of Finance and Economic Planning (MoFEP), Ministry of Petroleum (MoP), Ministry of Commerce, Industry and Investment (MoCII) and the Ministry of Environment (MoE). Table 4-2 presents the institutions involved in the electricity sector of South Sudan and summarizes their roles in dealing with electricity matters.

Institutions	**Roles and Responsibilities**
MoED	In the absence of any regulatory body, MoED serves as a regulatory entity for the electricity sector. It formulates the necessary legislation and regulations for the management, development, and maintenance of the electricity supply institutions (ESI) including the development and implementation of government policies and strategies on electrification. Further policy roles include: ✓ Development of sector policies for the utilization of all forms of energy available in the country. ✓ Development of rural electrification programs. ✓ Promotion of energy efficiency and conservation ✓ Mobilization of financial resources for generation and distribution expansion, operation, and maintenance of these facilities ✓ Security of electricity supply through diversification of sources and mixes in a cost-effective manner; ✓ Completion of the legal, regulatory and institutional frameworks to create both consumer and investor confidence ✓ Enhancing and achieving economic competitiveness and efficiency in energy production, supply, and delivery; Promotion of the development of power plants through public-private partnership (PPP) interventions

SSEC	Established in 2006 as a semi-autonomous national electricity utility that is responsible for the generation, transmission, sale of electricity to distributors and revenue collections. Additionally, it is the mandate of SSEC to ensure that power produced by the independent power producers (IPPs) is purchased and transmitted for distribution
SEDC	Under MoED and in consultation with state governments, SEDC manages and operate the local electrical power distribution services at the states levels by facilitating the work of rural electricity cooperatives and community-owned and operated distribution entities. It also licenses these rural entities to develop, finance, and operate decentralized electric generation systems like mini-grids.
MoFEP	It is responsible for financing the operational costs and investments in the new generation projects. 80% of the collected electricity revenue is directly controlled by this institution and sets all procurement procedures that SSEC must follow in the event of procuring any spare parts for its generators
MoP	It is responsible for financing the operational costs and investments in the new generation projects. 80% of the collected electricity revenue is directly controlled by this institution and sets all procurement procedures that SSEC must follow in the event of procuring any spare parts for its generators
MoE	This institution is responsible for the protection and management of the environment. When it comes to issues of climate change resulting from electricity generation such as carbon emissions, MoE collaborates with MoED in regulating the practice, as it's the only entity with the mandate of reviewing the environmental social impact assessment (ESIA) plans of projects and issuing environmental compliance permits. It has formulated a national environmental Bill, which aims to establish a national environmental management authority to be directly supervised by the office of the president of the Republic
MoCII	This institution in coordination with MoFEP is responsible for setting import taxes for all products entering South Sudan including energy related products indiscriminately

Table 4- 2: Summary of electricity governing institutions in South Sudan

Even with these institutions in place, maintaining consistent electricity supply continue to be a challenge. According to SSEC, the major problems affecting electricity generation of electricity in SSEC is lack of consistent supply of fuel, spare parts for the generators, high fuel consumption rates and financial irregularities. The government subsidizes the electricity tariffs as a result, after selling the generated electricity the cash received is always less than what was spent to buy fuel and on top of that, MoFEP takes 80% of the sales making planning for supply so difficult.

4.3.2. Policy and regulatory framework

Critical analysis based on the discussions conducted with the relevant government entities and the available literature indicate that the policies and regulatory frameworks for governing South Sudan's electricity sector are either in draft forms or proposed ideas yet to be developed. The drafts policies originate from the May 2007 South Sudan National Electricity Policy (SSNEP) paper that outlined the framework for the development of the Electricity Supply Industry (ESI) including strategies for Public-Private Partnerships (PPPs).

The most emphasized policy documents for the electricity sector is the draft South Sudan Electricity Bill of 2010 that is yet to be approved by the council of ministers. The Bill provides for the establishment of an effective governance system for the electricity sector through the formation of an independent regulator the "*South Sudan Electricity Regulatory Authority"* (SSERA) that will be mandated to:

(i) regulate the electricity market by granting licenses; (ii) review and approval all tariffs and charges for the supply of electricity; (iii) monitor the functioning of the electricity market and enforce necessary standards; (iv) facilitate disputes resolutions among concerned entities; and (v) prevent the tendency of electricity market monopoly by single entities (Clyde and Co, 2016). However, without the enactment of the Electricity Bill, it is clear that the electricity sector of South Sudan will continue to be unregulated. This makes all legal efforts for reforming the sector to be on hold pending the approval and enactment of the Bill into law by the council of ministers and the parliament respectively.

Other related policies that have been drafted and awaiting approval by the executive body of the government (council of ministers) include the *Electricity Act*, *Electricity Sector Strategic* *plan, Electricity Licensing Regulations and the National Environmental Bill*. They are currently utilized as reference governing instruments for the electricity sector.

This study however found no attempt being made for the development of a legal framework that specifically promotes the diffusion of Renewable energy technologies (RETs) and Energy Efficiency (EE) into the electricity mix. All forms of regulations such as FIT or Power Purchase Agreements (PPAs) that could play an important role in attracting private investment into generation, distribution, and transmission are not currently available in South Sudan. Additionally, no legal mechanism now exists on either parallel power generation and supply to the grid system or installing personal generator. Although IPPs are slightly highlighted in the would-be SEDC, it does not provide distinctly details on how they can be regulated. During the discussion, one respondent stated that there is currently no requirement to be met by any entity in order to install private electricity generation system that resulting into an increased number of privately owned generator sets in both residential and commercial sectors.

Asked about the challenges of operating such a big sector without legal and regulatory framework, the institutional stakeholders stated that it extremely difficult. For instance,

> *there are currently very many illegal connections to the distribution network all over Juba and without law, you cannot punish these people. You can only disconnect their connections from the lines but cannot recover the electricity they have used since there is no specific punish for these practices which could have been in the law (SSEC respondent pers. comm.).*

4.4. Socio-economic and environmental impact of diesel generators

In countries where electricity reliability is daunting, diesel-fired generator sets have been chosen as the immediate sources for generating electricity. However, the increase in the cost of diesel fuel is making it more expensive to produce electricity from diesel. Hence, the high cost of diesel generated electricity deters economic growth in countries with heavy reliance on generators because emerging enterprises are usually put off by the high electricity cost. Additionally, diesel-generated electricity produces social and the environmental impacts, which can lead to serious health-related issues.

4.4.1. Socio-economic impact

Diesel generated electricity is noisy and creates severe discomfort to societies and business. Out of the 44 companies surveyed in this study, 37% reported social issues related to the operation of the diesel generators (fig. 4-4). These include complaints from both customers and the neighbourhoods regarding continuous noise that is more likely to leads to serious mental and emotional stress. There is also an abrupt breakdown of the system which disrupts their social wellbeing. Additionally, the existence of the generator sets in the compound occupies social spaces.

Despite being regarded as the optimum solution for persistent electricity outages or Off-grid rural electrification programs, the economic costs associated with operating diesel-fired electricity generation is excessively high. To generate electricity for one month, the surveyed companies require up to 589,760 litres of diesel which amount to a total of US$ 533,204; excluding maintenance costs to keep the generators running. The hotel industry is the biggest consumer of diesel fuel and thus more expenditure standing at 78.4% and 78.7% respectively. In the banking sector, 73% of the participants reported an abrupt breakdown of the generator sets during business operation and complete absence of diesel fuel in the market causing financial losses and growing anger from customers. Figure 4-3 below shows the breakdown of the economic costs of running generators for electricity generation with hotels almost quadrupling the manufacturing and banking sectors.

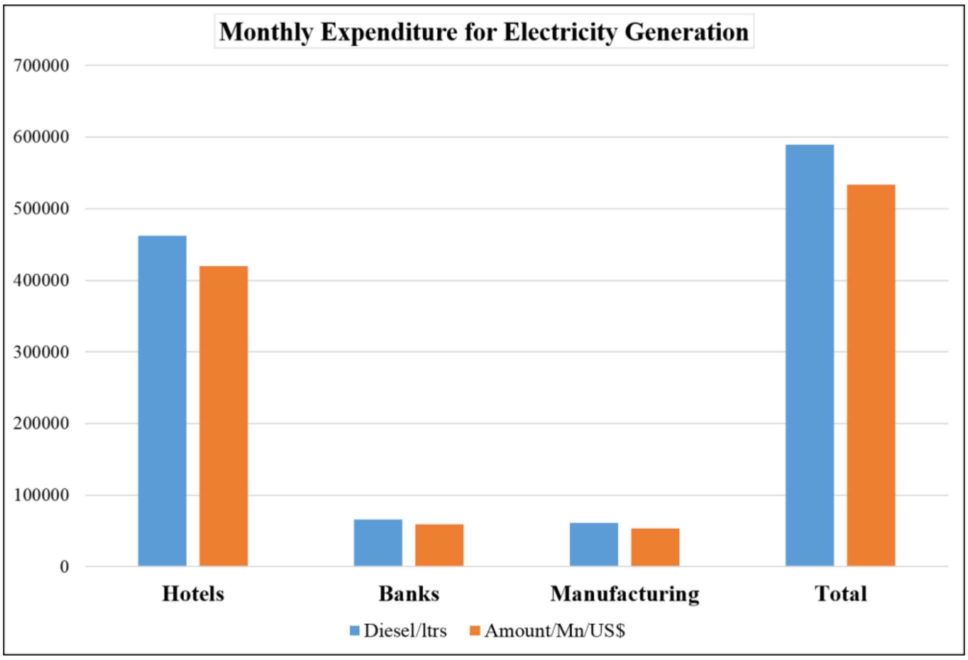


Figure 4- 3: Monthly fuel requirement against costs

4.4.2. Environmental impact.

The use of diesel fuel leads to many emissions being released into the environment. These emissions have implications on human health and the environment. More than 40 toxic air pollutants, some of which are linked to or suspected to cause cancer, as well as environmental degradation, are known to have been emitted through diesel exhaust (Anayochukwu and Nnene, 2013).

Although the environmental impact of diesel fuel combustion is quite serious on the local and global scale, only 18% of the companies reported environmental issues that include pollution of air and property due to black smoke, leakage of oil on the ground and drying of trees and flowers close to the generators. 45% declared that they have no idea whether there is any environmental impact of their generator.

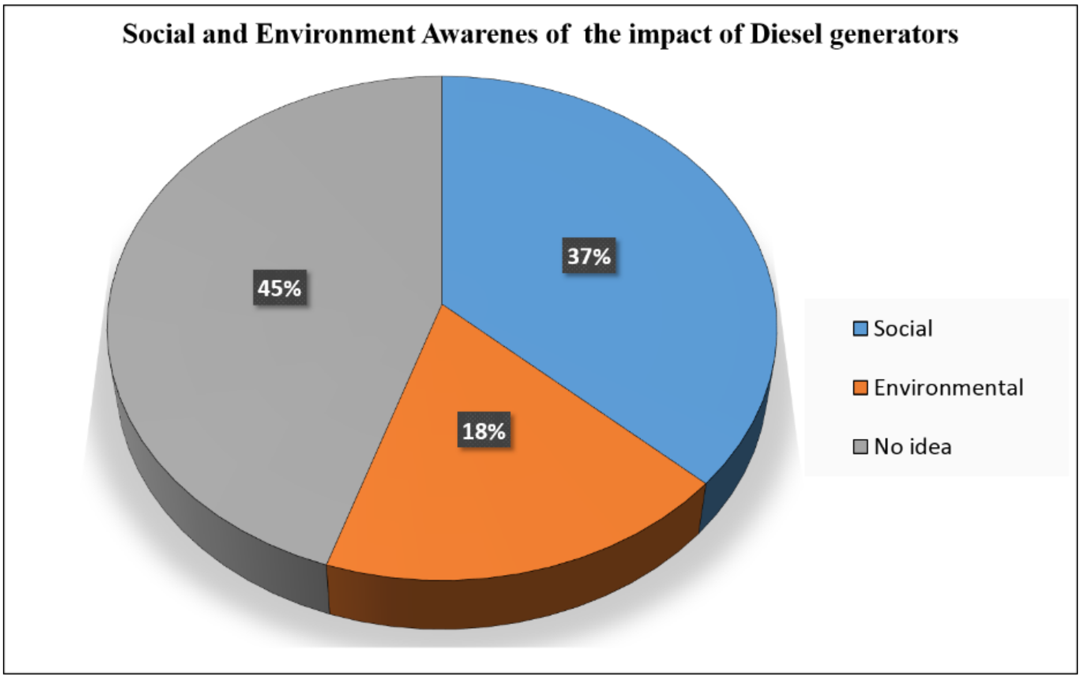


Figure 4- 4: Social and Environmental impact knowledge

This study also attempted to determine the carbon emission footprint of the private electricity generation in Juba to understand the environmental and health risks associated with diesel-fired electricity generation. Carbon emission from diesel generators can best be calculated based on the amount of fuel consumed by the diesel generators. Emissions were determined based on the method of Rukmini *et al.*, (2014) in which,

$$CO_2 \text{ Emissions} = \sum_{i=1}^{n} \text{Fuel}_i \text{ x } \text{HC}_i \text{ x } \text{C}_i \text{ x } \text{FO}_i \text{ x } \frac{CO_2(\text{m.w})}{C_{(\text{m.w})}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (v)$$

Where:

Fuel_i = Mass or volume of Fuel Type I Combusted

HC_i = Heat Content of Fuel Type i $\left(\frac{\text{energy}}{\text{mass or volume of fuel}}\right)$

C_i = Carbon Content of Fuel Type i $\left(\frac{\text{mass}}{\text{energy}}\right)$

FO_i = Fraction Oxidized of Fuel Type i

CO_2 (m.w) = Molecular weight of CO_2

C (m.w) = Molecular weight of Carbon

The emitted carbon can be expressed in terms kilogram (kg) by ensuring that the amount of fuel combusted in litres is converted into kg by a simple mathematical formula i.e.

$Fuel_{(kg)} = Fuel_{(L)} \times 1.1764$ …………………. (vi).

Where,

$Fuel_{(kg)}$ equals the required amount of fuel in kg while $Fuel_{(L)}$ is the amount of fuel combusted in litres. Table 4-3 below presents the quantities of CO_2 emissions by the different companies surveyed in this study.

Strata	Fuel Combusted /Month (ltr)	Fuel Combusted /Month (kg)	$kgCO_2$/Month	tCO_2/ Month
Hotels	452420	384580.0748	1212491	1212.5
Banks	65840	55967.35804	176452	176.5
Manufacturing	61500	52278.13669	164821	164.8
Total	**579760**	**492825.5695**	**1553763**	**1553.8**

Table 4- 3: Estimate of CO_2 diesel generators emissions in Juba

From the table above, it can be deduced that the environmental impact of diesel-generated electricity in Juba is so severe. More than 1553.8 tons of carbon-dioxide (CO_2) is being emitted into the air every month in Juba with the hotel sector accounting for 78% of the total emissions.

4.5. Potential of solar energy integration into the mix

The potential of solar energy in South Sudan is huge and is estimated at approximately 6.9 GJ/m2/year with an average of 8 hours of sunshine per day. There is currently no data on the exploitation of these potentials for electricity generation at scale.

Knowledge and willingness of the companies to incorporate solar PV system into their electricity generation were considered. Knowledge wise, the study found less than half responses. Only 36.4% (Fig. 4-5) of the respondents (i.e. 16) have some sort of understanding of solar energy and its importance for electricity generation. This knowledge is centred around costs and emissions reduction compared to diesel generators which require continuous maintenance services and high diesel prices as well as complaints from the surrounding neighbourhoods about smoke and noise.

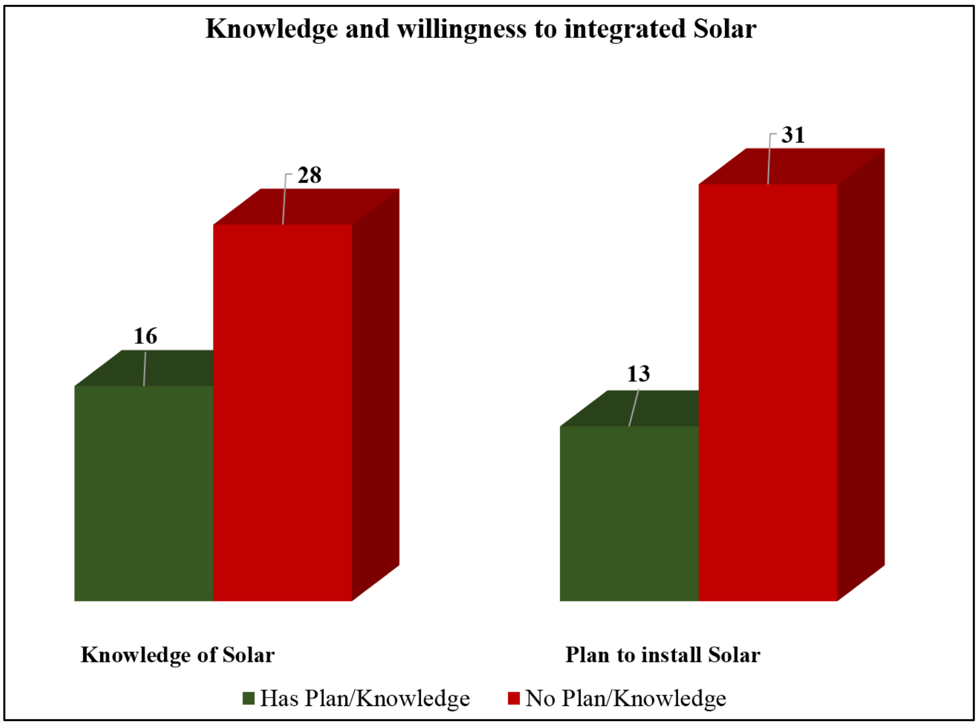


Figure 4- 5: Knowledge of solar energy and plan to install a solar system

Asked whether they would consider installing a solar system to work simultaneously with the diesel generators or in an alternating basis, the study found only 29.5% (Fig. 4-5) of the companies have a form of plans to install a solar system in the future. The majority of the companies expressed lack of interest in solar energy due to three main impediments encompassing: (i) the initial cost for installing solar system is extremely high and there are currently no financing mechanisms in South Sudan for sourcing financial resources (ii) the capacity of solar system may not match the load demand for the companies and unpredictable weather might also affect the functioning of the system, which can lead to economic losses and (iii) large space is usually required for installing a reasonably good system compared to the space requirement for generators. Coupled with a high rate of solar panel theft, installing the solar system within the business premises of the companies is practically not feasible.

Nevertheless, those who have already installed some solar system reported financial savings from diesel fuel purchase as the system can effectively run lightings, a number of fridges, TV sets and provision of warm water for some hours during the day. Additionally, one private company dealing in solar trading reported tremendous market for the solar system in which the company had sold a total of 1MW solar equipment in 2015 to various clients that included NGOs and individual residents. However, the volume of the sales dropped in the following years to an average of 800kW per annum due to conflict and economic crisis in South Sudan that has eroded the purchasing power of the individual household clients.

Finally, the renewable (solar) energy knowledge gap is crosscutting the commercial companies and the institutional stakeholders. For example, of the four institutional stakeholders involved in the discussions, only one had the knowledge of solar energy in substituting the current diesel-fired electricity generation although was also dismayed with the absence of any guiding policy in the country. Meanwhile the other representatives believed solar energy can only be used at household level or in individual institution building not for a large scale commercial supply through the grid network because solar electricity is weak.

4.6. Electricity trading

In the developed economies with well-established stock markets, electricity can be traded in the financial markets like any other commodity to help traders diversify their investment and revenue. However, this does not apply to countries struggling to maintain a constant electrical power supply for few hours each day. In these marketplaces, electricity must be generated, transported, delivered and used continuously by the final users. To ensure this continuity, electricity supply must always match demand. An effective and functioning electricity trading brings together several generators, suppliers and system operator who compete in the market so that customers can choose a supplier of their choice, suppliers choose a generator they prefer, generators improve their generation to be chosen and system operators improve the efficiency of their transmission infrastructure.

This study tried to understand the current and future participation of the surveyed companies in electricity trading and categorized the companies into four groups based on their responses (Fig. 4-6).

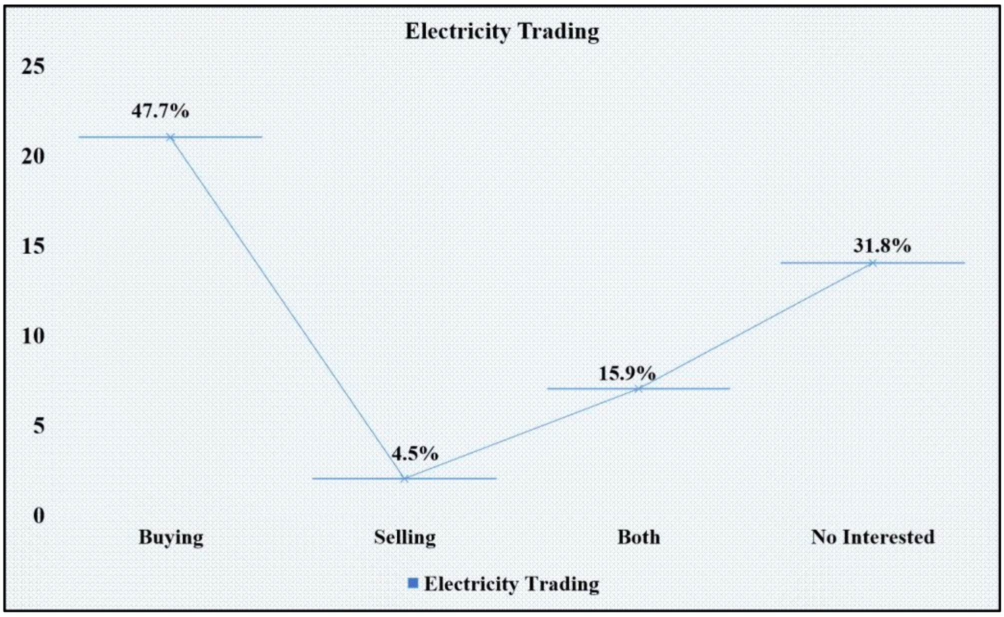


Figure 4- 6: Companies willingness to participate in electricity market

Based on the different parameters of electricity trading used in the study, the results indicate that 47.7%, 4.5% and 15.9% of the companies are interested in buying, selling and both (i.e. buying and selling) respectively. Meanwhile, 31.8% are not interested in any trading citing the potential of their installed generator sets in supplying their electricity demand and the unreliability of buying from external supplier. For those with plans to selling electricity will need to access grid system to supply electricity to their customers. With over 47% ready to but electricity, this indicates a potential market demand that could be met through diversified generation and supplier systems. At the sectoral level however, 100% of the companies willing to specifically participate in electricity selling are from the hotel sector. These companies seem to be seeking new lines of diversifying their business portfolios. Similarly, 76% of those interested in buying electricity are from the same sector.

5.0. DISCUSSIONS

5.1. Introduction

This chapter presents a detailed discussion of the research findings and establishes the linkage with the study objectives and the general literature for a wider understanding. Most of the results presented in this thesis agree with previous studies focusing on the socio-economic and environmental implications of self-electricity generation from diesel generators and the challenges experienced in governing electricity markets particularly in SSA. The national climate change narrative that the current absence of industrial sector in South Sudan economy implies having negligible GHGs emissions was challenged. Interestingly, the current Off-grid self-generation of electricity exceeded the On-grid installed capacity in Juba; and the aim to co-supply the national grid appears infeasible due to market governance dilemma. Finally, incorporating the solar energy into the current/future generation practice is potential but minimally understood by most stakeholders.

5.2. Electricity generation options and supply

Electricity is one of the basic requirements for any socio-economic development of a society. It is extensively used in all human activities such as administrative, commercial, industrial and residential (Azodo 2013). Despite this importance, only 1 % of South Sudan population have access to electricity while majority of the population relay on traditional biomass particularly in the rural areas that account of 83% of the total population.

Juba has an official installed generation capacity of 12 MW exclusively from thermal diesel generators against a growing electricity demand of 154 MW (Deng 2009). This demand poses a challenge to the electricity sector because of low level of electricity generation coupled with inefficient transmission and distribution networks which cause continuous blackouts and load shedding that distresses social comfort and derail business development. Although these blackouts are a challenge from the electricity utility perspective, they are opportunities from the prosumers perspective as they become fully in charge of the management of their own electricity demands and supply. After assessing generation capacity of 44 companies, this thesis found additional Off-grid installed capacity of 28.35 MW from diesel-fired generators and 0.56 MW from solar systems, which bring the total known installed capacity of Juba to 45.93MW. Diesel generators are still the main choice for Off-grid electricity generation due to their convenience and low cost of installation. Like in any developing country struggling with electricity generation options, the World Bank recommends the use of the current diesel generators in South Sudan's electricity sector in the short-term until the time when South Sudan has the financial resources to invest in other sustainable options (World Bank 2013).

Nevertheless, South Sudan has the potential to capitalize on and diversify its electricity generation mix by developing the renewable energy resources wealth and sustainably powering Juba. Diversification in this sense means developing an energy trajectory away from the incumbent oil-fired power generation. Of the available hydropower potential, more than 60% is located within the vicinity of Juba city (AfDB 2013a) which makes it easy to connect directly to the transmission system already built in the city. Biomass and organic wastes production in Juba and surrounding areas are very high (Omer 2005; REEEP 2012 and UNEP 2013) and with appropriate technology, they can have a significant contribution to Juba electricity generation mix and hence, increase electricity access within the city.

Companies with the solar system as well as those dealing in solar business are optimistic about the importance of solar in the electricity mix. Juba street lights, public infrastructure like administrative offices, schools and hospitals as well as some residential housing are using different form of solar system (UNDP and MoED 2013; Whiting *et al.*, 2015; REEEP 2012) and this potential can be up scaled to a much higher level of electricity generation given a conducive environment.

Electricity generation can also be diversified not only in terms of sources but also in those involved in the generation. SSEC currently monopolizes the generation, transmission, distribution and sales of electricity. During the survey process of this thesis, one private company was already building a 21 MW diesel-fired generation power plant as part of a 100MW generation agreement with the government. Its long-term plan according one solar energy retailer who participated in the study is also to establish a diesel-solar hybrid system to experiment its potential in Juba given the high solar panel theft rate.

Finally, some of the companies involved in this study expressed optimism in getting involved in the electricity generation and supply to the grid system. Similarly, they are also sceptical of the mechanisms of participation in a vertically integrated market under the monopoly of one player with direct state influence. As stated by Shen and Yang (2012), this kind on markets limit competition, innovation and efficiency if not unbundled. Co-supplying the grid through prosumers lens using excess electricity hard to elucidate in the context of South Sudan. As will be discussed later, legal frameworks that stipulate the process of connecting to the grid with the purpose of supplying electricity is not available and according SSEC, they do not permit such connection unless it is made legal from the high level of the government.

5.3.Diesel generators and the socio-economic and environmental impact

The adoption of diesel generators in the Off-grid electrification program or for self-generated electricity continues to grow in SSA in general and South Sudan in particular. More than 6% of the installed generation capacity of SSA is made up of own-generation mainly using diesel generators (Steinbuks and Foster 2010). Previous studies estimated that Juba has between 5000-10000 small and medium size generators with varying power output capacities (UNDP/MoED, 2013). This thesis however, uncovered 142 sets of diesel generators with the companies and 195 others in parallel with the UN Mission in South Sudan-UNMISS (Mozersky and Kammen 2018) and since Juba had more than 25 months of no grid electricity supply, the number of private generators must have increased higher than previous estimates.

The proliferation of diesel generators for electricity generation has become a major concern for the government in Juba and elsewhere in the developing countries as they try to implement their commitments to the Paris Agreement on climate change. This practice has damaging effects on the environment, people's health and quality of life (Kranzberg 2012). Communities living near the generation power plant or residential neighborhoods can suffer from endless sound from the running generators. 37% of the companies surveyed in this thesis reported having experienced negative reactions from the neighborhoods and hotel customers regarding noise, smoke and unnecessary heat. Getting direct comments from the society was out of the scope of the study as such no respondent was contacted to attest the consequences they faced.

Furthermore, the combustion of diesel fuel emits dangerous pollutants into the air that can affect human health causing a number of respiratory diseases like lung cancer among others (Rukmini et al, 2014). Gasses like carbon dioxide (CO_2), nitrogen oxide (NOx), sulfur dioxide (SO_2) and methane (CH_4) released by generators are potential GHGs that are responsible for climate change and rise in global temperature above average. Even beyond direct health concerns, pollutants such as black soot, sulfur oxides (SOx) and heavy metals in diesel exhaust or oil leakages from storage facilities lead to soil and water contamination which subsequently affects water retention ability of the soil and plants extraction of nutrients from the soil (Ghosh, 2007). In the long run, this can affect urban farming for food production in and around Juba and the worst-case scenario will be when the diesel exhaust pollutants cross into the food chain through food crops or livestock consumed as meat.

Fortunately, these gases can now be quantified to provide exact estimations of emissions and costs (Rukmini et al, 2014; Anayochukwu and Nnene 2013) to better understand the scale at which GHGs emissions do occur in a given place. These estimates are crucial and can help in future emission management and how to evaluate mitigation measures. Juba GHGs emissions was thus estimated to be 1553.8 tons of carbon-dioxide (CO_2) per month based on the monthly diesel fuel consumption reported. According to Jakhrani *et al.,* (2012), a standard factor of 0.27 can convert emissions units from kg of CO_2 to kg of carbon and vice versa by a multiplication or division. This, therefore, means that the total carbon emission this thesis reports is 419.5tons.

Becoming electricity prosumer through fossil fuels is extremely expensive than purchasing power from the publicly generated grid electricity due to the global increase in diesel fuel prices (Steinbuks and Foster 2010). For the 44 companies in Juba to supply their monthly electricity demand, 589,760 litres of diesel fuel are needed which equates to a total sum of US$ 533,204 apart from maintenance costs. SSEC's 12 MW in Juba consumes as much as 10,000 litres per day (SSEC Respondent's pers. comm) yet only 33.3% of the monthly 60 million litres of diesel fuel imports required for the entire country is available (Odubasa 2017) making serious fuel shortages in Juba and the emergence of black markets for fuel. According to one hotel manager, the price for hotel is also determined by the diesel fuel price and when there is no fuel in the market, they shut down business since every customer requires electricity in the hotel rooms. The high economic burden of own-electricity generation in Juba this thesis found also agrees with Mozersky and Kammen (2018) who stated that between 2011 and 2014, UNMISS consumed 68.7 million litres of diesel fuel for both electricity generation and transportation which all together amount to US$ 325 million. All these fuel consumptions present significant environmental, social and health risks and also sets spotlights on the role humanitarian agencies in carbonizing or de-carbonizing South Sudan in general.

5.4. Solar integration and its role as South Sudan's model for energy transition

Undoubtedly, solar energy will remain South Sudan's immediate and cost-effective energy pathway towards sustainable energy transition and stated by Mozersky and Kammen (2018), it could also be one options for creating jobs and promoting peace in the fragile country. Even with huge potential for hydropower generation, hydroelectricity will require large investment in both generation and infrastructure; and given the fact that more than 80% of South Sudanese live in the rural areas, extending the national grid to those scatter villages will take decades to complete if at all the financial resources were to be secured.

Given its 8 hours daily sunshine potential with radiations estimated at 6.9 GJ/m2/year, solar energy can out compete the current diesel generators because it is clean, cheap and long lasting. Two percent (2%) of the companies covered in this thesis have integrated solar system and attested the financial saving in terms of diesel expenditure they make from the solar. The two solar power retailers contacted during the study further commended the growing solar demand within and outside Juba and given the existence of the international organization and UN agencies like UNICEF, long term contracts (approximately three years) have been made for the supply of various solar systems. Outside the scope of the thesis however, solar energy is penetrating quite well in the Off-grid system particularly in residential and rural administrative buildings. Estimates have showed that there are currently 54000 households in South Sudan using different forms of solar devices including state government's street lights in Juba and Maridi towns and water pumps in several other locations countrywide (UNDP/MoED 2013).

Several factors can contribute to the fact that solar is a model for energy transition in South Sudan by taking on the lead to over the incumbent diesel generators. First, at the micro levels, the absence of or erratic grid electricity supply and changing living standards among the members of the public making people turn towards solar energy installation. The second and the most important factor can be broken into:

- There are currently millions of donor's funds being channelled to the country for humanitarian activities of which a portion of it is used for diesel energy for both electricity and transportation. These funds can pave solar energy trajectory for South Sudan. For example, the initial establishment and expansion solar market in the Kenya to the point that in 2012 it became world's second after China in SHS installation was through donor-led intervention (Hansen, 2014), and South Sudan with the current donor activities in the country would harness rigorous support for the development of solar energy. As started above, UNICEF and UNDP have already began installing solar systems either at local government levels or in public infrastructure like schools, health care units and hospitals (UNDP, n.d.), while USAID has switched a community radio, Mayardit 90.7 FM in Turalei, Warrap State from diesel-generator to a 100% solar PV (Internews 2016)

- Donor-led solar energy transition from the humanitarian perspective has successfully worked in Jordan refugee camps (Mashem, 2017). With the current IDPs and refugee crisis in South Sudan, transition from the predominant biomass use to solar energy can be championed by humanitarian agencies through means of capacity building of locals and establishment of demonstration projects that contributed to generating a demand for PV to save the environment and existing forests near refugee settlements. In the long run, the government and the host communities would benefit from solar infrastructure in the post refugee era, which can lead to community-based electricity prosumers.
- Environment protection has to some extent been mainstreamed into the humanitarian programming and with just a slight trigger by the donors against agencies' fossil fuel-based energy plans in favour of renewable solution like solar PV, can cause rapid solar energy installation by all humanitarian agencies now operating in South Sudan hence, sustainable energy.

However, to facilitate this transition, removing curtails along the pathway such as excessive taxes, poor solar knowledge and lack of financing will be desirable. Solar energy retailers and the World Bank (2014b) have reported lack of knowledge regarding solar energy in South Sudan and this was further proven by the fact that 63.6% of the companies had no idea about the importance of solar energy or its integration with the incumbent compared to the used of the incumbent diesel generators. While in terms of taxes, imports of solar system incur higher tax rates compared to diesel generators of which the retailers claimed that tax officials interpret Solar’s limited/no operational cost advantages for tax compensation since the user will be saving more money in comparison to diesel generators which have addition fuel costs. At the institutional level, MoED stated that all issues related to taxes in the country is the work of the MoCII and there is no exception for any product (i.e. renewable or conventional) when it comes to taxes.

5.5. Electricity market design and governance

Electricity market is the major underlying factor that determines any functioning of power system. The contemporary market designs focus on reliable electricity systems that provide electricity to end-users at least costs (Cramton 2017) through a liberalized market where participants can jointly invest in electricity supply capacities. According to Bublitz *et al.,* (2015) electricity markets are going through a phase of transition characterized by an increasing share of renewable energies. However, this development has only come to supersede the past electric power systems that relied on generators to supply energy needs for the consumers.

Data derived from the draft South Sudan Electricity Bill and backed by the discussions held with the institutional stakeholders showed that SSEC is legally responsible for the administration and management of the national grid systems for power transmission and distribution, purchase of power from IPPs and setting electricity tariffs in collaboration with MoED and MoFEP. This entitlement demonstrates the vertical integration of the electricity sector with a high sense of monopoly. As a vertically integrated market design with only SSEC as the sole player in the generation, transmission, distribution and system operation, it faces many discrepancies specifically in the amount of electricity generated, billed for by the utility and the actual amount paid. For instance, the World Bank (2013) reveals that in 2011 SSEC generated 99 GWh of electricity at an operational investment of US$ 71 million on its thermal power plants. However, it only sold 70 GWh of electricity and made US$ 17 million return on investment, which was less by 76.1% of total investment.

This financial loss is in part due to inefficient grid system with losses estimated at 30% and electricity theft along the transmission line as well as non-payment of bills mainly by high ranging government officials. Currently, SSEC has limited capacity to develop and maintain the grid system or invest in generation and capacity development of its staff. This scenario agrees with Strbac and Wolak (2017) who state that most vertically integrated electricity markets in the developing countries are state-owned with poor history of providing reliable supply of electricity and usually have huge difficult in raising the capital needed for investments in electricity market supply systems (i.e. generation, transmission, and distribution).

In a liberalized electricity markets, markets are designed to be able to deal with most of the impediments experienced in the vertically integrated market design to ensure efficiency, reliability and transition towards sustainable low carbon emitting energies (Beus *et al.,* 2018; Ang *et al.,* 2015). Even if this can be incorporated into the South Sudan electricity market, SSEC has neither experience in dealing with private connection to the grid system to co-supply electricity nor technical skills in metering system for revenue collection. The present prepaid metering devices used in Juba are remotely controlled from South Africa. This, in addition to the absence of legal regulatory frameworks can significantly obstruct the establishment of a viable electricity market. However, the AfDB has recently injected US$ 17 million funding for the rehabilitation and expansion of the of the Juba transmission and distribution network and professional development of staff (AfDB 2013b).

Direct involvement of the state in the electricity market if not strategically crafted can introduce a paralyzing power against the effective development of the sector. One evident this study recorded showed that, for every kWh of electricity generated by SSEC, the government subsidized it by 70%, making commercial customers, for instance, pay only 30% of the production cost and the national budget of the country is being stressed by 4% annually to cover electricity subsidies. Other concerns also come from the revenue collection system by SSEC where continuous disappearance of cash within the finance offices of the company has persisted without any sort of accountability.

Furthermore, MoFEP controls 80% of all revenue collected giving only 20% to SSEC for its administrative expenses. This according to SSEC is the major challenge in maintaining continuous electricity generation because any financial request to the ministry to procure spare part for the generators takes more than three months to be approved and tender made public for biding. Even worst enough, there is no concurrent coordination mechanism among the various institutions involved in the energy sector. For example, MoCII sets import on energy products taxes without involvement of MoED or MoP and in practice, MoED or MoP execute fossil-based project with massive environmental impact without the involvement of MoE.

Electricity market under the monopoly of a state-own utility like that of South Sudan can substantially liberalize the market by introducing a system of incentives using a regulatory framework such as PPAs and FITs to bring into play various IPPs. Unfortunately, all known incentive modalities currently applied in all electricity markets are missing in South Sudan. As a new emerging market with almost all legal frameworks in draft forms, attracting IPPs to participate in the market will undoubtedly take lone to evolve to a level of full liberalization where the private sector can become active player in all aspects of market design.

6.0. CONCLUSION AND RECOMMANDATIONS

This chapter provides a summary of the finding of the study as a conclusion drawing the background to the study and the findings. It then ends with recommendations which, if appropriate actions taken on them would contribute toward the development of the electricity sector of South Sudan in a sustainable way.

6.1. Conclusion

South Sudan is among the few SSA countries blessed with an abundance of both renewable and conventional (oil) energy resources. The socio-economic development of the country rests on oil extraction and exports. Despite its renewable energy resources potential, electricity generation in Juba with an installed generation capacity of 12 MW is exclusively oil-fired and SSEC is the only player in its supply, distribution and revenue collections. As the only entity in the sector, SSEC's generation capacity presents a huge mismatch against electricity demand of Juba being the national business and administrative hub as well as having the largest population in the whole country. These disparities consequently lead to continuous electricity outages and load shedding that disrupts social comfort and ruin business development. Hence, diesel generators dramatically spread all over Juba for Off-grid self-electricity generation. This study then assessed how the various options for Off-grid generation currently in practice can contribute to the grid system to elevate the capacity of SSEC and ensure adequate electricity supply in Juba.

The study found that the current Off-grid installed electricity generation capacity in Juba is higher than the known installed capacity run by SSEC. In this Off-grid capacity, hotel businesses owned the largest portion with an exceptionally high number of diesel generators followed by the manufacturing companies while the banks have the least capacity. Some of the companies have high generation power than their daily electricity needs and presents potential electricity trading opportunities. Although there is renewable energy (i.e. Solar) penetration in and around Juba, its contribution to the mix is less when compared to the growth of diesel generators for electricity generation and there are limited or no promotional programs for solar energy adoption in place.

Diesel based electricity has a huge burden on the companies, society, and the environment. Each month, the companies spend thousands of dollars to procure diesel fuel to run their generators. While at the same time, the running of the generators rises social reaction against noise and air pollution due to emission from the burning diesel. Hundreds of tons of carbon dioxide were found to have been emitted each month into the air that may result in health-related issues. Adoption of solar could be a remediating strategy for the socio-economic and environmental issues now superseding the electricity generation in Juba. Unfortunately, knowledge regarding the importance of solar energy among the companies is low and most of them would prefer using their own diesel generators than adopting solar system or buying electricity from an external provider.

Contrary to the management of electricity markets in the region, the governance of South Sudan's electricity sector is woefully unsatisfactory with a prevailing sense of politics. Although there are national institutions with an overall mandate to govern the electricity sector, these institutions generally lack the legal instruments for the management of the sector making personalities influences to reign. Drafts of all legal frameworks that would have helped transform the sector from vertical to horizontal integration have found a resting place in the council of minister's desks for the last six to eight years without being approved for use. This makes the sector to be run without any legal strategies thus, failing to attract any private investment in electricity development.

Even if there were private entities ready to engage in electricity generation and supply in Juba to improve people access to electricity, the environment may not be favourable for the business.

Additionally, in the absence of legal frameworks guiding the effective participation of various players in South Sudan's electricity market, the current electricity prosumers in Juba find it extremely complicated to connect to the national grid so that excess electricity can be sold to other customers and in return, they get paid for the supply. SSEC which is responsible for the administration of the grid and metering system is a vertically integrated company with direct influence of MoED and MoFEP; and due to the high bureaucracy in these institutions, any private supply of electricity to the grid might not get its payment promptly.

Finally, solar energy has been identified as the immediate option for South Sudan's energy transition towards sustainable energy security for all, given its solar radiation potential. This trajectory could be developed through the humanitarian intervention lens since donors are channelling millions of funds for humanitarian activities including energy demands through the path. With effective humanitarian energy programming, the current beneficiaries would become future electricity entrepreneurs in generation and management of the established transmission and distribution network.

6.2. Recommendations

Based on the findings of the research, this thesis identified four broad recommendations for actions which include:

- ***Legal framework for the electricity sector.*** All draft legal and regulatory frameworks including the energy policy and the Electricity Bill should be adopted, implemented or enacted to reform the electricity sector and MoED in collaboration with MoE should formulate RE and EE policy to guide the development and promotion of renewable energy technologies in the country. Additionally, the government should consider removing all forms of electricity subsidies and introduce FIT and PPAs into the electricity sector to attract private sector investments especially IPPs in grid and Off-grid electricity development and if necessary adopt carbon tax to incentivize RETs.

- ***Electricity market liberalization.*** The government of South Sudan should develop and immediately enact policies to ensure that the current monopoly of the electricity market by SSEC is de-integrated and generation separated from distribution. Open access to the transmission line could enable competition among generators thus creating efficiency in electricity services delivery. Additionally, restructuring the current market system would incentivize participants including the present generators owners to supply electricity to the national grid in Juba.
- ***General awareness creation.*** It is generally known that diesel generated electricity is expensive and comes several social and environmental consequences compared to the use of solar energy. There is need for the government particularly MoE in partnership with MoED, Ministry of Health (MoH) and development partners to initiate awareness trainings or sensitization workshops for the public and private sectors including the general public in Juba on the socio-economic, health and environmental impacts of both diesel generators and solar energy. Establishment of a solar learning hub could be instrumental in creating awareness and advancing transition to sustainable energy.
- ***Mainstreaming renewable and energy efficiency into humanitarian programming.*** South Sudan now have more than 200 humanitarian organizations with intensive energy use mainly for electricity and transport and diesel is the sole provider. By mainstreaming renewable energy technology like solar into programming and making it funding requirement will set excellent and sustainable precedent for saving the environment from GHG emissions on one hand and reducing high operation costs on the other hence, more funds for tackling real life saving interventions.

- ***Future research in the electricity sector.*** This thesis covered only small number of companies now operating in Juba excluding the residential settlements. It is recommended that a comprehensive study be done to document the exact figure of diesel generators currently installed in Juba and their monthly or annual fuel consumption to help in future estimation of carbon emissions and setting standards on acceptable rates for the country. Although solar radiation is generally considered good in South Sudan, there is need to conduct comprehensive studies to map which geographical locations are conducive for what scale of solar energy and other renewable energy investment.

7.0. REFERENCES

Ackermann, T. (2000). Wind Energy Technology and Current Status: Review, Renewable and Sustainable Energy Reviews, (4) 315-374, UK, Elsevier Science Ltd.

AfDB (African Development bank) 2013a. South Sudan: An Infrastructure Action Plan-A Program for Sustained Strong Economic Growth. URL: https://www.afdb.org/en/documents/document/south-sudan-infrastructure-action-plan-a-program-for-sustained-strong-economic-growth-full-report-33384/

______. 2013b. Juba Power Distribution System Rehabilitation and Expansion Project. URL: https://www.afdb.org/en/news-and-events/adf-us-26-million-grant-to-expand-electricity-distribution-networks-in-south-sudan-12704/

Africa energy series. 2017. South Sudan. URL: http://africaoilandpower.com/wp-content/uploads/2017/06/Africa-Energy-Series-South-Sudan-2017.pdf

Ahlborg, H., and Sjöstedt, M. 2015. Small-scale hydropower in Africa: Socio-technical designs for renewable energy in Tanzanian villages. *Energy Research and Social Science*, *5*, 20-33.

Amogpai, A. 2007. Lighting and Energy Usage in Sudan, Master Thesis, Helsinki University of Technology, Espoo, Finland.

Anayochukwu, A. V., and Nnene, E. A. 2013. Measuring the environmental impact of power generation at GSM Base Station Sites. *Electronic Journal of Energy and Environment*, *1*(1), 71-79.

Ang, B.W., Choong, W.L., Ng, T.S., 2015. Energy security: Definitions, dimensions and indexes. Renewable and Sustainable Energy Reviews 42, 1077–1093. doi:10.1016/j.rser.2014.10.064.

Ani, V. A. 2016. Design of a Reliable Hybrid (PV/Diesel) Power System with Energy Storage in Batteries for Remote Residential Home. *Journal of Energy*, *2016*.

Avila, N., Carvallo, J. P., Shaw, B., and Kammen, D. M. 2017. The energy challenge in Sub-Saharan Africa: A guide for advocates and policy makers: Part 1: Generating energy for sustainable and equitable development. *Oxfam Research Backgrounder series*.

Azodo, P. A. 2014. Electric power supply, main source and backing: A survey of residential utilization features in Obantoko, Ogun State, Nigeria. *Annals of the Faculty of Engineering Hunedoara*, *12*(4), 51.

Baurzhan, S., and Jenkins, G. P. 2016. Off-grid solar PV: Is it an affordable or appropriate solution for rural electrification in Sub-Saharan African countries?. Renewable and Sustainable Energy Reviews, 60, 1405-1418.

______. 2017. On-grid solar PV versus diesel electricity generation in Sub-Saharan Africa: Economics and GHG emissions. *Sustainability*, *9*(3), 372.

Begum, S., and Nazri, A. H. 2013. Energy Efficiency of Biogas Produced from Different Biomass Sources. In *IOP Conference Series: Earth and Environmental Science* (Vol. 16, No. 1, p. 012021). IOP Publishing.

Beus, M., Pavić, I., Štritof, I., Capuder, T., and Pandžić, H. 2018. Electricity Market Design in Croatia within the European Electricity Market—Recommendations for Further Development. *Energies*, *11*(2), 346.

Birol, F. 2014. *Africa energy outlook-a focus on energy prospects in Sub-Saharan Africa* (Vol. 808). Tech. rep., International Energy 807 Agency, Paris, France.

Blechinger, P., Cader, C., Oyewo, A. S., Breyer, C., and Bertheau, P. 2016, September. Energy access for Sub-Saharan Africa with the focus on PV-hybrid mini-grids. In *Proceedings of the 1st International Conference on Solar Technologies and Hybrid Mini Grids to Improve Energy Access Conference, Bad Hersfeld, Germany* (pp. 21-23).

Blinker, L and Grassi, S. 2001. Fact-finding mission to Sudan, 8-20 May 2001: for an investigation of Sudan's geothermal resources, the Jebel Marra area. UNESCO. URL: http://unesdoc.unesco.org/images/0014/001418/141825eo.pdf

BP's Statistical Review of World Energy. 2017. URL: https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review-2017/bp-statistical-review-of-world-energy-2017-full-report.pdf

Breyer, C., Bogdanov, D., Aghahosseini, A., Gulagi, A., Child, M., Oyewo, A. S. and Vainikka, P. 2017. Solar photovoltaics demand for the global energy transition in the power sector. *Progress in Photovoltaics: Research and Applications*.

British Business Energy. 2016. World Solar PV Energy Potential Maps. URL: https://britishbusinessenergy.co.uk/world-solar-map/

Bublitz, A., Keles, D., Zimmermann, F., Fraunholz, C., and Fichtner, W. 2018. *A survey on electricity market design: Insights from theory and real-world implementations of capacity remuneration mechanisms* (No. 27). Working Paper Series in Production and Energy.

Cader, C., Hlusiak, M., and Breyer, C. 2013. High-resolution global cost advantages of stand-alone small-scale hybrid PV-Battery-Diesel Systems. In *Proceedings of the second International Conference on Micro Perspectives for Decentralized Energy Supply, Berlin, Germany* (28).

Cascão, A. E. 2013. Resource-based conflict in South Sudan and Gambella (Ethiopia): When water, land and oil mix with politics, In Dias, A. M. (ed.) *State and Societal Challenges in the Horn of Africa: Conflict and processes of state formation, reconfiguration and disintegration.* Center of African Studies, University of Lisbon. (pp. 143-165).

Castellano, A., Kendall, A., Nikomarov, M., and Swemmer, T. 2015. Brighter Africa: The growth potential of the Sub-Saharan electricity sector. *McKinsey Report.* URL: *http://www.mckinsey.com/insights/energy_resources_materials/powering_africa*

Chaurey, A., and Kandpal, T. C. 2010. Assessment and evaluation of PV based decentralized rural electrification: An overview. Renewable and Sustainable Energy Reviews, 14 (8), 2266–2278.

Chhetri, A. B. 2007. Decentralization of Energy Systems for Sustainable Economic Development in Nepal. *Proceedings of Unfolding Futures: Nepalese Economy, Society, and Politics. Canada.* URL: http://cffn.ca/2007/10/decentralization-of-energysystems-for-sustainable-economic-development-in-nepal/ .

CIA- (Central Intelligence Agency) n.d. The World Factbook. [Online] Accessed May 7th, 2018. URL: https://www.cia.gov/library/publications/the-world-factbook/

Cioablă, A. E., and Ionel, I. 2011. Biomass Waste as a Renewable Source of Biogas Production-Experiments. In *Alternative Fuel*. InTech.

Clyde and Co. 2016. Renewable energy: Investing in Africa. South Sudan. URL: https://www.clydeco.com/uploads/Blogs/offshore/files/Energy_profile_-_South_Sudan.pdf

Colthorpe, A. 2017, May 9th. Navigant: Distributed solar-plus-storage worth US$49 billion in less than 10 years. Accessed May 14th, 2018. URL: https://www.energy-storage.news/news/navigant-distributed-solar-plus-storage-worth-us49-billion-27.4gw-in-less-t

Conway, D., Dalin, C., Landman, W. A., and Osborn, T. J. 2017. Hydropower plans in eastern and southern Africa increase risk of concurrent climate-related electricity supply disruption. *Nature Energy*, *2*(12), 946.

Cordaid. 2014. Oil Production in South Sudan: Making it a Benefit for All. Baseline assessment of the impact of oil production on communities in Upper Nile and Unity States. URL: https://www.cordaid.org/en/wp-content/uploads/sites/3/2014/06/Oil_Production_in_South_Sudan_Summary_Report_DEF__LRS.pdf

Cramton, P. 2017. Electricity market design. *Oxford Review of Economic Policy*, *33*(4), 589-612.

Dasappa, S. 2011. Potential of biomass energy for electricity generation in Sub-Saharan Africa. *Energy for Sustainable Development*, *15*(3), 203-213.

David, D. and Dodd, J. 2002. Qualitative research and the question of rigour. Qualitative Health Research, 12 (2), 279-289.

Demirbas, A., Alidrisi, H., Ahmad, W., and Sheikh, M. H. 2016. Potential of geothermal energy in the Kingdom of Saudi Arabia. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *38*(15), 2238-2243.

Demirbas, A., Hashem, A. A., and Bakhsh, A. A. 2017. The cost analysis of electric power generation in Saudi Arabia. *Energy Sources, Part B: Economics, Planning, and Policy*, *12*(6), 591-596.

Deng, J. M. 2009. Energy status in South Sudan. MSc. Thesis, University of Nairobi, Kenya

Eberhard, A., Gratwick, K., Morella, E., and Antmann, P. (2016). *Independent power projects in Sub-Saharan Africa: Lessons from five key countries*. World Bank Publications.

El-Zein, M. 2017. Solar Energy Potential in the Sudan. URL: http://www.diva-portal.org/smash/get/diva2:1110877/ATTACHMENT01.pdf

ESI Africa. 2016. Regional cooperation catalyst for hydropower development in East Africa. Africa’s power journal (3). URL: https://www.esi-africa.com/regional-cooperation-catalyst-hydropower-development-east-africa-2/

EXIM Bank. 2017. Power Sector in Africa: Prospect and Potential. Working Paper No. 67. URL: https://www.eximbankindia.in/Assets/Dynamic/PDF/Publication-Resources/ResearchPapers/75file.pdf

FAO/WFP. 2013. Crop and Food Security Assessment Mission to South Sudan report 22 February 2013

Foster, V., and Steinbuks, J. 2009. *Paying the price for unreliable power supplies: In-house generation of electricity by firms in Africa*. Policy Research Working Paper. Washington, DC: World Bank

Gan, L. K., Shek, J. K., and Mueller, M. A. 2015. Hybrid wind–photovoltaic–diesel–battery system sizing tool development using empirical approach, life-cycle cost and performance analysis: A case study in Scotland. *Energy Conversion and Management*, *106*, 479-494.

Gashaw, G. 2013. Addis to have 1st Sub-Saharan Africa waste-to-energy plant. The Ethiopian Herald. Accessed May 20th, 2018. URL: http://www.ethpress.gov.et/herald/index.php/herald/news/715-addis-to-have-1st-Sub-Saharan-africa-waste-to-energy-plant.

Georgsson, L. S. 2014. Geothermal energy in the world from an energy perspective. *001374011*.

Ghosh, U. 2007. The role of black carbon in influencing availability of PAHs in sediments. *Human and Ecological Risk Assessment*, *13*(2), 276-285.

Global, L., and Finance, B. N. E. 2016. Off-grid solar market trends report 2016. *Bloomberg New Energy Finance and Lighting Global in cooperation with the Global Off-Grid Lighting Association (GOGLA).*

Goldthau, A. 2014. ‘Rethinking the governance of energy infrastructure: Scale, decentralization and polycentrism,’ Energy Research *and* Social Science 1 134–140.

GOSS. 2014. Expression of interest: Scaling up Renewable Energy Programme in Low Income Countries. Juba: Ministry of Electricity, Dams, Irrigation and Water Resources. Republic of South Sudan (ROSS)

GWEC- (Global Wind Energy Council). 2017. Global wind statistics. URL: http://gwec.net/wp-content/uploads/vip/GWEC_PRstats2017_EN-003_FINAL.pdf

Hansen, U. E., Pedersen, M. B., and Nygaard, I. 2014. Review of Solar PV market development in East Africa. UNEP Risø Centre, Technical University of Denmark. (UNEP Risø Centre Working Paper Series; No. 12).

Hill, J. S. 2015, October 15th). Revenue for Global Solar PV and Energy Storage Nanogrid Expected to Reach $23.1 Billion. *Clean Technica.* URL: https://cleantechnica.com/2015/10/15/revenue-for-global-solar-pv-energy-storage-nanogrid-expected-to-reach-23-1-billion/

Hoggett, R. D. 2017. People, demand and governance in future energy systems. 2017 EPG Working Paper: 1701. URL: https://ore.exeter.ac.uk/repository/handle/10871/26689

Hosford, B., and Cole, R. 2015. An Economic Analysis of Solar Photovoltaic Installations in Ireland. URL: https://pdfs.semanticscholar.org/fcd0/758904e912a90ef186265ec0654d7a78b0e7.pdf

Hrayshat, E. S. 2009. Techno-economic analysis of autonomous hybrid photovoltaic-diesel-battery system. *Energy for Sustainable Development*, *13*(3), 143-150.

IEA-(International Energy Agency) 2014a. World Energy Outlook 2014. Accessed June 1st, 2018. URL: https://www.iea.org/publications/freepublications/publication/WEO2014.pdf

______. 2014b. Africa Energy Outlook. A focus on energy prospects in Sub-Saharan Africa. Accessed May 4th, 2018. URL: https://www.iea.org/publications/freepublications/publication/WEO2014_AfricaEnergyOutlook.pdf

______. 2015a. Energy Climate and Change. World Energy Outlook Special Report

______. 2015b. *Solar Photovoltaic Energy*, IEA Technology Roadmaps, OECD Publishing, Paris. URL: https://doi.org/10.1787/9789264238817-en.

______. 2010. Energy technology perspectives. URL: https://www.iea.org/publications/freepublications/publication/etp2010.pdf

______. 2016. Market design and regulation during the transition to low-carbon power systems. *International Energy Agency*.

IMF-International Monetary Fund) 2016. Republic of South Sudan. Debt Sustainability Analysis. URL: https://www.imf.org/external/pubs/ft/dsa/pdf/2017/dsacr1773.pdf

Internews 2016. Solar Powered Transmission: A Case Study from South Sudan. URL: https://www.internews.org/sites/default/files/Solar_Powered_Transmission_CaseStudy_SouthSudan2016-11.pdf

IPC-(Integrated Food Security Phase Classification) 2017, Feb). Acute Food Insecurity and Acute Malnutrition Situation. URL: http://www.ipcinfo.org/ipcinfo-detail-forms/ipcinfo-map-detail/en/c/471270/

Jäger-Waldau, A. 2017. PV statuts report 2017. JRC108105. URL: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC108105/kjna28817enn.pdf.

Jakhrani, A. Q., Rigit, A. R. H., Othman, A. K., Samo, S. R., and Kamboh, S. A. 2012. Estimation of carbon footprints from diesel generator emissions. In *Green and Ubiquitous Technology (GUT), 2012 International Conference on* (pp. 78-81). IEEE.

Javadi, F. S., Rismanchi, B., Sarraf, M., Afshar, O., Saidur, R., Ping, H. W., and Rahim, N. A. 2013. Global policy of rural electrification. *Renewable and Sustainable Energy Reviews*, *19*, 402-416.

Johnson, D. 2003. The root causes of Sudan’s civil war. African Issues. The International African Institute. London.

Kaabeche, A., and Ibtiouen, R. 2014. Techno-economic optimization of hybrid photovoltaic/wind/diesel/battery generation in a stand-alone power system. *Solar Energy*, *103*, 171-182.

Kadam, P., and Bhalerao, S. 2010. Sample size calculation. *International journal of Ayurveda research*, *1*(1), 55.

Kaitano, S. R. 2016. Factors Influencing Utilization of Direct Geothermal Energy in Kenya. A Case of Menengai Geothermal Project in Nakuru County. Masthers Thesis. University of Nairobi-Kenya.

Kalambe, S. M. 2017. Economic and Environmental Analysis of Remote diesel generator with photovoltaic cogeneration. Int. J. Sci. Res. 7(8), 533-541.

Karekezi, S., and Kithyoma, W. 2003. Renewable Energy in Africa: Prospects and Limits. Prepared for: The Workshop for African Energy Experts on Operationalizing the NEPAD Energy Initiative. 2-4 June 2003.

Kelle, U. 2006. Combining qualitative and quantitative methods in research practice: purposes and advantages. *Qualitative research in psychology*, *3*(4), 293-311.

Klunne, W. J. 2013. Small hydropower in southern Africa-an overview of five countries in the region. *Journal of Energy in Southern Africa*, *24*(3), 14-25.

Kolawole, A., Adesola, S., and De Vita, G. 2017. A Disaggregated Analysis of Energy Demand in Sub-Saharan Africa. *International Journal of Energy Economics and Policy*, *7*(2).

Koyama, K. 2017. An analysis of global energy governance. *The Institute of Energy Economics, Japan.* Accessed July 7th, 2018. URL: https://eneken.ieej.or.jp/en/special_bulletin.html

Kranzberg, D. G. 2012. *Submitted in Partial Fulfillment of the Requirements for the Degree of master's in engineering and Public Policy* (Doctoral dissertation, McMaster University Hamilton).

Kronsbein, P. 2017, February 7th. Global solar power demand grows nearly 50% in 2016, Europe drops. Accessed June 3rd, 2018. URL: http://www.sunwindenergy.com/photovoltaics/global-solar-power-demand-grows-nearly-50-2016-europe-drops

Kuzemko, C., Lockwood, M., Mitchell, C., and Hoggett, R. 2016. Governing for sustainable energy system change: Politics, contexts and contingency. *Energy Research and Social Science*, *12*, 96-105.

Langbein, J., Peters, J., and Vance, C. 2017. Outdoor cooking prevalence in developing countries and its implication for clean cooking policies. *Environmental Research Letters*, *12*(11), 115008.

Lindgren, G., Cox, D. R., Gudmundsson, G., Bondesson, L., Harsaae, E., Laake, P. and Lauritzen, S. L. 1981. Statistical analysis of time series: Some recent developments [with discussion and reply]. *Scandinavian Journal of Statistics*, 93-115.

Liu, H., Masera, D. and Esser, L., eds. 2013. World Small Hydropower Development Report 2013. United Nations Industrial Development Organization; International Center on Small Hydro Power. Available from www.smallhydroworld.org.

Mager, A., Wirkus, L., and Schoepfer, E. 2016. Impact Assessment of Oil Exploitation in South Sudan using Multi-Temporal Landsat Imagery. *Photogrammetrie-Fernerkundung-Geoinformation, 2016*(4), 211-223.

Mandelli, S., Barbieri, J., Mereu, R., and Colombo, E. 2016. Off-grid systems for rural electrification in developing countries: Definitions, classification and a comprehensive literature review. *Renewable and Sustainable Energy Reviews*, *58*, 1621–1646. https://doi.org/10.1016/j.rser.2015.12.338

Maps of the World 2013. Juba map. Accessed July 148, 2018. URL: https://www.mapsofworld.com/south-sudan/juba.html

Marwa Hashem, M. 2017, November 14th. Jordan's Za'atari camp goes green with new solar plant. Accessed July 19th, 2018. URL: http://www.unhcr.org/en-us/news/latest/2017/11/5a0ab9854/jordans-zaatari-camp%20-green-new-solar-plant.html

Meng, X. 2013. Scalable simple random sampling and stratified sampling. In *International Conference on Machine Learning* (pp. 531-539).

Mishnaevsky Jr, L., Freere, P., Sinha, R., Acharya, P., Shrestha, R., and Manandhar, P. 2011. Small wind turbines with timber blades for developing countries: Materials choice, development, installation and experiences. *Renewable Energy, 36*(8), 2128-2138.

Mitchell, C. 2014, December 15th. Britain's dinosaur capacity market will worsen energy 'trilemma'. Accessed June 29th, 2018. URL: https://www.businessgreen.com/bg/opinion/2386742/britain-s-dinosaur-capacity-market-will-worsen-energy-trilemma

MoE-(Ministry of Environment) 2013. Republic of South Sudan's National Adaptation Programme of Actions (NAPA) to climate change

Morris, C., and Pehnt, M. 2016. Energy Transition: The German Energiewende. *Heinrich-Böll-Stiftung*.

Mundo-Hernández, J., de Celis Alonso, B., Hernández-Álvarez, J., and de Celis-Carrillo, B. 2014. An overview of solar photovoltaic energy in Mexico and Germany. *Renewable and Sustainable Energy Reviews*, *31*, 639-649.

Mwangi, J., Kimani, N., and Muniafu, M. 2013. Renewable Energy Governance in Kenya: Plugging into the Grid 'Plugging into Progress'. In *Renewable Energy Governance* (pp. 119-135). Springer, London.

Newell, P., and Phillips, J. 2016. Neoliberal energy transitions in the South: Kenyan experiences. *Geoforum*, *74*, 39-48.

Niglas, K. 2000. Combining quantitative and qualitative approaches. In *Paper presented at the European Conference on Educational Research* (20), 23.

Njogu, M., Njuguna, P. M., and Da Silva, I. P. 2015. Rural Electrification using off-grid Solar PV powered Energy Kiosks. URL: https://su-plus.strathmore.edu/handle/11071/3488

Noguera, A. L. G., Castellanos, L. S. M., Lora, E. E. S., and Cobas, V. R. M. 2018. Optimum design of a hybrid diesel-ORC/photovoltaic system using PSO: Case study for the city of Cujubim, Brazil. *Energy*, *142*, 33-45.

Odubasa, A. 2017. Survey report for electricity generation and utilization in Juba (*Unpublished).*

Oketola, D. 2014, February 6th. Power outage drains consumers' purse. Accessed June 13th, 2018. URL: http://sweetcrudereports.com/2014/02/06/power-outage-drains-consumers-purse/

Omer, A. 2005a. Biomass Energy Potential and Future Prospect in Sudan, Energy Review, 9, 1-27. UK, Elsevier Science Ltd.

______. 2005b. Biomass energy potential and future prospect in Sudan. Renewable and Sustainable Energy Reviews, 9, 1-27

______. 2016. An overview of biomass and biogas for energy generation: recent development and perspectives. *Agric Adv*, *5*(2), 251-268.

______. 2015. Evaluation of sustainable development and environmentally friendly energy systems: case of Sudan. *E3 Journal of Environmental Research and Management.* Vol. 6(3). p.237-261.

Ondraczek, J. 2013. The sun rises in the east (of Africa): A comparison of the development and status of solar energy markets in Kenya and Tanzania. *Energy Policy*, *56*, 407-417.

Phuangpornpitak, N., and Kumar, S. 2011. User acceptance of diesel/PV hybrid system in an island community. *Renewable Energy*, *36*(1), 125-131.

Platts, 2009. *UDI World Electric Power Plants database (WEPP)*. Platts – A Division of the McGraw-Hill, Washington.

Pragst, F., Stieglitz, K., Runge, H., Runow, K. D., Quig, D., Osborne, R., ... and Ariki, J. 2017. High concentrations of lead and barium in hair of the rural population caused by water pollution in the Thar Jath oilfields in South Sudan. *Forensic science international*, *274*, 99-106.

PV Magazine 2017, Mar 17th. South Africa's PV capacity reaches 1.47 GW, new PV installations for 2016 total 509 MW. URL: https://www.pv-magazine.com/2017/03/17/south-africas-pv-capacity-reaches-1-47-gw-new-pv-installations-for-2016-total-509-mw/

Quansah, D. A., Adaramola, M. S., and Mensah, L. D. 2016. Solar Photovoltaics in Sub-Saharan Africa–Addressing Barriers, Unlocking Potential. *Energy Procedia*, *106*, 97-110.

Rawn, B., and Louie, H. 2017. Planning for Electrification: On-and Off-Grid Considerations in Sub-Saharan Africa. *IDS Bulletin*, *48*(5-6).

REEEP 2012. South Sudan. URL: https://www.reeep.org/south-sudan-2012

Reja, U., Manfreda, K. L., Hlebec, V., and Vehovar, V. 2003. Open-ended vs. close-ended questions in web questionnaires. *Developments in applied statistics*, *19*(1), 160-117.

Reuters 2018, 21st March. U.S. targets South Sudan oil firms with sanctions to choke off war funds. URL: https://www.reuters.com/article/us-usa-southsudan-oil-sanctions/u-s-targets-south-sudan-oil-firms-with-sanctions-to-choke-off-war-funds-idUSKBN1GX27N

Roche, O. M., and Blanchard, R. E. 2018. Design of a solar energy centre for providing lighting and income-generating activities for off-grid rural communities in Kenya. *Renewable Energy*, *118*, 685-694.

Rosnes, O. and Vennemo, H. 2008. Powering Up: Costing Power Infrastructure Investment Needs in Southern and Eastern Africa- World Bank Africa Infrastructure Country Diagnostic Paper No. 61813. URL: http://www.eu-africa-infrastructure-tf.net/attachments/library/aicd-background-paper-5-power-invest-summary-en.pdf

Rukmini; Harun, N., Adisasmita, S. T. and Sitepu, G. 2014. Estimated emissions from diesel generators of containercranes at makassar container terminal. *Int. J. Mechanical and*

Sandwell, P., Chan, N. L. A., Foster, S., Nagpal, D., Emmott, C. J. M., Candelise, C., … Nelson, J. 2016. Off-grid solar photovoltaic systems for rural electrification and emissions mitigation in India. *Solar Energy Materials and Solar Cells*, *156*, 147–156. https://doi.org/10.1016/j.solmat.2016.04.030

Schwandt, T.A. 2007. Sage dictionary of qualitative inquiry. Third edition. Thousand Oaks, CA: Sage.

Shankleman, J. 2011. Oil and State Building in South Sudan. *United States Institute of Peace. Special Report*, *282*.

Shen, D., Yang, Q. (2012), Electricity Market Regulatory Reform and Competition – Case Study of the New Zealand Electricity Market in: Wu, Y., Shi, X., Kimura, F. (eds.), *Energy Market Integration in East Asia: Theories, Electricity Sector and Subsidies*, ERIA Research Project Report 2011-17, Jakarta: ERIA, 103-139.

Smith, A. 2009. Energy governance: The challenges of sustainability. In *Energy for the Future* (pp. 54-75). Palgrave Macmillan, London.

SolarGis. 2017. Maps of Global horizontal irradiation (GHI). URL: https://solargis.com/maps-and-gis-data/download/south-sudan

SSNBS-(South Sudan National Bureau of Statistics) 2012. South Sudan Household Baseline survey report

Statista 2018. South Sudan: Inflation rate from 2012 to 2022 (compared to the previous year). Accessed May 14, 2018. URL: https://www.statista.com/statistics/727347/inflation-rate-in-south-sudan/

Steinbuks, J., and Foster, V. 2010. When do firms generate? Evidence on in-house electricity supply in Africa. *Energy Economics*, *32*(3), 505-514.

Stewards, C.J. and Cash Jr, W.B. 2008. Interviewing: Principles and practices. 12th Edition. New York: McGraw Hill.

Tiitmamer, N. 2015. Understanding the Enforcement of Environmental Provisions of Petroleum Act 2012 and Environmental Ruin Continue. *Sudd Institute Policy Brief*.

Toklu, E. 2017. Biomass energy potential and utilization in Turkey. *Renewable Energy*, *107*, 235-244.

Tummala, A., Velamati, R. K., Sinha, D. K., Indraja, V., and Krishna, V. H. 2016. A review on small-scale wind turbines. *Renewable and Sustainable Energy Reviews*, *56*, 1351-1371.

Uğurlu, A., and Gökçöl, C. 2017. A case study of PV-wind-diesel-battery hybrid system. *Journal of Energy Systems*, *1*(4), 138-147.

Ullah, M. H. 2013. An efficient solar-wind-diesel-battery hybrid power system for St. Martin Island of Bangladesh. *International Journal of Renewable Energy Research (IJRER)*, *3*(3), 659-665.

Ulsrud, K., Winther, T., Palit, D., and Rohracher, H. 2015. Village-level solar power in Africa: accelerating access to electricity services through a socio-technical design in Kenya. *Energy Research and Social Science*, *5*, 34-44.

UNDP n.d. Solar for Health. Accessed July 13th, 2018. URL: http://www.undp-globalfund-capacitydevelopment.org/en/about-us/solar-for-health/

UNDP/MoED. 2013. Rapid Situation Assessment and Gap Analysis Report (draft).

UNEP 2013. Municipal Solid Waste Composition Analysis Study Juba, South Sudan. URL: http://postconflict.unep.ch/publications/UNEP_South_Sudan_Juba_Waste_com-position_2013.pdf.

______ 2014. Prospects for Investment in Large-Scale, Grid-Connected Solar Power in Africa; United Nations Environment Programme (UNEP), RISO Centre: Copenhagen, Denmark.

______ 2017. Atlas of Africa Energy Resources. Energy profile South Sudan (p274). URL: https://wedocs.unep.org/bitstream/handle/20.500.11822/20476/Atlas_Africa_Energy_Resources.pdf?sequence=1andisAllowed=y

UNIDO and ICSHP 2016. World Small Hydropower Development Report. URL: https://www.unido.org/sites/default/files/2016-11/WSHPDR_Executive_Summary_2016_0.pdf

UNECA-(United Nations Economic Commission for Africa) 2014. *Energy Access and Security in Eastern Africa: Status and Enhancement Pathways.*

US Energy Information Administration 2014, September 24th. Saudi Arabia uses largest amount of crude oil for power generation since 2010. URL: https://www.eia.gov/todayinenergy/detail.php?id=18111

______. 2018. Country Analysis Brief: Sudan and South Sudan. URL: https://www.eia.gov/beta/international/analysis_includes/countries_long/Sudan_and_South_Sudan/sudan.pdf

USAID-(United States Agency for International Development) 2016a. Climate Change Risk Profile-South Sudan. Fact sheet. URL:

https://www.climatelinks.org/sites/default/files/asset/document/2016%20CRM%20Fact%20Sheet%20-%20South%20Sudan_0.pdf

______. 2016b. Greenhouse Gas Emissions in South Sudan. URL:https://www.climatelinks.org/sites/default/files/asset/document/2017_USAID_GHG%20Emissions%20Factsheet_South%20Sudan.pdf

WEC-(World Energy Centre) 2013. World Energy Resources. 2013 Survey. London: World Energy Council (WEC).

Whiting, K. E., Amogpai, A., Carmona, L. G., and Esser, L. J. 2015. South Sudan: A Review of the Development of Sustainable Energy Policy and Practices. *Investigación ambiental Cienciay política pública*, *7*(1).

World Bank 2013. *South Sudan - Electricity sector strategy notes (ESSN) (English)*. Washington DC; World Bank. URL: http://documents.worldbank.org/curated/en/354201468102894108/South-Sudan-Electricity-sector-strategy-note-ESSN

______. 2014a. Doing Business: Understanding Regulations for Small and Medium-Size Enterprises. Washington, DC: World Bank Group. DOI: 10.1596/978-0-8213-9615-5. License: Creative Commons Attribution CC BY 3.0

______ 2014b. South Sudan: Mapping the Supply Chain for Solar Lighting Products. Accessed June 3rd, 2018. URL: https://www.lightingafrica.org/wp-content/uploads/2016/07/South-Sudan-Mapping-the-Supply-Chain_July-2014.pdf

______ 2016. Country profile-South Sudan. Accessed May 15th, 2018. URL: http://databank.worldbank.org/data/views/reports/reportwidget.aspx?Report_Name=CountryProfileandId=b450fd57andtbar=yanddd=yandinf=nandzm=nandcountry=SSD

Yilmaz, S., Ozcalik, H. R., Aksu, M., and Karapınar, C. 2015. Dynamic simulation of a PV-diesel-battery hybrid plant for off grid electricity supply. *Energy Procedia*, *75*, 381-387.

8.0. APPENDICES

8.1.Research questionnaire

May. 2018

Graduate Research Questionnaire

Dear Respondent,

My Name is **Ladu David Morris**, a postgraduate student at Central European University in Budapest, Hungary. As part of my master's degree study, I am conducting a research survey on private electricity generation in Juba city and I am glad that your company is among the randomly selected companies in Juba to participate in this research survey.

Your participation in this research is voluntary, and you are free to decline or skip a question that you do not feel comfortable to respond to. It is, however, essential for me to learn about your experiences and opinions regarding the importance of electricity and the challenges it poses in running businesses in Juba city. Your responses to this questionnaire will be strictly confidential, and all information you provide will be coded and used only for the purpose of my study. The final report will not show the detail of your company. **Please note** that this research survey is only for academic use and will not have any financial benefit for the participants.

You may contact my supervisor **Prof. Michael LaBelle** on email: labellem@ceu.edu in the case of further inquiry about this research. Also, see my contact details at the end of this document in case you want further information.

I will appreciate your time in answering the questions below for my research

Part 1: Respondent's details

Company Name: ____

Address: ____ Tel. No: ______________________

E-Mail: ____

Part 2: Electricity generation:

1. Do you use electricity for running your business? □ Yes □ No
2. If yes, from where do you get the electricity for running your business?

   □ We buy the electricity □ We generate our own electricity □ Both
3. If you buy, kindly state who your supplier is. ____
4. If you generate your own electricity, how do you generate the electricity?

   □ Diesel generator □ Solar system □ Both diesel generator and solar system

   □ Others *(Specify)*.

   ____

   *(If your response is by diesel generator, answer questions **5 to 14;** If the response is by solar system, proceed to question **15 to 18;** If your response is Both, then answer all questions).*

5. How many generator(s) does your company own? ____
6. What is the total power capacity of the generators (kW or kVA)? ___________________________
7. For how many hours do you run the generator(s) in one month? ____________________________
8. How many kWh do you generate in one month? ____
9. Do you share your electricity with another nearby company or household?

☐ Yes ☐ No

10. If yes, what kind of arrangement do you have with them? _________________________________
____
11. How many litres of diesel do you use in one month? _____________________________________
12. Who is your diesel supplier(s)? ____
13. On average, how much in USD do you pay for one litre of diesel? __________________________
14. How much in USD do you pay in a year for the maintenance services of your diesel generator(s)?
____

15. What is the capacity of your solar system? ____
16. How do you run the solar system?

☐ Day hours ☐ Night hours ☐ Both Day and Night

17. Who are your solar system suppliers? ____
18. For how long have you been using the solar system for your business? ______________________

19. What plans does your company have regarding installing, increasing or decreasing the capacity of solar systems for your business?
____
____
20. If you have both diesel generator and solar system, how do you use them each day?
____
21. What do you think are the advantages/disadvantages of generating electricity using solar systems compared to diesel generators? ____
____
____

Part 3: Social and Environmental issues *(Complete this ONLY if you use diesel generator)*

22. Do you experience problems from the public or neighbours regarding running your diesel generator(s)? If so, what are they?
____
____
____
23. Do you think the diesel generators are causing problems to your business premises or compound?

☐ Yes ☐ No ☐ Don't know

24. If yes, what are the problems you experienced?
____
____
____

Part 4: Electricity usage:

25. Please state the types of electric appliances installed in your business facility (ies).
____
____

26. Please estimate the total electricity consumption of all the installed appliances in one month *(If possible, an electrician should make this estimate)*.

____

Part 5: Willingness to participate in electricity trading

27. Is your company a member of a business association in Juba? ☐ Yes ☐ No
28. If yes, state the name of the association. ______________________________
29. Do you think your business would be interested in selling or buying excess electricity to/from the grid?

    ☐ Yes, buy electricity ☐ Yes, sell excess electricity ☐ No, not interested
30. If your response above is yes, you would buy, how much would you pay per kWh?

    ____
31. If your response above is yes, you would sell excess, how much would you charge per kWh?

    ____
32. What are the opportunities and/or challenges in selling or buying electricity in Juba?

    ____
    ____
    ____

Thank you very much for participating

Contact details:

Tel: 0912709668

Email: Lemi_ladu@student.ceu.edu

8.2. Stakeholders discussions guiding questions

A. Institutional Stakeholders

1. How has the relationship between the government and the private sector been regarding electricity?
2. Who is responsible for the generation, transmission and distribution in Juba and elsewhere in South Sudan?
3. What are the requirements for connecting to the grid or becoming an electricity entrepreneur in South Sudan?
4. What legal and regulatory frameworks are available for the electricity sector development?
5. Are there any thoughts on renewable energy development in the country?

B. Solar Retailers

1. What is the general overview of solar market?
2. Who are your major clients?
3. What are the challenges and opportunities for solar energy in South Sudan?
4. Are there government regulations on solar energy?
5. Do you receive any incentives in form of tax or finance as solar energy retailer?
6. How many kilowatts of solar capacity in total do you sell in 2015, 2016 and 2017?