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Institute of Water and Energy Sciences (Including Climate Change)

COMPARATIVE COST-BENEFIT ANALYSIS OF HYBRID-SOLAR SYSTEM USING NET METERING: CASE STUDY OF KYAGALANYI COFFEE FACTORY-UGANDA

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Declaration and Certification

I **Andrew Mugumya**, hereby declare that this thesis presents my personal work, realized to the best of my knowledge. I also declare that all information, material and results from other works presented here, have been fully cited and referenced in accordance with the academic rules and ethics.

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Abstract

In the business arena especially industries, energy has a very big role and direct impact on the production cost of any given product. Reduction in the amount of energy consumed to produce a unit product has a direct influence on its market price thus competitiveness and more benefits to the manufacturer. This reduction can best be achieved as a result of efficient and conservative use of energy. For the past 12 years in Uganda, there has always been increments in the electricity tariff rates. This increment has led to hiking of the end-users' electricity bills and thus making their products more expensive compared to the same imported goods. This study aims at devising a means of reducing energy bills of industrial customers through energy integration and net metering. This was done by designing an alternative solar hybrid system for Kyagalanyi Coffee Limited using HOMER software. The system is compared with the common one in Uganda of grid backed up with a generator. A saving of $668,033 is recorded throughout the project life of 25 years with a discounted payback time of 10.9 years. HOMER results were validated, with net metering analysis using 2015 as a baseline year. From the analysis, Kyagalanyi Coffee Limited is saved $195,484.6 within one year. If factors are to remain the same throughout the project life time the payback period of the system will be 9.9 years using HOMER's total Net Present Costs (NPC). This is in agreement with HOMER's results considering grid alone. Considering only the initial capital investment of the system, the simple payback reduces to 5.5 years. Taking 1% as the annual PV degradation due to aging and soiling effects, the payback becomes 10.4 and 5.6 years using the system's total NPC and initial capital respectively. Therefore, this study recommends industrial customers to invest in distributed generation systems for self-consumption and the government to support them through establishment of net metering policies.

Key words: Energy-consumer, Distributed generation, Energy bill, Policies

Résumé

Dans le domaine commercial, en particulier les industries, l'énergie a un très grand rôle et un impact direct sur le coût de production d'un produit donné. La réduction de la quantité d'énergie consommée pour produire un produit unitaire a une influence directe sur son prix de marché, sa compétitivité et ses avantages pour le fabricant. Cette réduction peut être obtenue grâce à une utilisation efficace et conservatrice de l'énergie. Au cours des 12 dernières années en Ouganda, les taux de tarifs de l'électricité ont toujours augmenté. Cet accroissement a conduit à la randonnée des factures d'électricité des utilisateurs finaux et rend leurs produits plus chers par rapport aux mêmes produits importés. Cette étude vise à concevoir un moyen de réduire les factures d'énergie des clients industriels grâce à l'intégration énergétique et au comptage net. Cela a été réalisé en concevant un autre système hybride solaire pour Kyagalanyi Coffee Limited en utilisant le logiciel HOMER. Le système est comparé au commun en Ouganda de la grille sauvegardée avec un générateur. Une économie de 668 033 $ est enregistrée pendant toute la durée de vie du projet de 25 ans avec un temps de récupération réduit de 10,9 ans. Les résultats de HOMER ont été validés, avec une analyse de mesure nette en utilisant 2015 comme année de référence. À partir de l'analyse, Kyagalanyi Coffee Limited est économisé 195 484,6 $ en un an. Si les facteurs restent identiques tout au long de la durée de vie du projet, la période de récupération du système sera de 9,9 ans en utilisant les coûts actuels nets totaux (NPC) d'HOMER. Ceci est en accord avec les résultats de HOMER compte tenu de la grille seule. Compte tenu de l'investissement de capital initial du système, le remboursement simple se réduit à 5,5 ans. Prenant 1% en raison de la dégradation annuelle de PV due aux effets de vieillissement et de salissure, la récupération devient 10,4 et 5,6 ans en utilisant le NPC total et le capital initial du système respectivement. Par conséquent, cette étude recommande aux clients industriels d'investir dans des systèmes de production distribués pour la consommation autonome et le gouvernement pour les soutenir par l'établissement de politiques de.

Mots clés : Énergie consommatrice, Production distribuée, Facture énergétique, Politiques

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Abbreviations and acronyms

$	US dollar
AC	Alternating Current
AHP	Analytical Hierarchy Process
DC	Direct Current
BSPQ	Better Solar Power Quotes
BOU	Bank of Uganda
COE	Cost of Electricity
CREEC	Centre for Research in Energy and Energy Conservation
DG	Distributed Generation
ERA	Electricity Regulatory Authority
FiT	Feed-in-Tariff
GETFiT	Global Energy Transfer for Feed-in-Tariffs
HOMER	Hybrid Optimization Model for Electric Renewables
IPP	Independent Power Producer
IRR	Internal Rate of Return
KCL	Kyagalanyi Coffee Limited
kW	Kilowatt
kWh	Kilowatt hour
LCOE	Levelized Cost of Electricity
LEAP	Long-range Energy Alternatives Planning
MEMD	Ministry of Energy and Mineral Development
MW	Megawatt
NEMA	National Environmental Management Agency
NIS	Negative Ideal Solution
NNEC	Network for New Energy Choices
NPC	Net Present Cost
PPA	Power Purchase Agreement

PAUWES	Pan African University Institute of Water and Energy Sciences
PIS	Positive Ideal Solution
PV	Photovoltaic
PQA	Power Quality Analyzer
REA	Rural Electrification Agency
REC	Renewable Energy Credit
TOU	Time-of-Use
TOPSIS	Technique of Order Preference by Similarity to Ideal Solution
UBOS	Uganda Bureau of Statistics
UEB	Uganda Electricity Board
UEDCL	Uganda Electricity Distribution Company Limited
UEGCL	Uganda Electricity Generation Company Limited
UETCL	Uganda Electricity Transmission Company Limited
UGX	Uganda Shillings
UMEME	Largest Limited Electricity Distribution Company in Uganda

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CHAPTER 1: INTRODUCTION AND BACKGROUND

Outline

1.1 Introduction

Uganda is a landlocked country laying on the Eastern part of Africa with Kenya as its neighbor in the East, Tanzania in the South, Democratic Republic of Congo in the West, South Sudan in the North and Rwanda in the South West. The country is endowed with abundant renewable energy resources, significant among being biomass, small and large hydropower and solar energy. Other resources include geothermal mostly in the western part of the country in the rift valley areas, wind energy for small scale applications like water pumping and battery charging mostly in the northern parts of Uganda like Karamoja. The wind speeds range between 2 and 4m/s at a base height of 10m (MEMD, 2007). Save for the large-scale hydropower which serves as a major source of national grid electricity, the current state of exploitation and utilization of other renewable energy sources is still wanting. Large scale hydropower has been majorly exploited along the Nile basin areas. Although the potential for small scale hydropower (Pico, micro, and mini) in the country is also high standing at 210 MW (Tumwesigye et al., 2011), not much work has been done. However, sites and their corresponding potential have been largely studied, at least a step towards realization of their development (Adeyemi & Asere, 2014). Biomass which takes up the largest percentage (90%) of energy used in the country (Tumwesigye et al., 2011) is majorly utilized in its traditional form. Uganda’s strategic location along the equator assures it of solar irradiation and this can be harnessed throughout the year. This, however, is an opportunity that Uganda is just yet to fully exploit as regards use of this assured solar resource for energy production particularly electricity through PV deployment. The opportunity to use solar rooftop PV has been limited to villages with no grid connection just like in the neighboring country Kenya (Ondraczek, 2014), moreover at a very low scale. The perception that the technology is for the poor, comparative low power quality solar systems normally installed and absence of supporting instruments for its development hinders grid tied solar system penetration especially in the urban areas of the country. Discriminatory policies like feed-in-tariffs that exclude solar energy (ERA, 2012), lack of supportive policy mechanisms for the development of renewable energy sources like net metering, soft loans, grants, tax incentives etc., and low involvement of the private sector in the field of energy in the country are some of the main constraints hindering the development and diffusion of renewable technologies like solar PV more especially in the peri urban and urban areas.

As many renewable energy-supporting instruments exist, many studies have ranked net metering on top of the list due to its vast benefits [Hugo & Juan, (2017), Beach & Mcguire, (2013), Poullikkas, (2013), Darghouth. et al., (2011), Poullikkas, (2013)]. Net metering promotes distributed generation with a focus on self-consumption that leads to customer savings on energy bills. Unlike other policies such as feed in tariff, net metering covers all customer categories from residential to industrial. Considering small capacities of 5 kW to moderate energy system capacities of 5 MW is also an added advantage for the policy (IREC, 2013). The policy has been continuously refined to the extent of no need for physical remuneration (Curran & Clarke, 2012). This has made it more acceptable, sustainable and manageable to utility owners.

Over the last 10 years, the electricity tariff has increased by 193.8% in Uganda (ERA, 2017). This has been mainly due to the unstable currency as a result of increasing inflation rate in the country, increased demand that calls for marginal development of other generating facilities and increase in the operation and maintenance costs of the utility (ERA, 2016). Such situation leaves grid customers especially businesses crippled with a lot of uncertainties on what to expect as regards their energy bills. As a solution, one would recommend generation of own energy for self-consumption for these grid customers. This study wishes to compare net metered self-consumption with a business as usual scenario where a customer solely depends on the grid for all his energy needs. This will be followed with the determination of how much savings on the energy bill can be achieved with net metering for a particular customer.

1.1.1 Problem statement

Over the years, grid electricity tariffs have been unstable; increasing every year in Uganda. Customers especially large-scale electricity users e.g. factories are affected in a way that their production costs increase with the increased energy bills per month thus a need for increasing the cost of their products as well. This leaves these local manufacturers’ products with no competitive advantage compared to the same imported and substitute goods. With the weak policies and institutions in the country to protect the local manufacturer from cheap imported goods, manufacturing business will continue to cripple. As such, this calls for a need to devise means of reducing the energy bills of grid customers so as to remain relevant in the business arena.

1.1.2 Research questions

How do different energy systems compare for a large-scale energy consumer in Uganda?

What's the best net metering policy for implementation in Uganda?

How does net metering mechanism affect customer generator's energy bill?

1.1.3 Research hypotheses

Distributed generation is a better energy system for large scale energy consumers in Uganda than centralized system.

Net metering without physical remuneration is a better tool.

Net metered system produces more savings for large scale energy consumers in Uganda than distributed generation without net metering.

1.1.4 Aim and research objective

The study intends to recommend the best way on how grid tied customers especially factories can reduce their energy expenditure which will in turn lower their production costs thus making their manufactured goods economically competitive on the market. The study intends to do this by (i) designing and optimizing an alternative energy system for the selected institution (ii) analyzing the economic benefit of distributed generation energy system compared to depending on the grid and/ or backed up with the grid, (iii) determining the impact of net metering on the energy bill.

1.1.5 Relevance of this study

The findings from this study can trigger grid customers especially medium factory owners to start thinking about and installing alternative energy systems for self-consumption. This in turn will reduce grid customers' expenditure on energy thus reducing their production costs hence making their products highly competitive. The recommendations made in this report can help Ugandan energy regulators i.e. the electricity regulatory authority (ERA) and the ministry of energy and mineral development (MEMD) to come up with appropriate design of net metering policies that support the penetration of renewable energy technologies through distributed generation. The study justifies the applicability of net metering to both the customers and the regulators.

1.1.6 Scope of the study

This study covers the design and optimization of an energy system. Comparison of the designed and optimized system to the grid and/ or backed up with a generator, then energy bill savings due to net metering program being in place. Although net metering encompasses many aspects to include; policy, compensation and the technical aspects, this work is confined to only the compensation aspect which is relevant to the aim of bill saving. It would be appropriate to include time-of-use rates within the study but due to limitations of data it was impossible.

1.2 Background of the Study

This study was inspired by the gaps in the energy use and exploitation in Uganda. It zeros down to the sectorial problems (in particular the industrial sector) caused by issues in energy use and exploitation. It deems that integrating conventional energy sources with renewable energy can be a remedy to the situation. This should be accompanied with strong and supportive policies. Therefore, this section looks at the energy status of Uganda, utilities and tariff description, grid power, the organization structure of the sector, and the energy policies currently in the country to draw you close to the study's aim, objectives and recommendations.

1.2.1 Energy status in Uganda

Uganda's energy sector is made up of both renewable and non-renewable sources. Non-renewable sources are mainly petroleum products i.e. gasoline, diesel, kerosene, liquified petroleum gas etc. This section highlights energy consumption by different sectors in Uganda, discusses the solar renewable energy source that is relevant to this study as well as petroleum products used in Uganda.

1.2.1.1 Sectorial energy consumption

Energy consumption in Uganda is dominated by the residential sector. This trend is quite different from other developing and emerging economies. The reason is majorly due to the limited industrialization of the country (Byakola, 2006). For both total energy and electricity use, the residential sector takes up a higher percentage followed by the commercial sector and then industry as shown in Figure 1.1.

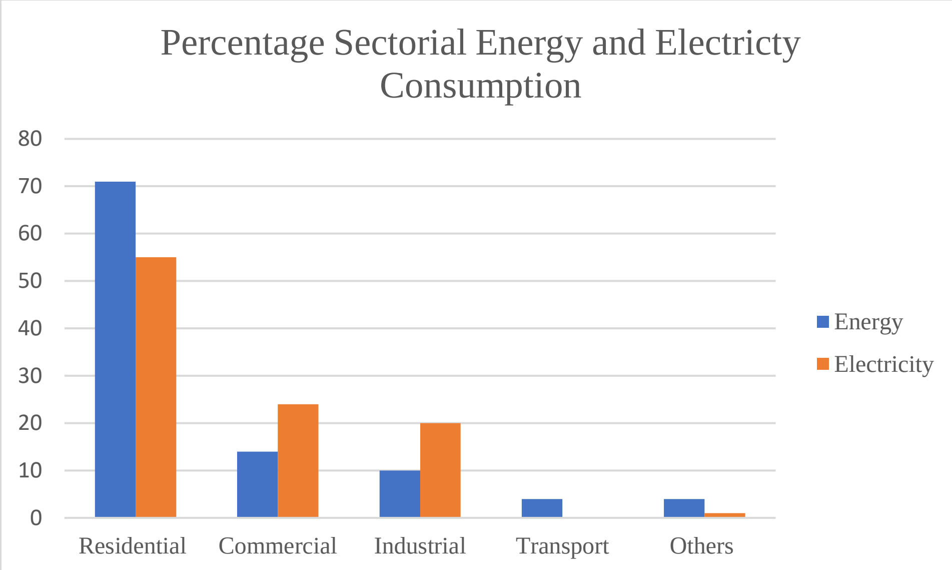

Figure 1.1: Energy and electricity consumption of various sectors
Source: (Byakola, 2006)

1.2.1.2 Renewable energy

Uganda has a variety of renewable energy sources such as biomass, solar, wind, hydro, geothermal, among others. Traditional biomass contributes more than 90% of Uganda's primary energy and about 80% of electricity is produced from hydro power. Excluding biomass, by 2007, the remaining renewable energy sources contributed approximately 5% of Uganda's energy consumption (MEMD, 2007). This to a great extent has limited the development of economic activities in the different parts of the country hence something urgent needs to be done to rectify the situation. Biomass which contributes significantly to the energy mix of Uganda is majorly used in a traditional manner. Figure 1.2 shows the renewable energy potential in the country. Relevant to this study is the solar resource and below is its account as well as the future of renewable energy in the country.

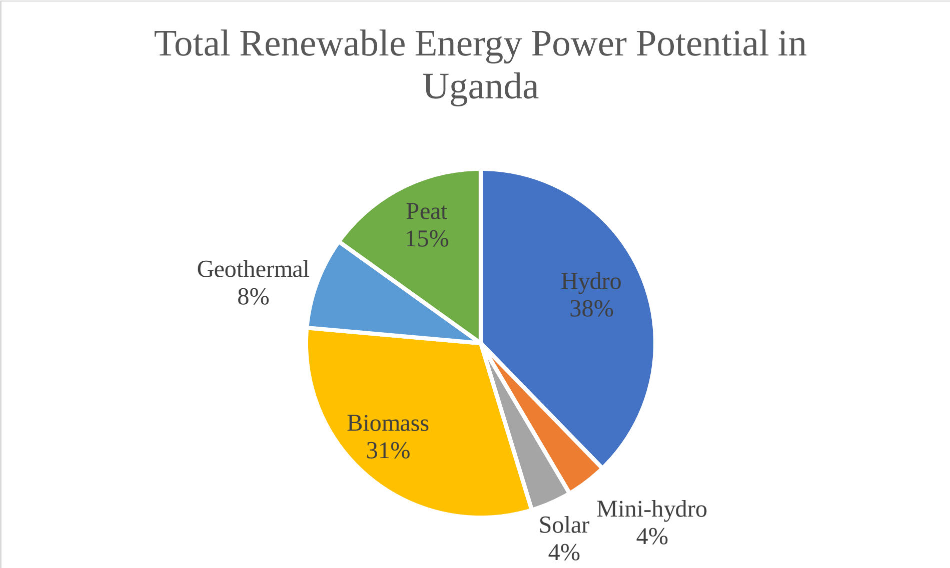

Figure 1.2: Uganda's total renewable energy potential
Source: (MEMD, 2007)

a) Solar energy

Amongst all renewable energy sources, solar is the most promising due to its abundance and unlimited potential throughout the globe. Energy from the sun is transmitted unto the boundary of the atmosphere as electromagnetic radiation. Solar irradiations from the sun before reaching the earth's surface go through obstacles that can scatter, absorb and reflect them. Thus, uninterrupted radiation from the sun is referred to as beam/direct radiation while total radiation is a sum of direct and diffused radiation and it's referred to as solar global radiation on a horizontal surface. Though the earth receives only 1 kW/m^2 of energy from the sun due to the above, that energy is so much that it's sufficient to meet all our demands (K. Ajao, Oladosu, & Popoola, 2011). This energy is uniformly spread all over the earth's surface. Uganda being in the tropical region, the existing solar data clearly shows that the solar energy resource is high throughout the year. The mean solar radiation is 5.1 kWh/m^2 per day, on a horizontal surface. This level of insolation is quite favorable, for the application of solar technologies such as solar water heating and solar photovoltaic systems for supply of electricity in rural institutions and households as well as areas not connected to the grid (MEMD, 2007). Additionally, it can help those connected to the grid to reduce their electricity bills. Solar thermal has a great potential in the form of solar water heaters in electrified areas. By 2012, solar PV systems had been installed in 5,600 households, 420 small commercials, and 1700 institutions through schemes initiated by Rural Electrification Agency (REA) and other donor agencies (Gustavsson et al., 2015). Today electricity is most often used for water heating, in spite of the fact that it will in many cases be cheaper for the consumer to use solar energy especially in the urban set ups where it's less supported. Below is an account of the technology's current situation in the country.

i. Off-grid and On-grid solar PV

The market for off grid systems mostly businesses privately owned, Pico and home solar systems has steadily grown within the last fifteen years reaching 1.1MW as of 2012 and still growing at a rate of 20%. With players like M-Kopa, solar lanterns have been widely spread through the Pay-As You Go system in the country. Through the Rural Electrification Program approximately 7,720 systems were installed in households, small commercials and institutions like schools, police etc.(Gustavsson et al., 2015). Uganda's solar irradiation ranges from 1,825 KWh/m^2 to 2,500 KWh/m^2 per year. Two large solar PV plants are at planning stage and the government has plans to build 500 MW capacity whose implementation has been awarded to Ergon Solair a Taiwan-US partnership. A 10 MW PV power plant has been developed in Soroti and is the first PV project to benefit from the GETFiT programme (EUEI PDF, 2017). Below is the solar map for Uganda.

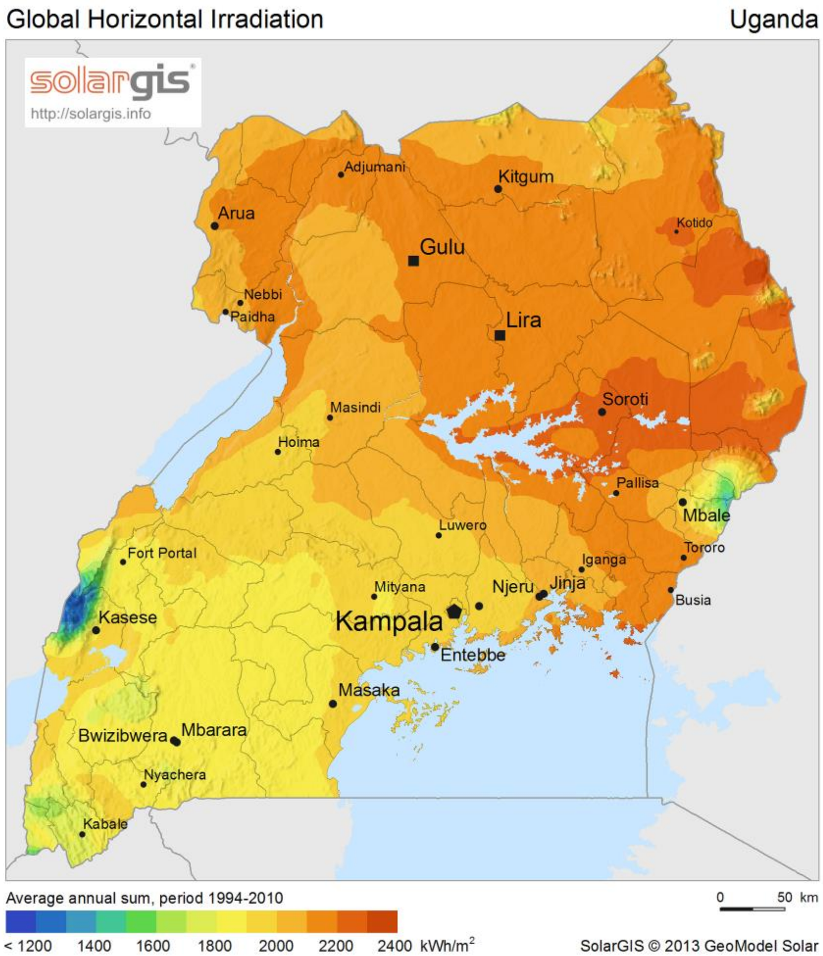

Figure 1.3: Solar map of Uganda
Source:(EUEI PDF, 2017)

b) The future of renewable energy in Uganda

According to the World Wide report (Gustavsson et al., 2015), the Uganda renewable energy scenario established using LEAP software presents a viable model in which modern energy services based on currently available technology, are accessible to all. According to the authors, Uganda can stimulate a growing economy based on renewable energy instead of venturing down a business-as-usual path with increased dependency on fossil fuels. Furthermore, the report recommends that to be sustainable, the renewable energy solutions ventured in must have limited negative impact on biodiversity, ecosystems and climate.

1.2.1.3 Generation mix and petroleum products

According to a report by UBOS, (2016) on energy, by 2015, Uganda had an installed electricity capacity of 895.5MW. This was from hydro, thermal (petroleum products) and cogeneration as shown in Figure 1.4 below. This changed by the end of 2016 with addition of a 10 MW solar plant in Soroti. This is currently the biggest solar plant in east and central Africa. Other large-scale hydro projects such as Karuma and Isimba are ongoing. A study by (Gustavsson et al., 2015) to project the future of renewable energy in Uganda by 2050 stated that 9.2% of Uganda's primary energy supply is met by petroleum products. Currently Uganda imports all her petroleum products. Being a landlocked country, all the imported petroleum products are routed through Kenya and Tanzania in the ratio of 17 to 3 respectively. This makes her incur high transportation costs through the seaports of Mombasa and Dar es Salaam (Tumwesigye et al., 2011). Having discovered her own oil reserves in 2002, the exploitation is just yet to start (Gustavsson et al., 2015). In 2015 alone, Uganda imported 1.622 billion liters of petroleum products (UBOS, 2016). On a daily basis, the country imports roughly 7,000 barrels of oil per day from Kenya's Mombasa oil refinery.

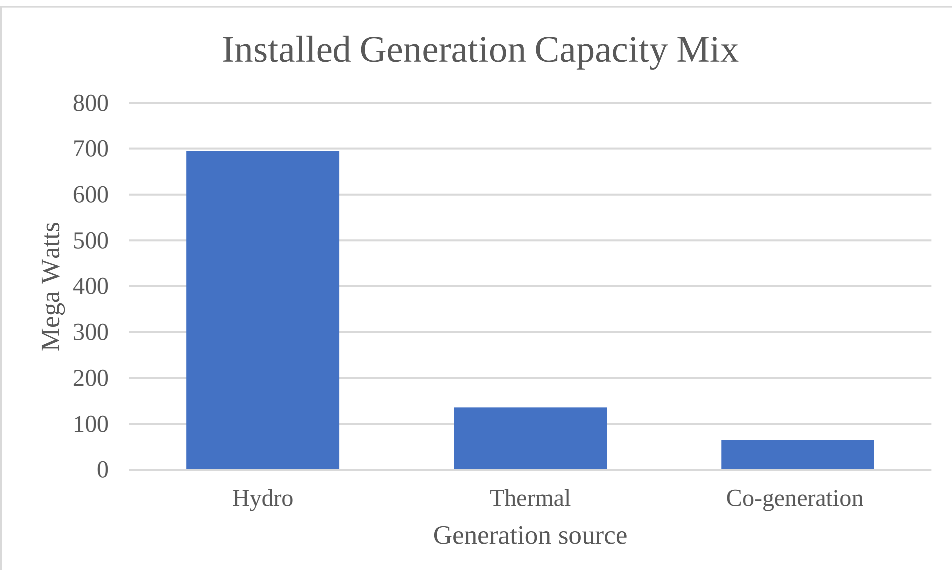

Figure 1.4: Installed generation mix
Source: (UBOS, 2016)

1.2.2 Utilities and tariff description in Uganda

Currently there are ten utility companies in Uganda namely; UMEME Limited, West Nile Electrification Company, Ferdsult Engineering Services Limited, Kilembe Investment Limited, Bundibugyo Electricity Co-operative Society, Pader Abim Community Multipurpose Electricity

Co-Operative Society, Kalangala Infrastructure Services Limited, Kyegegwa Rural Electrification Co-Operative Society, and Uganda Electricity Distribution Company Limited (ERA, 2017). At the national level, UMEME limited is the sole distributor with a twenty-year concession since 2005 (ERA, 2007). The analysis in this work depends on the industrial tariff rates as approved by the Electricity Regulator Authority and perpetual rollover net metering. Although time of use tariffs apply to UMEME the main distributor for commercial and industrial customers, flat rates from ERA are considered in this study for the years under consideration. Three time of use periods exist for any given day i.e. off-peak, shoulder and peak periods as illustrated in the Table 1.1 below. In the year 2016 industrial rates were \$0.14 – peak, \$0.11 – shoulder, and \$0.07 – off-peak (ERA, 2016). Most of the work in this study based on this year.

Table 1.1: Utility time-of-use in Uganda

Load Pattern	**Time range**
Shoulder	6:00 - 18:00 hrs.
Peak	18:00 - 24:00 hrs.
Off-peak	24:00 - 6:00 hrs.

Source: (ERA, 2007)

Since the national electricity distribution role was licensed to UMEME in 2005 (ERA, 2007), the electricity tariffs have been unstable increasing from year to year as shown in the Figure 1.5 and 1.6 below. Details of the data are in Appendix A, Table 1.

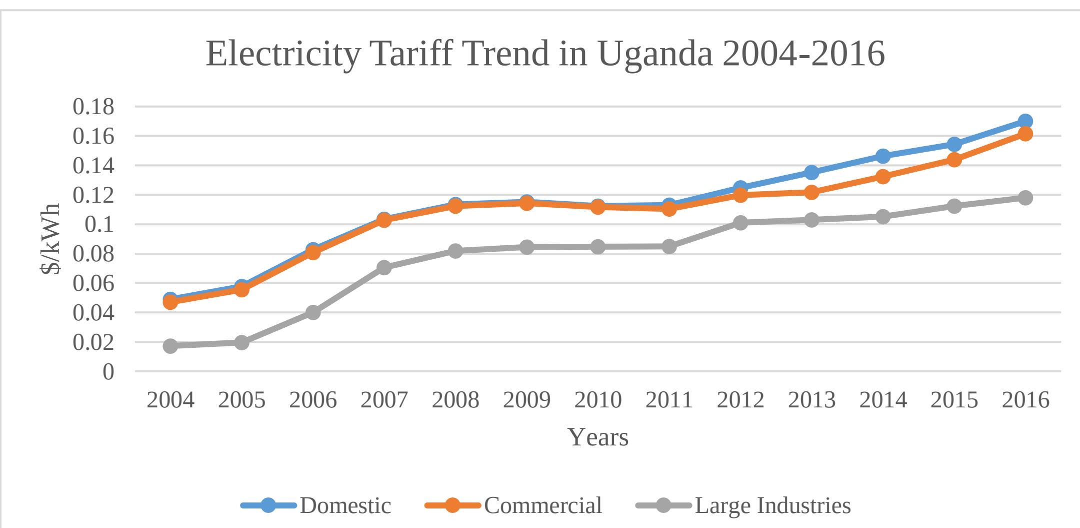

Figure 1.5: Electricity tariff trends in Uganda
Source: (ERA, 2017)

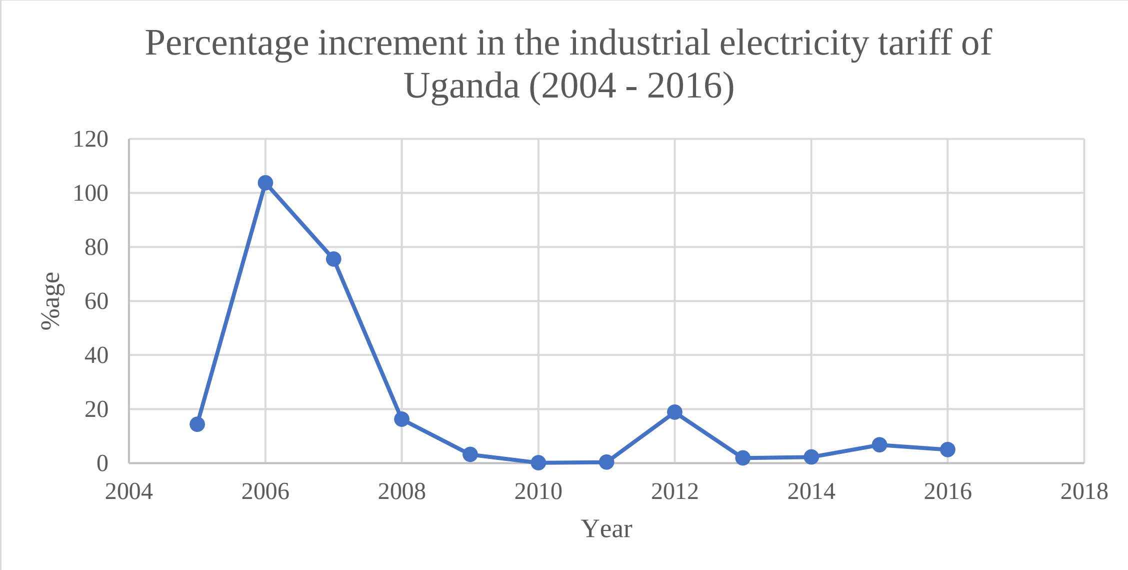

Figure 1.6: Percentage industrial tariff rate increment
Source: own elaboration

1.2.3 Grid power in Uganda

Grid power is predominantly hydropower serving 80% of the current grid capacity (Byakola, 2006). The source is usually affected by drastic climate changes which create a gap between the installed capacity and the generated capacity resulting into the frequent outages. Transmission is done at 33 kV and above while distribution is at 33 kV and below (ERA, 2011). The grid users are categorized according to the supply voltage and energy demand as illustrated in table 1.2.

Table 1.2: Categories of grid customers

Consumer	**Phase**	**Volts (V)**	**Energy demand (KVA)**	**Energy charge**
Domestic	Low voltage 1- phase	240	N/A	Ushs/kWh
Commercial	Low voltage 3-phase	415	≥ 100A	Ushs/kWh
Medium Industry	Low voltage 3-phase	415	≥ 500	Ushs/kWh
Large Industry	High voltage 3-phase	11000/33000	≥ 10,000	Ushs/kWh

Source: (ERA, 2016)

The cable line as reported by Gustavsson et al., (2015) extends a distance of 14,312 km with an estimated loss of 4% and 26% in transmission and distribution respectively. UEDCL constructs and owns the distribution network. However, UMEME operates, maintains, upgrades and expands the network under a 20-year concession agreement [Gustavsson et al., (2015), ERA, (2011)]. Due to the above mandate, the company is constructing more substations to support its already existing 66 substations to reduce the problem of load shedding. These substations majorly run on diesel generators. UMEME also introduced an automated metering system with a prepaid mechanism for the electricity consumption as a way of upgrading its services. This system is being implemented gradually amongst its estimated 450,000 customers (Gustavsson et al., 2015).

1.2.4 Uganda electricity sector organization structure

The electricity sector of Uganda was unbundled in 2000 through the establishment of the Uganda Electricity Regulatory Authority (ERA) under the reviewed Electricity Act (1999) to regulate the sector. ERA regulations include issuance of licenses to generators, transmitters and distributors of electricity; tariff structuring; handle tariff complaints etc. The vertical integrated Uganda Electricity Board (UEB) was separated into UEGCL, UETCL and UEDCL (ERA, 2007) . Generation and distribution were licensed to ESKOM (U) limited and UMEME respectively all South African franchises while transmission remained a public/government responsibility (Byakola, 2006).

1.2.5 Energy policy perspective and institutional frameworks in Uganda

The energy sector in the republic of Uganda is under the mandate of the MEMD of the republic of Uganda. As a policy support mechanism, the energy policy of Uganda was put in place in 2002 with a main goal of meeting Uganda's energy needs in the most economical, socially and environmentally sustainable manner possible (MEMD, 2002). This emphasized the need to develop Uganda's energy sources both renewable and non-renewable for sustainable development. As a result, it laid a foundation for the development of the renewable energy policy of 2007. The goal for its formulation was to increase modern renewable energy use by approximately 57% of the total country's energy consumption within a period of 10 years. Through the renewable energy policy of 2007, the Government of the republic of Uganda created a renewable energy department at MEMD and established a national committee and several committees at local government level to promote sustainable use of renewable energies in Uganda (MEMD, 2007). This department is mandated to implement the renewable energy policy targets as set out in the relevant renewable energy policies and programs. The policy obligates investment in solar technologies for urban developers. In addition, both residential and commercial building owners in the urban area plus medium income households are encouraged to invest in the technology. Implementation is supposed to be done by the urban and local authorities (MEMD, 2007).This policy put in place strategies among which were: credit support facility and smart subsidies which are intended to scale up investments in renewable energy and rural electrification. However, 2017 being the last year for the policy to be reviewed, little can be noticed as regards the diversification of the energy sector that it talks about. Business as usual investment in hydro projects especially large scale continue to dominate the sector. Technologies like solar have only registered a 10 MW plant and very few rooftop PVs. Probably with the review of the renewable energy policy of 2007, more policy incentives for the promotion of PV rooftops like net metering can bring about a greater change. It also gave rise to the establishment of the National Environmental Management Authority (NEMA) (MEMD, 2007). The policy was meant to answer the question of accessibility and also create favorable environment for penetration of renewable energy technologies whilst addressing the global environmental concerns.

1.2.6 Section summary

The background of this study gives a snapshot of the energy sector of Uganda with a major focus on solar and petroleum products that are relevant to this study for designing a hybrid system. It summarizes the energy consumption trends of Uganda which is dominated by the residential sector followed by commercial and lastly industrial sector justifying how Uganda is less industrialized. Many factors may contribute to the low industrialization levels amongst which energy is at the forefront. Therefore, there is need to put in place services that can attract investors in the industrial sector like electricity. The country's grid power is mainly from hydro, thermal and cogeneration technologies. However, from this section, it's clear that the electricity generation is dominated by hydropower. This calls for more diversification in the electricity sector. With the availability of a vast number of renewable energies, there is need for exploitation and inclusiveness of other sources apart from hydro. This forms the backbone of this study which compares; dependence on the grid and other alternative self-generating electricity sources like solar. Before 1999, UEB was responsible for electricity generation to distribution. However, in 2000 it was unbundled to UEGCL that became responsible for generation, with ESKOM dominating the area, transmission remained a public mandate managed by UETCL while distribution is done by UEDCL with UMEME which is under a twenty-year concession also dominating the field (ERA, 2016). Since UMEME's acquisition of the contract, tariff rates have been increasing probably due to a number of reasons. This study seeks to devise a means on how electricity customers can overcome the problem of these increasing tariffs. Administratively, the energy sector is under the mandate of MEMD that has established different policies in her course to develop the sector. The energy policy of 2002, the renewable energy policy of 2007 and the national oil and gas policy of 2008 are amongst the instruments that Uganda has been running on. These policies need tools that can propel them in achieving their goals. This study focuses on net metering, an instrument for boosting renewable energy technologies.

CHAPTER 2: LITERATURE REVIEW

Outline

2.1 Introduction

This chapter reviews the different literature about distributed generation narrowing down to the energy technology (solar) relevant to this study. Design and optimization of hybrid energy systems is also reviewed. Lastly, net metering as a supporting policy tool is studied from the different literature. But first, let's look at the difference between power producers.

2.2 Customer Generator Versus Independent Power Producers (IPPS)

Electricity generation can be by utility and non-utility producers. The non-utility generators are further classified into independent power producers (IPPs) and customer generators. The IPPs are large scale electricity generators with sale and purchase agreements with either the utility or the local communities. These agreements are normally long ranging from 20 years and above (Hughes & Bell, 2006). Customer generators have generation facilities in most cases to cater for whole or part of their load. In cases where this load is not fully facilitated by the customer generation facility, they can buy power from the grid while for those times where their generation exceeds their load demand they can send this power to the grid. The difference between customer generators and IPPs is that the former doesn't look for profits from the excess generation while the latter does. In the scenario where a utility allows a customer generator to connect to its grid, there should always be policies and guidelines both technical and for excess compensation put in place (Hughes & Bell, 2006). For regulators to come up with the right compensation mechanism, there are always factors that guide them. These may include; extent to which the customer generator is compensated, the form that the compensation takes, and a balance of interest amongst the producers, non-generators and the utility. However, let's first discuss one of the commonest technology (solar photovoltaics) used by these two power producers, then the design and optimization of an energy system for a customer and later the compensation mechanism for the excess produced power.

2.3 Photovoltaic (PV) System

This is a system that uses solar cells made of semi-conducting material to convert sunlight into electricity (Sinton, Butler, & Winnett, 2013). PV can be used as a sole generator or in combination with other sources like wind turbines, biomass, diesel generators etc. PV systems can be centralized or distributed. Relevant to this study is the distributed PV and the choice for its installation by grid customers depends much on its economics. These two are discussed below;

2.3.1 PV as a distributed electricity generator

Distributed generation (DG) has been defined by various researchers differently; some tagging it small scale and environmentally friendly while others emphasize that it has to be customer/end-user sited without any limit on the size or the generating source (Daly & Morrison, 2001). But in this work, we shall adopt DG as an electric power generating facility that is located within the distribution network and at the customer's site (Doyle, 2002). DGs capacity can't go beyond 50 MW [Doyle, (2002), Abou El-Ela et al., (2010)]. This study chose solar PV/diesel hybrid as the best alternative distributed energy system for the selected facility because it's less costly and the generator ensures the reliability of the system.

Distributed generations in general come with their advantages both to the energy system and the customer. These range from, (i) being emergency back up plans for customers during utility outages thus increasing the reliability and stability of power supply to customers, (ii) reduction in voltage fluctuations, (iv) differing capacity additions for utilities. This cuts down the investment costs in generation, distribution, and transmission hence this saving can be used to better customer services, (v) value addition through energy bill savings during peak hours when time of use rates are applicable. Simply put, DGs can provide the customer's full load requirement and the excess even fed to the grid. This makes the customer so independent, to operate with or without the grid [Daly & Morrison, (2001), Doyle, (2002)]. Examples of DG technologies include; fuel cells, microturbines, wind turbines, solar photovoltaics as well as combustion engines (Daly & Morrison, 2001). Therefore, this study wishes to exploit the benefits of energy bill saving through DG.

Solar PV is one of the most convenient sources of energy for distributed generation. The fact that the resource is available everywhere, adds to its advantage over many other sources. In Uganda, the resource is available throughout the year in both seasons, dry and wet. With the continuous improvement in technology, the PV components have tremendously reduced in prices. This makes the cost of electricity produced from PV currently cheaper than 10 years ago. In fact, in some places the solar PV electricity prices are competing with the prices of electricity produced from conventional energy sources, a condition referred to as socket parity [Christoforidis et al., (2013), Hugo & Juan, (2017)]. Reductions in the prices of PV components has been both commercial and non-commercial. Commercial factors include the continuous advancement in the technology of crystalline silicon for making solar cells over time, learning by doing has also been a major contributor to the drop in the prices of PV. Non-commercial factors include USA space program and semiconductor industry that invested heavily in solar energy, economies of scale have also largely contributed to the reduction in PV prices. The technology is preferred for installation because it requires almost no maintenance in the first years. The only cost the owner may face within a period of 5-10 years is the replacement of the inverter. However, with technological advancement some inverters can work up to 15 years without failure (K. Ajao et al., 2011). It's estimated that solar PV production declines at a rate of 1 per cent per year due to aging effect as well as soiling. Routine cleaning of the panels is therefore recommended (Borenstein S., 2008). Much value is also attached to Solar PV power due to its peak production timing in countries where it matches the peak demand and the location as a distributed resource. However, in the Ugandan context, peak demand starts at 1800hours and ends at 2400hours (ERA, 2007) so it doesn't match with the peak production of PV which normally occurs at around 1200hours to 1700hours. This research's choice for solar in this context is on the falling prices of the components.

Additionally, distributed energy generation has an advantage that power produced is not shipped to far ends for customer use. This helps to minimize transmission and distribution losses where some of the power being transmitted is lost as heat. Grid losses (both technical and non-technical) in Uganda stood at 40 percent before UMEME took over the distribution concession in 2005. It reduced to 31 per cent and later to 35 percent within a period of 2005 to 2009 (ERA, 2011). If solar PV distributed generation is encouraged, this problem will be reduced. Currently there are more investments in large hydro plants in Uganda like Ayago, karuma, Oriang, Isimba with capacities of 600 MW, 600 MW, 400 MW, 188 MW respectively (Adeyemi & Asere, 2014) which require a lot of capital. Therefore, if there were policies in place to promote distributed generation like from the available solar resource in the country, investments in large scale plants like the ones listed above would be required no more. The requirement for such huge investments arises from the ever-increasing demand which can be cut down adequately with distributed generation promotion.

Distributed generation encourages investment in renewable energy sources. Therefore, policies to promote it should be established for a country to increase its portfolio in the renewable sector. Solar PV is mostly adopted in off grid rural communities in Africa. Uganda in particular, it's majorly acquired in villages for purposes of lighting and mobile phones charging. Increase of solar

PV in both off-grid and grid connected areas helps to reduce investment in conventional sources of energy like fossil fuels. Any reduction in this kind of investment directly reduces the greenhouse effect since gases like carbondioxide, nitrogen oxide and Sulphur dioxide are avoided. DGs come with an added security advantage not directly related to the market. On-site generation reduces the susceptibility of the energy systems to terrorist attacks. Energy systems like oil wells and large nuclear plants are so vulnerable to such cowardice acts. A single strike can cut off power to hundreds of users (Borenstein S., 2008). Additionally, if there raises any issue with a large power generator's transmission line, again many users will suffer. All these problems combined can be solved through promotion of DGs like solar PV. If all these pros are made aware to end-users like industries that can easily mobilize finances, renewable energies would be at an advantage. This study seeks to help on this through its results and recommendations.

Solar Photovoltaic electricity production can either be grid connected or off-grid. It allows for different installation forms to include; domestic/non-domestic off-grid PV systems, distributed/ centralized grid connected PV systems or hybrid PV system. The hybrid PV system can either be a stand-alone or grid connected. This study analyzes a hybrid grid connected system. A PV system/array is composed of PV modules/panels (an arrangement of silicon cells), the inverter and a storage unit (battery, hydrogen fuel cells or grid). An arranged group of panels forms a string. Grid connected solar PV systems normally eliminate the battery mostly when programs like net metering are in place. The grid in such cases act as the battery which helps to reduce on the system's cost. The need to replace batteries almost every five years within the project lifetime, led to elimination of a storage system in our study.

By 2003, the reported lowest prices for a grid connected system was 4 USD/watt (Zahedi, 2006). However, PV technology is increasingly becoming competitive with the average world module price falling from $22 per watt in 1980 to $1.5 per watt in 2010 (Norberto et al., 2016). This has led to their increased deployment around the globe. A greater increase in the installed capacity was more in the developed countries due to government support programs compared to developing countries (Zahedi, 2006). However, developing countries have now taken a lead with China doing a lot compared to any other country. Zahedi (2006)'s, projections of PV power being competitive with traditional sources within 10 years from the year of his study can now be approved with some locations already attaining grid parity[IREC, (2013), Branker et al., (2011), Christoforidis et al., (2013)]. This shows how promising the technology is, hence the choice to assess a hybrid PV/diesel as this study's alternative energy system.

Through a study of long term prospects and developments in solar PV energy systems, (Zahedi, 2006), reported a continuous fall in the prices of the PV systems depending on the country. The grid systems were much cheaper compared to the off-grid systems because of non-requirement for storage batteries and the associated equipment according to that study. Ondraczek (2014), supports this argument when he compares the solar industry of Kenya and Germany which were once at the same level and pace. However, Kenya having concentrated much on solar home and off grid systems compared to Germany which gave attention to grid solar connected systems, currently there is a big gap between the two markets. The author argues in agreement with Ref. (Zahedi, 2006), that grid connected solar is more economical compared to off-grid. This recent work seeks to prove all these arguments through design, optimization and net metering.

Any technology would require thorough studies of its potential before development. In line with the above, Ordóñez et al., (2010) recommends establishing the architecture of the buildings followed by calculation of the roof space for the installation of PV modules. However, in line with my study area, this will not be an issue since if the panels can't be accommodated on the rooftop, they can be installed anywhere else because space is available. Additionally, solar irradiation and all the technical parameters need to be defined in order to estimate the amount of electricity that can be generated from the systems on an annual basis. Thus, the necessary policies to support the development of grid connected rooftop PV can be adopted. Studies like [MEMD, (2007), Gustavsson et al., (2015), Byakola, (2006), Tumwesigye et al., (2011), Adeyemi & Asere, (2014)] have carried out the feasibility studies about the different resources in the country but no comparison about alternative energy systems has been done before and this current study seeks to fill the gap. Norberto et al. (2016), examined and found out PV systems' deployment as distributed generation facilities are largely promoted by net renewable electricity consumption, policy incentives (e.g. feed-in-tariffs, net metering), sustainable building, and research and development (number of scientific publications). On the other side, PV deployment is impacted negatively by domination of fossil fuels, energy policies and laws, geographical conditions, human resource capacity, and low public awareness. Also, techno-economic factors of solar such as intermittence and high capital investment hinders the technology deployment. However much improvement in technology through scientific research plays a big role in lowering the prices of the solar system components, government support through adoption of different support programs is very paramount to its deployment. Duke et al. (2005), in their work focused their discussion on factors that would increase the penetration of grid connected residential PV electricity in the United States more especially in the newly constructed homes. In addition to strong public policies like net metering, external benefits of PV like zero environmental pollution, reduction in transmission and distribution costs, and their coincidental aversion of electricity demand peaks ought to be fronted. The authors recommend that broad and indefinite implementation of net metering at a nationwide level can proxy the true social value of PV electricity. Unique to the current study is my focus on industrial setup. Much work has been done on the residential setups but commercial and industrial are lagging behind thus this study will investigate the applicability of the above factors on the industrial setup.

However, solar PV as a distributed resource comes with challenges and according to Katiraei & Aguero, (2011), the impact of solar PV distributed generation on the grid includes; reverse power flow which affects coordination and operation of voltage regulators for the distribution lines. This can be reduced through monetary penalties (Ratnam et al., 2015). Secondly, Katiraei & Aguero, (2011) cites voltage rise and fluctuations by photovoltaic systems as another issue more so when large plants are connected at the very end of long lightly loaded feeders of the distribution line with low voltages. Contrary to this argument, Poullikkas et al., (2013) looked at it as a benefit that strengthens voltage and improves the overall grid service hence deferring maintenance and upgrades. Alternatively, automatic controls can be used to disconnect the systems in times of maximum output. This can best be done in the design of the interconnection codes which net metering program that is considered for this study puts much emphasis on.

Distributed generation technologies of energy particularly for electricity play a key role in the reduction of emissions in form of greenhouse gases [Branker et al., (2011), Rai & Sigrin, (2013), Ordóñez et al., (2010), Zahedi, (2006), Wiginton et al., (2010)]. So, one would ask, "what hinders these energy users from installing these technologies given this universal merit?". Rai & Sigrin (2013) cited financial models (like buy or lease) in place and information that customers use in making their decision as major stimuli to technology adoption. Contrary to many studies that have justified net present value as a basis for PV adoption [Poullikkas, (2013), Erdinc & Uzunoglu, (2012)], payback period forms a major basis for the decision of the PV adopters according to Rai & Sigrin, (2013). Third party system ownership (leasing) is preferred by customers because it generates more positive cash flows and reduces technological performance uncertainty. Therefore, payback period of the system to be designed is a major focus for this study in addition to net present cost that HOMER takes as its basic econometric parameter for all its simulations. Leasing is highly recommended under net metering for customers who can't afford the initial capital investment of PV systems.

Therefore, the best alternative energy system under consideration for distributed generation for the facility under study needs to be less costly, with a shorter payback period. Since it's a grid connected system, there will be no need for the storage unit instead the grid will serve the purpose since the study includes net metering. This section has clearly showed the various advantages that customers can enjoy with implementation of distributed generation for self-consumption. However, government has a big role to play in promoting distributed generation by creating an environment where they can suitably operate from. Such an environment comes with clear and supportive policies and incentives.

Many studies have been carried out and designed systems for residential but commercial and industrial are limited. This research seeks to add to the few already in place by designing an alternative energy system for an industrial setup. From the reviewed literature, solar PV has various advantages as a distributed generation source with its prices dropping continuously hence selecting it to be part of this study's system is worth. Since it's a grid tied system with roll over of credit, Eid et al., (2014) advise no use of a storage unit but instead to use the grid as the storage unit which this study will adopt in order to reduce the system initial capital and the operating costs of replacing the batteries every after approximately 5 years within the project lifespan (Madani et al., 2015). Since this study considers using HOMER software, NPC will be at the center of all the calculations instead of LCOE. Though TOU applies in Uganda, flat rate structure will be considered in this study's calculations due to data limitations.

2.4 Design and Optimization of Energy Systems

Most electricity end-users within the grid covered areas of Uganda currently dependent on the grid for all their energy needs backed up with diesel generators for large scale users in case the grid is off. This system is becoming unstainable with the unreliable grid and ever-increasing electricity retail rates in the country particularly for large scale consumers. Following the numerous merits of distributed generation as seen from the preceding section, an alternative energy system is designed and optimized for this study's selected electricity user. This will be compared to dependence on the grid and thus recommendations drawn. A lot of literature exists as regards designing and optimization of energy systems. Therefore, this section will review some of the work that has been done on design and optimization of energy systems particularly hybrid systems and the commonest software HOMER that is used.

2.4.1 Hybrid systems

Integration of renewable energy sources with a backup system forms a hybrid system [Erdinc & Uzunoglu, (2012), Bahramara, Moghaddam, & Haghifam, (2016), Bernal-Agustin & Dufo-Lopez, (2009), Yang, Lu, & Zhou, (2007)]. These systems can be stand-alone/off grid or grid connected. Hybrid renewable energy systems for electricity generation are generally reliable and less costly when compared to single sourced energy systems. Many studies have proven the economic viability of hybrid systems more so in the off grid case scenario (Erdinc & Uzunoglu, 2012). These systems can be photovoltaic (PV) and/or wind and/or diesel with storage units like batteries or fuel cells. A lot of studies have been carried out on hybrid systems current of which are summarized in (Bernal-Agustin & Dufo-Lopez, 2009) considering both systems with battery storage and hydrogen. This current study will design a hybrid system that is grid connected. The major resource of focus is solar backed up with a diesel generator.

2.4.2 Optimization

Optimization in the context of energy systems means sizing of a system sufficient enough to meet all the load requirements with the minimum possible investment and operation costs (Erdinc & Uzunoglu, 2012). A lot of work has been published about hybrid system optimization [Erdinc & Uzunoglu, (2012), Bahramara et al.,(2016), Bernal-Agustin & Dufo-Lopez, (2009), Al-Karaghouli & Kazmerski, (2010), Drouilhet, Muljadi, Holz, & Gevorgian, (1995), Yang, Wei, & Chengzhi, (2009)(Orhan & Banu Y, 2010)]. Focus is normally mainly about minimization of the net present value or the levelized cost of energy. According to Bernal-Agustin & Dufo-Lopez, (2009), Other factors like reliability are also taken important and restricted during optimization. This is usually evaluated by determining the loss of load probability given by power failure time period over a given period of time (standard one year). Loss of power supply probability is the probability that an insufficient power supply will result when the hybrid system is unable to satisfy the load demand. The unmet load is given by non-served load divided by the total load of a period of time (standard one year)(Bernal-Agustin & Dufo-Lopez, 2009). All these factors are catered for in HOMER software used in this study.

2.4.3 HOMER software

Different tools both commercial and non-commercial have been developed to execute the task of design and optimization. These include but not limited to; HOMERS, HYBRID2, HOGA, HYDROGEMS + TRNSYS, HYBRIDS, INSEL, ARES, RAPSIM, SOMES, SOLSIM, MEAD as reported in (Bernal-Agustin & Dufo-Lopez, 2009). Amongst all the listed, HOMER is the most used and preferred. It’s a software developed by the National Renewable Energy Laboratory (NREL) of the United States of America (NREL, 2015). Due to a variety of technology options and their differences in costs plus energy resource availability, it makes decisions difficult to take. The optimization and sensitivity analysis algorithms of HOMER software solves the problem of evaluating many system configurations that are possible. It simulates the operation of a system by making energy balance calculations thus displaying a list of configurations according to their net present cost to enable one to compare the system designs. However, on the negative side of the tool, Orhan & Banu, (2010) noted that the enumerative method that HOMER uses requires more time to carry out the calculation if a number of possible design point is very high. This problem was solved with the new HOMER Pro. Software that takes only seconds to do its calculations. Using HOMER an optimized equipment for hybrid renewable energy system (HRES) is obtained. The optimized equipment should be of a minimum investment and operational cost at the same time meeting technical and emission constraints (Bahramara et al., 2016). Using HRESs in grid connected places (like universities, hospitals and factories) is economical when the right design and control strategies are applied (Bahramara et al., 2016). According to Bahramara et al., (2016), HOMER has been used more in remote and rural areas of developing countries than anywhere else. A load range between 0.626 kW and 2213000 kW has so far been considered in the software with a popular resource being solar PV in most of the researches (Bahramara et al., 2016). The case study of the recent research is exactly in the same range of the load adding to the usage of solar PV in the software. This work will add to the limited studies for HOMER optimizations within urban areas instead of remote area.

2.4.4 Comparison of energy systems

K. R. Ajao et al. (2011), compared the cost per kilo-watt hour of electricity from the national grid of Nigeria and the hybrid system of solar PV and wind turbine for Ilorina – a rural area in Nigeria. According to the optimization results, the utility tariffs were cheaper than the hybrid system and the system had a payback period of thirty-three years. However, due to the unpredictability of the grid reaching most of the rural areas soon, the authors recommended installation of many hybrid energy systems in a farm which would lower the investment cost per kilo-watt (K. R. Ajao et al., 2011). Similarly, Al-karaghouli & Kazmerski, (2010) used HOMER to compare the optimized system to the use of generator alone to supply a daily electrical load of 31.6 kWh for the health clinic in southern Iraq. Based on humanitarian, technical and economic grounds the PV system was better than the generator. According to the study results, the net present value and the price of a kilowatt-hour of electricity for the generator was approximately six times greater than the PV system’s (Al-karaghouli & Kazmerski, 2010). All these studies are similar to the objective of this study of using HOMER to compare depending on grid for all energy requirements vis-a-vis an alternative optimized hybrid energy system.

2.5 Net Metering

In order to encourage development of distributed generation, regulators are supposed to create a conducive environment where they can operate competitively and favorably. This is best done by putting in place policies that can encourage them. Renewable energy technologies and efficient methods of energy use like cogeneration that form a better percentage of distributed generation were first promoted using FiTs. These FiTs were mostly higher than retail electricity prices hence encouraged a lot of investment into the areas. As time goes FiTs keep fading and they are being replaced by new policies like net metering. Fading of FiTs brings about stagnation in technologies like PV, therefore, introduction of net metering designed to suit a given jurisdiction can rejuvenate the market (Christoforidis et al., 2013). Currently in Uganda, electricity end-users within the grid area mind less about alternative energy systems but continue to complain and suffer with huge electricity bills due to escalating tariff rates every year. Net metering can be a booster to development and implementation of other energy generators other than depending on the grid alone. This section reviews some of the literature about the net metering policy.

Net metering was first adopted in the 1980s in the United States of America (USA) within the states of Minnesota and Lowa. As of 2009, forty two states of USA and the district of Columbia had implemented the policy that later spread to other countries throughout the world [Doris et al., (2009), Curran & Clarke, (2012)] .

Different authors have defined net metering as an electricity policy in support of renewable energy penetration. With the policy in place, customers connected to the grid can offset their electricity bills partly or wholesomely using electricity produced from renewable energy sources [Darghouth et al., (2011), Poullikkas, (2013), Poullikkas et al., (2013), Curran & Clarke, (2012)]. A meter that spins forward and backwards when the customer is drawing and feeding electricity to the grid respectively is employed (Hughes & Bell, 2006).

2.5.1 Net metering vis-à-vis compensation

According to Hughes & Bell, (2006) under net metering, the customer generator's excess production can either be ignored or compensated by the utility. If it's to be compensated, this compensation can be in two forms; buying back the excess kilo watt hours or banking for the customer his/her excess kilo watt hours (kWhs). For banking, the kWhs are credited to the customer and rolled onto the next billing period. Within a banking period might be several billing periods. The prominent banking period is usually one year, though it can be half, quarter a year or any other period dimmed appropriate in a net metering regulation. The billing period is normally one month worldwide. At the end of a banking period the compensation can be monetary, or credits taken to another year, else they are forfeited to the utility. Buy backs can be categorized into three; below retail, retail and premium (Hughes & Bell, 2006). Below retail means the customer is paid for his excess kWhs at a price less than what s/he buys electricity from the grid. This is normally referred to as wholesale/ avoided/marginal price. This compensation value can be at exactly the wholesale price, average wholesale price, or a percentage of the wholesale price like 80% considered in Thailand's net metering regulation (Greacen et al., 2003), the difference is usually to cater for the distribution charges. Retail compensation value means that sale and purchase prices of electricity to and from the grid respectively are the same. Lastly premium is a rate above the retail price at which the customer buys electricity from the grid. Premium is normally offered in places where governments or regulators are the owners of the utility (Hughes & Bell, 2006). Urgent need for penetration of a particular technology is normally the driver for premium payments. Premium rates promote fast adoption of a given renewable electricity generation technology. Australia is one of the countries that practice premium payments. Her feed in tariff plan works more like net metering where a customer can either choose to use the generated electricity from the renewable energy source to first offset the load and then sell the excess to the grid at a premium pay or sell all the generated electricity to the grid and buy all that they are supposed to use (Poullikkas et al., 2013).

2.5.2 Net metering vis-à-vis renewable energy penetration

Studies have proved that net metering leads to penetration of renewable energy technologies. For example, Christoforidis et al., (2013) commended net metering as an initiative for the promotion of PV in a cost-effective way without need for any financial support. Net metering influences electricity retail prices that forms a center for customers' decision on whether to install alternative systems or not (Yamamoto, 2012). This benefit of renewable energy penetration as a result of net metering compensation mechanisms in place comes with complaints like reducing the utilities' revenue and non-customer generators subsidizing customer generators (Eid et al., 2014). This cross-subsidy argument has led to a development of a corrective tariff for distributed generators in some countries like Spain. Beach & McGuire (2013), refuted the above argument of cross-subsidy and instead stated that net metering creates a small net benefit across the utilities' residential market according to his research carried out in California's market.

2.5.3 Net metering versus net billing

Based on the preceding section, net metering and net billing policy takes on different approaches from one jurisdiction to another (Doris et al., 2009). Hughes & Bell (2006), taxonomy (see: Table 2.1) differentiates net metering from net billing with the number of registers or meters employed in the two case scenarios. Net metering according to Hughes & Bell, (2006) utilizes a single register, the bi-directional meter while net billing always has two registers to record the customer consumption and generation respectively as will be discussed later. While under net metering self-consumption is the first priority, in net billing the customer can choose to sell all their generated power as in the Australian case given in the preceding text. Yamamoto (2012), agrees that net metering can involve exchange of money at the end of a stipulated period but also introduces another compensation mechanism that he claims is similar to the net metering, net purchase and sale. Net purchase and sale differs from net metering through instantaneous rewarding of the customer. The moment excess generation is fed to the grid, it's rewarded there and then. The mechanism is similar to TOU compensation mechanism that applies where different rates apply during different times of the day and seasons (Darghouth et al., 2011). For a day, two or three different rates can be peak, off peak and/or shoulder. Summer rates are always also different from winter rates for countries with such weather conditions. TOU can apply under both net metering and net billing. Contrary to the above, Hugo & Juan, (2017), argued in their net metering report for Latin America and Caribbean that net metering can never involve any physical (monetary) remuneration even at the end of the banking period. Instead excess credits are rolled over from one billing period to another for a period of one year. At the end of the banking period, the customer forfeits the excess credits in terms of kWhs to the utility else it's rolled over to the next banking year indefinitely. According to the report, it's only under net billing that the utility can compensate the surplus credits at a monetary value according to the set value in the regulation (below, retail or premium). In summary, the authors differentiated the two terms based on how the surplus energy is treated. When the electricity units fed to the grid are deducted from the total customer consumption, that's net metering whereas if they are assigned a monetary value and then deducted from the bill, net billing is the right term to use. This recent work, however, does not focus on the nomenclature but instead on the treatment of the excess generation which majorly depends on the prevailing tariff rates.

2.5.3.1 Tariff rates

Net metering is a sequential process that moves from metering to accounting and lastly billing. Billing is usually done every month and it depends on the prevailing cost drivers and the tariff design for the given network. Tariff designs cater for network transportation and distribution costs (Eid et al., 2014). Tariff rates are normally reviewed annually, however, in Uganda it's done quarterly. These tariffs are set by the Uganda ERA through approval. Rate of return methodology is the basis for approval of the revenue requirement for the companies. Utilities i.e. generation, transmission and distribution companies file in an application for the revenue requirements detailing all cost breakdowns for assessment by ERA. For purposes of transparency and accountability, the public is called up on to make comments from which ERA makes a public consultation and the decision is taken (ERA, 2007). Tariffs are divided into domestic, commercial, street lights, medium and large industrial tariff rates in Uganda.

2.5.4 Meters

Metering is very vital whenever we talk of electricity. Meters measure the amount of power consumed or generated for purposes of compensation. Hughes & Bell (2006) ,elaborated on the different meters that are available on the market from unidirectional to bi-directional. These can either be electromechanical or digital meters. Electromechanical meters can either be ratcheted or un-ratcheted and the digital meters are capable of tracking different accounts at the same time. For net metering, the commonly used meters are bi-directional (Eid et al., 2014) while for net billing as defined in the preceding section are normally unidirectional. The installation location of the meter matters what they will measure, whether net consumption, net production or total PV production. There are those that give a single value for net metering while others display double value for net consumption and net production (Eid et al., 2014).

2.5.5 Comparison of net metering to other compensation mechanisms

Net metering depends so much on the market retail prices of electricity hence most studies have analyzed it in line with the rate structure and designs. When grid retail prices of electricity exceed distributed generation electricity prices, few systems are installed for profit purposes rather focus will be on self-consumption for those being installed which is the main target for net metering. Electricity prices for grid and distributed generation majorly depend on; set fixed cost of generating electricity centrally and the management cost to accommodate a distributed generation technology on the grid, variation in the marginal cost of generating electricity from the utility's operation, reduction of social losses from environmental externalities (Brown & Sappington, 2017). Net metering compared to feed-in-tariffs works better as regards electricity bill saving. The higher the capacity of the system, the more the savings. Poullikkas (2013), assessed the above using a household with a constant monthly electricity demand of 10,310 kWh. With a 1 kWp installed system, the net metering reading was 8,699 kWh while with a 7 kWp installed system, net metering reading was -965 kWh (surplus generation). Therefore, increasing the capacity of a system, increases energy savings. Other factors that net metering bill savings depend on include;

value of the compensation in the policy, designs of the rates, users' load profiles and orientation of the PV itself (Darghouth et al., 2011). Again, when net metering is compared to feed-in-tariffs and TOU, it yields more profits to the utility and has more environmental benefits in terms of reducing greenhouse gases than the two mechanisms (Yamamoto, 2012).

In this paper, a net metered energy system is compared to the grid alone/ and or backed with a generator. Similar to Darghouth et al., (2011)'s study of how rate design and net metering impacts customer bill saving, this paper looks at the effects of net metering on the energy bill of the selected grid customer. Although TOU rates apply to large scale consumers in Uganda, flat rates are applied in calculations due to data limitations. However, Borenstein S., (2007)'s work proved how TOU contribute to customer savings when integrated with net metering. Also Darghouth et al., (2011) affirmed how savings are optimized with TOU within net metering program. Other researchers like [Borenstein S., (2008), Borenstein S., (2005)] deduced that TOU under net metering adds value to the customer PV generation according to their analyses. This study focuses on analysis of the value of energy bill saving through net metering.

2.5.6 Net metering/billing approaches

As earlier stated the intension behind net metering is for self-consumption. In order to ensure that customers don't oversize their systems to act like IPPs who are profit oriented, the excess power at the end of the banking period is usually forfeited to the utility or rolled over indefinitely (Hugo & Juan, 2017). Net metering that involves remuneration (Net billing) is mostly disliked by utilities because it comes with a lot of accounting that would even incur them extra administrative costs. Its promotion has to go hand in hand with the development of the information systems. With the development of smart systems like meters that do not require physical monitoring, the management and administrative costs would be cut down.

Table 2.1: Summary of the different net metering and net billing forms

Comparison of compensation arrangement definition				
Compensation arrangement	**Definition characteristics**			
	Meters	**Banking**	**Buy-back**	**Price**
Net metering (general)	1	n/a	n/a	n/a
Simple net metering	1	no	no	n/a
Net metering with buy back (general)	1	n/a	yes	n/a
Net metering with below retail buy back	1	no	yes	below
Net metering with retail buy back	1	no	yes	retail
Net metering with premium buy back	1	no	yes	premium
Net metering with rolling credit (general)	1	yes	n/a	n/a
Net metering with rolling credit, below retail buy back	1	yes	yes	below
Net metering with rolling credit and retail buy back	1	yes	yes	retail
Net metering with rolling credit and premium buy back	1	yes	yes	premium
Net billing (general)	2	no	n/a	n/a
Net billing with below retail buy back	2	no	yes	below
Net metering retail buy back (two-meter net metering)	2	no	yes	retail
Net billing with premium buy back	2	no	yes	premium
Net billing with rolling credit	2	yes	no	n/a
Net billing with rolling credit and below retail buy back	2	yes	yes	below
Net billing with rolling credit and retail buy back	2	yes	yes	retail
Net billing with rolling credit and premium buy back	2	yes	yes	premium

Source: (Hughes & Bell, 2006)

Based on the table 2.1 above, approaches to net metering and net billing (Hughes & Bell, 2006) can be;

Simple net metering – consists of one billing period. In case of net consumption at the end of this period, customer pays for the consumed electricity from the grid. However, for net generation the customer owes nothing to the utility and is paid nothing for the excess. Instead the value on the meter is used as the starting value for the next billing. Simple to put, the approach involves offset and exchange of kilo watt -hours instead of money.

Net metering with buy back – this approach involves monetary exchange. Customer excess generated electricity is paid for at below retail, retail or premium.

Net metering with rolling credit – this approach is an extension of simple net metering with a banking period that covers more than one billing period. Excess electricity in one billing period is credited to the subsequent one to reduce its electrical charges in case there is under generation.

This stops at the end of the banking period. All credits at this stage are reverted to zero hence no compensation is received by the customer generator at this point.

Net metering with rolling credit and buy back – this net metering combination allows the customer to be compensated in terms of money for any excess generation at the end of the banking period. The payment follows the schemes described before. But in case the customer consumed more electricity from the grid at the end of the banking period, he/she will be required to pay at the retail rate for the consumption.

Before the customer generator is compensated for any excess electricity or the customer generator pays for his/her net consumption, billing is done first. Amongst the approaches discussed by Hughes & Bell, (2006) include; net billing with buy back – no banking is permitted i.e. billing period is equal to the banking period; net billing with rolling credit – same as for net metering with two registers for consumption and generation whose data is combined by the utility to determine the credits. No compensation for the excess generation at the end of a banking period but instead excess credits are rolled to the next banking period; net billing with rolling credit and buy back – exactly the same as net metering with rolling credit and buy back approach.

2.5.7 Design approaches for net metering.

Technology eligibility. All renewable energy technologies should be allowed for net metering. Selection and exclusion of particular technologies may hinder renewable energy market development. It may also lead to neglect of a would be viable and efficiently produced resource while promoting the opposite. For example, Kenya dropped the development of solar PV technology under its 10 year least cost power development plan because the planning committee believed it was so much expensive compared to other technologies yet Ref. (Ondraczek, 2014) proved otherwise using the LCOE methodology.

Customer class eligibility. It’s important to allow all classes of customers; residential, commercial and industrial to participate in net metering. This can best be done by setting the size limits differently according to the customer category. Many countries are already practicing this for example Mexico, Brazil (Curran & Clarke, 2012), and states like; Illinois, Guam, Puerto Rico (Poullikkas et al., 2013). Large energy consumers can help to propel the renewable energy market with in a country. In return, this helps to lower the price of a kilowatt as well as offload the grid.

Utility applicability. Net metering once established should apply to all utilities within a country or state. This eliminates confusion and creates consistency within a country. If there is selective applicability, complaints from both utilities that are offering it and the customers in locations without such policy will always arise due to this injustice. Knowledge can be uniformly passed on to the installers and prospective generators.

Additional fees. In a fight against net metering, utilities sometimes put up special charges claiming that they cater for distribution and transmission costs, they may require additional equipment or insurance from the customer generators. The state/country should therefore put up provisions to ensure net metering customers do not suffer from such inequalities that other customers are exempted from.

Ownership of RECs. Customer generators should be the owners of RECs. Acquisition of RECs by utilities from the system owners should be through payment of market prices to them else the credits should be rolled over indefinitely on the customers' account. This creates a revenue stream to customer generators hence encouraging more installations.

Meter aggregation. Group metering should be allowed to simplify the process of net metering. Meter aggregation should extend to such a way that it can as well allow a single customer with multiple accounts to offset his/her load on all those accounts with a single distributed generation system account. Shared-system net metering should also be allowed. This is a form of meter aggregation where groups of electric customers can invest in one energy (renewable) system such that it offsets their individual load demands at their different properties. Virtual net metering is also another form of meter aggregation that the policy needs to consider.

Net excess generation. The best net metering design is one that allows for an indefinite rollover of net excess generation at a retail price. This encourages customers not to undersize or oversize their systems. Rollover helps customer generators to receive RECs for their excess generation during peak seasons such that they can apply them during periods of lower output to reduce on their consumption [Doris et al., (2009), Curran & Clarke, (2012)].

Aggregate net metering limit. There should be no arbitrary limits on aggregate distributed generation capacity. This can restrict the expansion capacity of on-site renewable generation which may hinder the RES market.

Maximum size of renewable energy systems. NNEC specified no less than 2 MW as the maximum system size for net metering in 2008. However, this was revised in 2013 to 5 MW or below due to the high PV penetration. Within this limit, proper sizing of any distributed generation system can be possible as well as participation of most cost-effective systems in net metering [Rose, (2008), IREC, (2013)]. Other countries have opened up their policies without any limit (Hugo & Juan, 2017). This is the best option for net metering but would require a very stable distribution network. For most of the developing countries, this might be a very difficult application since many have unstable grids.

Compensation timeframe. Grid connected distributed generation comes with surplus generation that is fed to the grid. This excess generation is normally converted into credits in form of the kilowatt-hours (kWhs). Net metering should set a given period over which these excess kWhs should count no more. This period is normally referred to as a banking period. The best and mostly applied banking period is one year where compensation is involved. Half a year or a month can also apply. However, time of use (TOU) can also apply under this compensation mechanism where the customer's compensation is done hourly.

Net metering limit. This refers to the percentage of distributed generation system that can be accommodated under net metering for a given distribution network. The temporary or quantitative bounds should be clearly stated in the policy. Beyond this percentage, review of the conditions for the new installations should be done else suspended (Hugo & Juan, 2017).

Third party ownership. The policy may be open to where the consumer is not the owner of the generating facility (Hugo & Juan, 2017). The investor installs a renewable energy generating system at the host's location, makes power purchase agreement (PPA) with the host to buy all the generated power or it can be a lease agreement. Under PPA, the host pays for all the generated power on-site and in case of any excess generation, the agreement lies between the host and the utility. The electricity price is normally lower compared to if the host himself would install the system. For leases the agreement is usually to pay a fixed monthly monetary amount not directly grounded on the on-site generated power. This business model can best be applied to schools, government infrastructures and non-government organizations (Curran & Clarke, 2012).

Installation, operation and maintenance costs. These involve; administrative costs, cost of retrofitting the infrastructure, meter installation, installation certification costs, and many more costs. Clear setting of these costs should be done and who is responsible for what should be stated in the policy (Hugo & Juan, 2017).

Interconnection codes. These ensure the safety of the grid user and the grid itself which is exposed to bi-directional current flows and the intermittent nature of renewable energy technologies. Mandatory technical Installation interconnection codes to be followed for self-consumption should be clearly spelt out in the policy [Curran & Clarke, (2012), Hugo & Juan, (2017)].

Permit requirements. An effective policy should clearly state the procedure to be followed in obtaining permits (Hugo & Juan, 2017). However, reduction of the procedural requirements for small scale self-consumers can make the policy more efficient. It's much preferred and better for small scale self-consumers to just inform the authorities and go right ahead with the installation of course using a qualified installation personnel. Later the authorities can verify. Where before installation approval should be a must, the duration should be shortened as much as possible.

New and existing installations. The policy may come into force in presence of already operating self-generating facilities that would wish to connect to the grid in the presence of the policy. The regulation should state what happens in each case new and old respectively.

Penalties. This relates to the legality and quality of the installation hence the power quality fed to the grid. In case of a bleach in any of the above, the regulation should clearly state the punishment to the offender (Energy Commission, 2014).

2.5.7.1 Case studies of net metering approaches

Net metering dates back to 1980s as has been cited in (Curran & Clarke, 2012). It started in USA and it has spread out so rapidly to different countries in the world. The regulation in net metering vary from one state to another as well as from country to country. It's usually designed to suit a given jurisdiction. Many countries have replaced feed in tariff compensation mechanism for renewable energy development with net metering policy (Christoforidis et al., 2013). This has been especially boosted by net metering evolution from physical remuneration of customer generators to nonphysical remuneration that involves no exchange of money (Curran & Clarke, 2012). Due to its numerous benefits, more especially on the customer side like offset of bills, it has led to a rapid uptake of the technologies that it targets. As a result, utility operators end up on the wrong side of it when there is a high penetration of distributed generation. This is mainly due to the claim that utility revenues are reduced. Although net metering is so famous in America and Asia, its uptake in Africa is still very limited with countries like Ghana, South Africa and Namibia implementing it at a very limited scale while in others like Morocco, Kenya it's under pilot schemes. Contrary to the African status about the policy, if clearly studied, designed and properly implemented there are unlimited benefits to both customers, utilities and the communities at large. In this section, different countries where the policy has been implemented are studied to include; Canada, Brazil, United States of America in general and narrowing down to some of her states that have implemented the program in different ways. Also in Europe countries like Belgium, Denmark and Italy that properly practice this net metering program have been highlighted. Thailand's net metering is properly documented to represent Asia. While Ghana and South Africa's net metering rules proposed have also been discussed here. Focus has been on the capacity limit, technology under consideration, compensation mechanism and banking period.

Canada

In Canada also rolling over of renewable energy credits is mostly applied in the net metering policy with customers losing their excess credits at the end of the banking period (12 months for all states) save for areas of British Columbia. Customers are paid 9.99 Canadian dollar cents for any excess kWh exported to the grid. In South Central British Columbia customers are compensated for their excess generation at the prevailing retail rate. The net metering capacity limit for all regions of British Columbia is 50 kW. In Ontario, net metering is up to a capacity of 500 kW for a banking period of 12 months and just like in New Brunswick whose capacity limit is 100 kW, the customer loses the excess RECs at the end. March marks the end of a banking period in New Brunswick (Poullikkas et al., 2013).

Brazil

Under the net metering program established in April 2012 by the Brazilian Federal Energy Agency (ANEEL), small scale customer generators of 1 MW and below were considered. The technologies under consideration are solar, wind, biomass, hydro and cogeneration. The banking period under the regulations is 36 months with TOU rates being applied for the credits. On the technical side, whereas the customer is responsible for infrastructure and meter at the onsite generating facility, maintenance to include testing and required replacement is by the distribution utility (Curran & Clarke, 2012).

United States of America (USA)

All public electric utilities in USA are obliged to avail net metering services to customers up on request. As of 2013, Alabama, Mississippi, South Dakota and Tennessee were the only states out of the 47 states of USA that were not applying net metering (Poullikkas et al., 2013). The capacity limit for net metering varies from state to state. Many states have limits to the number of subscribers for net metering. Mostly determined depending on the percentage of the utility's peak load. However, already 20 states in addition to Washington D.C are open with no limits to net metering subscription (Curran & Clarke, 2012). Out of 47 states, 28 practice aggregate net metering with capacity limit and its determined as a percentage of the peak demand of a given state's utility. 30 states practice roll over of RECs for 12 months at a retail rate. For 5 states compensation is done at an avoided cost rate while in other 4 states its done at various rates to include, TOU rate, utility predetermined rate, or just as a percentage of retail rate or avoided cost rate. Eight of these states rollover customer credits via a combination of retail rate and any of the above-mentioned rates. Excess credit at the end of the twelfth billing month is granted to the utility within 11 states, carried indefinitely to the customer's next bill in 8 states, reconciled at an avoided cost rate in 6 states and in 5 states at any of the above-mentioned rates. However, there some special cases where the excess RECs are granted to the utility every month. In 2 states customers are compensated at any rate of the utility's choice at the end of the annualized period else they lose their credit to the utility while in 8 states the choice is between indefinite rolling over of the excess credit or being compensated at any rate (Poullikkas et al., 2013). Below is a detailed account of Virgin Islands and Illinois states.

Virgin Islands

Residential, commercial and public customers are considered under net metering in Virgin Islands. Capacity limits up to 20 kW, 100 kW and 200 kW for residential, commercial and public respectively are allowed under the program. Public stands for government, hospitals and schools under the net metering program of Virgin Island. Meter aggregation is also part of the net metering policy on the Islands accounting for 10% of the peak demand load for the Islands' electric utility. An aggregate capacity limit of 5 MW is set for St. Croix whereas for St. Thomas, St. John, Water Island and territorial islands it's 10 MW. Rollover for the net excess generation is done at the full retail rate of the utility onto the customer's following monthly bill for an annual cycle, however, at the end of the twelveth month billing, an excess credit is granted to the utility (Poullikkas et al., 2013).

Illinois

Net metering in this state captures a variety of renewable energy technologies to include; solar, wind, hydropower, dedicated energy crops, livestock and food processing waste anaerobic digestion, fuel cells and micro-turbines powered by renewables. The capacity limit is 40 kW of a customer generator. The number of net metering subscribers allowed is 1% of the total utility's peak demand in the preceding year. Residential and non-residential customers are allowed to net meter. The latter is allowed up to 2 MW capacity. However, whereas the metering system/equipment (single bi-directional meter) for customers up to 40 kW or less is a utility's responsibility, those above 40 kW but less than 2 MW are required to pay for all the installation costs of their metering system. It's a utility's choice to allow group aggregate metering or shared metering system e.g. for apartment buildings though the capacity is not identified. Net excess generation in one billing month is rolled over as credits in kWh to the next month for an annualized period. The billing cycle ends either in the last day of April or October and this remains a choice of the customer. Any excess in the last billing month is taken by the utility. TOU in Illinois net metering is applicable and customers under this service their credits are equivalent to the electricity charges at the time of production. Ownership of RECs and greenhouse gas credits belongs to customers. Important to note in Illinois net metering policy is that credits of net excess generation can be used to offset any other utility charges (Poullikkas et al., 2013).

Belgium

In Belgium, different regions have got different net metering regulations. Brussels, Flanders and Wallon regions have the policy in place. In Brussels, the eligible capacity limit is 5 kW. Customers are required to install two meters, a bi-directional and a green meter. There is compensation for the electricity fed into the grid only on condition that it doesn't exceed the consumption from the grid. This makes it more like a feed in tariff more so with the installation of the green meter to measure the net production from the customer generator. In Flanders, the eligible net metering capacity limit is 10 kW with no monetary compensation but only bill offset mechanism. Excess electricity fed to the grid at the end of a billing period is just donated to the utility for free. Lastly in Wallon 10 kVA is the eligible net metering capacity limit with an exact compensation mechanism like for Brussels only valid throughout the technical lifetime of the installation (Poullikkas et al., 2013).

Denmark

In Denmark, net metering comes more like a favour exempting renewable energy (all technologies) onsite generators from some obligatory additional charges for electricity consumption from the grid. Every customer according to the electricity act of Denmark is mandated to pay a Public Service Obligation (PSO) for usage of the grid. PSO is a tax for grid electricity use equivalent to 50% of the final price (Curran & Clarke, 2012). However, under net metering, customer generators with PV systems up to 50 kW, wind energy systems up to 25 kW and all the other renewable technologies up to 11 kW are exempted from PSO as a whole. Customers with system capacities exceeding the above mentioned for PV, wind and the rest of the technologies are exempted from the surcharge for the support of renewable energy sources for power generation. Net metering covers households, commercial and office buildings (Poullikkas et al., 2013).

Italy

Unlike in Spain and Netherlands where customer generators have to pay a grid user fee referred to as back-up fee for feeding their excess in the grid [Eid et al., (2014), Poullikkas et al., (2013)], in Italy it's different. The net metering capacity limit in Italy is 20 kW for all systems, and 20 kW to 200 kW for systems installed and operated beginning of January 2008. Unlimited rollover of renewable energy credits is used as a compensation mechanism for excess generation but in case of net consumption, the customer is required to pay (Poullikkas et al., 2013).

Thailand

Thailand's grid coverage by 2002 was 99%. This came with challenges of 6% rate of increase in electricity consumption per year. Due to continuous protests against development of new large-scale power plants (conventional), the government thought it wise to develop a net metering policy. This was meant to increase renewable energy deployment in the country to cover up for the contested large power plant construction. In May 2002, Thailand introduced a net metering policy for small electricity producers from solar, wind, biomass/biogas and micro hydropower. The policy covered up to 1MW installed capacity. Net monthly production is compensated at an average cost of Thailand's generation and transmission, equivalent to about 80% of the retail rate. The authors (Greacen et al., 2003) refer to it as a bulky supply tariff.

The regulations for net metering covered both commercial and technical aspects. Commercial aspects included; application and connection procedures, utility and renewable energy generator's costs to be incurred, billing period and tariffs. On the technical aspect, the customer generators' requirements to connect to the grid were set. Amongst which included; technical responsibilities of the utility and customer generators (e.g. acceptable voltage, frequency, power factor and harmonics); requirements for relay protection; and emergency disconnections in case of any problem. All the above was set according to the technical standards of the Institute of Electrical and Electronics Engineers (IEEE).

Ghana

In Ghana, all renewable energy sources are considered in the net metering policy. The capacity limit captured under the policy is up to 200 kW per installation. Renewable energy credits in form of kWhs are rolled over from one month to another for a period of a calendar year. Excess credits accumulated by the customer generator at the end of a calendar year are lapsed. The calendar year starts on 1st January and ends on 31st December. In case a customer terminates service or changes the distribution utility, no compensation is made an accrued excess credits (Energy Commission, 2014).

South Africa

In 2013, net metering scheme was discussed by different stakeholders to include; utility companies (Eskom and municipalities), National Energy Regulators, GIZ and its consultants etc. for small scale embedded generators particularly rooftop PV system owners. The following aspects were covered; the applicable maximum net metering capacity to be 100 kVA for experimental purposes but with hopes of increasing it to 1 MVA, the import and export rate of electricity to the grid to be fixed, however, with export tariff a little lower than the import, the billing cycle to be taken for one year, and the export tariff to be guaranteed for a three period estimated to be the pay-back time for an ideal rooftop PV system (Pöller, 2011).

Therefore, with all the success stories of the above case studies, Uganda can easily adopt and refine a net metering approach to suit its context more so borrowing a leaf from its fellow African countries.

2.5.8 Rewards and misapprehensions of net metering

Net metering impacts three different categories of people to include the customer generator, the community and the utility. Net metering promotes democratization of energy through customer generation, empowers customers to become their own energy producers, indirectly reduces energy subsidies and makes use of the existing electrical infrastructure. It reduces the unpredictability of electricity prices to customers. It's universally known that net metering helps customer generators to reduce on their energy bills. This is through excess generation on a particular day cancelling out consumption for a day where the load surpasses the production [Poullikkas et al., (2013), IREC, (2013)]. The policy targets renewable energy more especially at a small-scale level therefore encouraging private investment. This brings about energy independence and security to customers as well as the community. In return, the energy sector is diversified which leads to its rapid growth. Energy being a key economic driver, therefore net metering directly leads to national economic growth (Stoutenborough & Beverlin, 2008). According to Greacen et al., (2003), net metering provides an exciting vehicle for harnessing plentiful renewable energy resources for cost-effective electricity generation in ways that draw on the creativity and entrepreneurial spirit of small businesses and communities. IREC (2013), emphasized net metering promotion of onsite renewable energy generation as a push for countries in achieving their goal of renewable energy portfolio standard.

To communities, net metering increases property value as well as local businesses opportunities through the promotion for development of electricity generation units. Through businesses jobs are created. Renewable energies being clean, greenhouse gas emission is reduced which improves the air quality and in turn public health is improved also (IREC, 2013). Promotion of small scale investment adds value to the generated electricity as well as enhancing market development.

To utilities, net metering reduces transmission and distribution system losses and as well solves the problem of congestion in the transmission lines. The excess kWhs fed into the grid by the customer generator can be used to serve a load for another. This acts as an additional capacity to the utility without incurring any cost of investment in generation, distribution and transmission or purchasing power from the external market. Such costs have direct impact on the tariff design for any utility, therefore net metering helps to stabilize the rates (Hugo & Juan, 2017). Since generation sources like solar mostly match the utility peak demand and it occurs almost every day of the year, it helps to reduce the burden on the grid (IREC, 2013). Additionally, utilities benefit from the fact that distributed generation helps to boost the network voltage more especially if situated towards the end of the line where voltage has mostly dropped. Voltage drop below a threshold value with an increase in the load would result in blackouts and damage to the equipment. Therefore, net metering directly helps utilities to reduce on their costs for maintenance and upgrading of their system through encouragement of distributed generation facilities (Poullikkas et al., 2013).

Misapprehensions about net metering are also existent especially on the technical part. Complaints majorly fall into technical feasibility, grid stability, utility revenue, and additional administrative costs to the grid (Curran & Clarke, 2012). The argument that net metering reduces utility revenues (Eid et al., 2014), is not universally fitting because this can only be true if the penetration of onsite generation is so high to the level passed grid parity at a premium rate for compensation. Grid parity, however, is no yet attained in most countries or states and to achieve it takes time. The policy also allows for routine reviews of the technology and market development such that incase the utilities are affected, restructuring of the rates is done immediately. Given the famous recent design of net metering where a customer is not given physical remuneration but instead continuously rolls over his/her electricity credit indefinitely, the argument cannot stand at all. This can equally be compared to discussions that energy efficiency hurts utility revenues (Poullikkas et al., 2013). Secondly, the misconception that non-customer generators tend to subsidize customer generators is caused by lack of utilization of time of use (TOU) charges. When a customer using electricity during peak hours of the day pays the same amount as the customer that uses electricity at night when it’s off peak, this can best be described as double standards of doing business. Therefore, in this case one customer still subsidizes the other’s consumption. Factoring in TOU rates cancels out the argument. Lastly, that net metering possesses a burden to utilities in form of administration. Compared to feed in tariff that will require installation of a second meter and carrying out routine books of accounts, the new design of rolling over electricity credits in net metering is so simple that it only requires how many units are to be carried forward (Poullikkas et al., 2013).

2.5.9 Challenges and solutions to net metering development

Case study one: Thailand context

Development of net metering policy in Thailand did not stop at structuring the regulations. A lot more was to be dealt with to include educating the potential customer generators, developing financial models for acquisition of the required equipment, as well as assisting utilities in meeting the regulatory requirements timely (Greacen et al., 2003).

The major barriers to net metering mostly included; (i) lack of awareness about net metering, (ii) lack of knowledge about some renewable energy technologies. For example, many farmers were not knowledgeable that agricultural waste can be converted into electricity, (iii) shortage of high quality and affordable equipment necessary for grid connection of renewable energy systems e.g. integrated protection relays for rotating generation interconnection, (iv) lack of experts for designing and installation of small scale renewable energy systems (v) strict and tough technical requirements for interconnections, (vi) uncertainty in the appropriate testing procedures for net metered systems (Greacen et al., 2003). It is important to note that all these challenges are not limited to Thailand's case only but cut across general net metering development anywhere.

Some of the administrative challenges were dealt with by organizing a study excursion to the United states for the Thai utility officials to meet their counterparts. Net metering experts from USA utilities led a workshop for both engineers and administrators in Thailand.

Case study two: Chile context

Problems that hinder net metering development in Chile from finance, institutions, administration to technical. Financially, the project developers focus more on the internal rate of return (profits) as well as the payback period. To industrial and business owners, the payback period seems to be too long hence low moral for them to take part in net metering. This truly explains that they haven't understood the context in which net metering comes. For household owners, however, there exists problems of high initial investment. With the renewable technology advancement, the problem will be no more since technology improvement leads to reductions in the components prices. Amongst the recommendations to overcome this challenge are preferential financing, subsidies to importers, tax incentives for households, increasing the compensation value for the excess generation etc. (Hugo & Juan, 2017).

The policy design also lacked differentiation of the customer category as regards the size limit. This is a very big issue since residential, commercial and industrial vary so much in different aspects like the installation space, access to finance etc.

Lack of information and awareness cuts through as a barrier to net metering, Chile is not exceptional. The average person in the country has little knowledge about energy and almost nothing about net metering existence and its benefits that it can save them energy bills. This calls for massive awareness campaigns which are also somewhat challenging to carry out due to diversity of the customers. Nevertheless, they should be carried out using appropriate channels.

Institutionally, there was insufficient control capacity by the regulatory body the Superintendence of Electricity and Fuels (SEC) in rural areas at commissioning of the net metering program. This is being mitigated through increase in the SEC's staff as well as the financial resources. Chile is also trying to transform to telematics in its administrative procedures (Hugo & Juan, 2017). Although things are changing tremendously, at first the process was very complex for low power systems, could take so long for an installer to get approval, required expensive diagrams. Modifications in the decree for net metering now include reduction for permit periods for small projects, special connection procedure for systems to be installed in residential, reduction of the required connection documents and legalization of SEC to implement the process online (Hugo & Juan, 2017).

2.5.10 TOPSIS

From the many net metering compensation approaches as reviewed above, this study determines the best applicable approach in the African/Ugandan context. To do this a decision-making tool TOPSIS is used. Using the tool, Hwang and Yoon (1981) deduced that the ranking of alternatives should be based on how shortest and furthest their distance from the PIS and NIS is. Different studies like Majid. B., et al (2012) who carried out a review on state of art survey on TOPSIS applications and Srikrishna, A, & Vani, (2014) Who used TOPSIS to determine the procedure for car selection all recommend use of the tool.

2.5.11 Chapter Summary

Many studies exist about distributed generation especially solar PV and a few have been cited above. Some have designed and compared energy systems involving renewable sources like solar and wind with diesel (Al-Karaghouli & Kazmerski, 2010), while others have compared grid electricity rates to the cost of electricity from their designed microgrids (K. Ajao et al., 2011). However, most of these studies concentrate on remote areas leaving out customers within the grid connected areas that continue to suffer with the ever-increasing electricity tariff rates. This study bridges this gap by comparing dependence on the grid for all the customer energy needs to having an alternative net metered system. Net metering that forms a better part of this study has also been vastly studied. Many comparisons have been carried out between net metering and other policy mechanisms like feed-in-tariffs as regards energy bill saving [Yamamoto, (2012), Campoccia et al., (2009), Poullikkas, (2013)]. Net metering has also been related with tariff deigns and structures in different studies about energy bill saving [Mills et al., (2008), Darghouth et al., (2011)]. From the reviewed literature, it's clear that net metering is a far better tool for energy bill saving than any of the above. However, no study has compared the different compensation approaches within the policy itself before. With all the different compensation approaches of net metering as discussed by (Hughes & Bell, 2006) and (Curran & Clarke, 2012), this study focuses on perpetual rollover of credits (kWhs) and cash buyback at the end of the banking period first to establish the most applicable approach in Uganda and then to establish its impact on the customer energy bill savings. As many case studies with success stories have been studied, Uganda can freely borrow a leaf especially from its fellow African countries that have implemented the policy.

CHAPTER 3: METHODOLOGY

Outline

3.1 Background and Preference for the Study Area.

Kyagalanyi Coffee limited is the biggest exporter of coffee from Uganda. Founded in 1992 after the liberalization of the coffee markets in the country, it's one of the oldest licensed coffee dealers, exporting roughly 24,000 tons on average annually (Kyagalanyi Coffee Ltd, 2014). The factory procures, processes and exports Arabic and Robusta coffee types. Processing of this coffee is largely done at their new facility in Kampala Industrial Business Park, Namanve (latitude-0.357500; longitude - 32.694167). The company has different units in different parts of the country that help partly in the washing and processing of the coffee beans. These are smaller units that can fully utilize the results and recommendations of this study. These include; the precleaning, drying and warehousing facility in Mbale, six eco-washing stations in the Elgon mountain areas of Uganda, Erussi, West Nile and Sheema Robusta eco-washing stations, Mukono-Nakanyonyi Robusta processing facility with a mother garden for quality planting material production. With the ecological mentality behind the various units under Kyagalanyi group (Kyagalanyi Coffee Ltd, 2014), this project should be of great use thus the preference for the case study. The company has made efforts to reduce its electricity consumption so as to remain on top of the coffee processing industry in the past years. Efforts included carrying out energy audits by contracted external auditors.

3.2 Kyagalanyi Coffee Limited (KCL)'S Daily Load Requirement.

For purposes of determining the efficiency and reliability of the power generating system to be designed and optimized, a load profile was obtained from KCL. The load requirement for the factory varies with the available coffee to process which depends mostly on the seasons of coffee. This load was obtained using a power Quality analyzer (PQA 824) at an integration interval of thirty minutes for a period of one week. Thereafter an average hourly consumption was calculated as shown in Appendix A., Table 1 and used in the HOMER software to simulate the annual load profiles for the factory.

3.3 System Design and Optimization

Using the National Renewable Energy Laboratory's HOMER software, different energy systems were simulated and optimized based on the load profile; the components': - sizes, capital, replacement and operational costs, lifetime, derating factor, efficiency; fuel cost; electricity rates;

solar irradiation and interest rate. The maximum annual capacity shortage, operating reserve of the load and the renewable output (in this case the solar output) were the constraints specified for this project. A derating factor is set due to the fact that the panels' output will vary from the manufacturer's specification with changes in the geographic locations. The project lifetime was also set based on the lifespan of the panels. HOMER ranked the systems according to their net present cost values in an ascending order. All systems were designed to sell and purchase electricity from the grid at the same rate. This is because the net metering compensation mechanisms under consideration for analysis are; perpetual rollover where all the PV production in a particular month is to offset the consumption in the same month else rolled over to the following months indefinitely and compensation with buy back preferably at a retail price. Although time of use rates apply to the network distributor UMEME for commercial and industrial customers, this doesn't affect the mechanisms under consideration as offset is done under the same time of the day when production happens. Currently in Uganda no emission penalties exist, but the grid emission factors for carbondioxide, sulfur dioxide and nitrogen oxides were specified as 513, 2.74 and 1.34 g/kWh respectively for this study.

3.3.1 HOMER model inputs

The average monthly daily solar radiation used was obtained from NASA surface solar energy data set (NASA, 2016) at latitude 0.3575 and longitude 32.69. The estimated solar PV components' prices and specifications where obtained from Better Solar Power Quotes (BSPQ)'s website of Australia (BSPQ, 2015) while the generator prices were quoted from America's generators (Americas Generators, 2017). All the component prices used include the hardware and labor for installations costs. The hardware components include support structures, wiring, fuses and safety devices. Other costs may include shipping, dealer make ups and taxes etc.

3.3.2 Description of the components used.

a) PV array

This is an interconnection of panels. A PV panel or module as it's referred to in Al-Karaghouli & Kazmerski, (2010) is an interlinkage of silicon solar cells on a base plate which produces direct current (DC) proportional to the incident global solar irradiation on it. This electricity production by these panels is independent of the temperature and voltage to which they are exposed. However, too much heat tends to reduce their overall efficiency. Panels are classified into first, second and third generation. First generation include mono and poly crystalline cells which are fully commercial taking more than 80% of the market. Second and third generation are in market development and demonstration stages respectively. Amorphous PV cells are examples of second generation while concentrated and organic are third generation cells. At standard testing conditions, the efficiency of monocrystalline, poly crystalline and amorphous stands at 15%, 12% and 8% respectively (Sinton et al., 2013). The difference in the efficiency is mainly due to mono PV layer comprising of a single crystalline with thinner layers than poly and amorphous layers thus electrons taking less time to travel through the holes across the layers. They range in sizes to include but not limited to 200W, 250W, 260W, 300W etc. With the country's location being at latitude 0^0, tilting of the panels is not required, however, to maximize their production horizontal axis tracking was considered. According to BSPQ the lifespan of the panels is 25 years. For sensitivity analysis 600 – 710 kW system capacities were considered and a lifespan of 20 and 25 years was analyzed.

b) Inverter

This converts DC to AC for use by AC loads. Efficiency and lifetime were the major parameters considered. For sensitivity analysis, efficiency of 95% and 90% where considered with lifespan of 10-15 years (K. Ajao et al., 2011). Different sizes were considered again and the optimal was selected by the software.

c) Generators

Generators use fuel to produce electricity. These exist in different types based on the fuel they use. Fuels used in generators include; gasoline, diesel, propane and biofuels. Of all the above, generators that use diesel are most preferred for their efficiency and longer lifespan (Al-Karaghouli & Kazmerski, 2010). Therefore, a diesel generator was considered for this study. The operation per hour was taken to be 0.15% of the capital cost (Americas Generators, 2017). No forced on and off was scheduled instead it was left to HOMER to optimize its use. Since it's just a backup plan, the generator can only be used in absence of PV production and the grid (power outage). Different sizes were considered for sensitivity analyses.

d) Storage

No storage devices like batteries or fuel cells were considered for this study since the system is connected to the grid under net metering program. Therefore, the grid acts as the storage facility for this system. Besides, including a storage device would hike the overall prices of the system for no good reason.

3.4 Comparison of Energy Systems

Comparison of the selected hybrid system against the grid and/or backed up with the generator was carried out using HOMER where the former was considered as the current system and the latter as the base system. Present and annualized worth, return on investment and the IRR, payback and discounted payback were the parameters that formed the comparison.

3.5 The Net Metering Analogy

This analysis focuses on specifically two approaches of net metering with respect to its aspect of compensation. Perpetual roll over of excess credits (kWhs) versus buy back of excess kWhs at the end of the banking period especially at a retail price. The two other compensation values (wholesale and premium) are not of a major focus in this study because; (i) below the electricity market retail price is in favour of the utility since it gains more from the excess generation charged to their system, (ii) premium payments will obviously be rejected by the utilities especially those not nationally owned because it threatens the utility revenues in addition to the costs involved in implementing it. Rolling over of credits from one billing period to another in net metering is done at a retail price of electricity. The study wishes to establish the approach that fits in the African/Ugandan context where both the utility and the customer can both be comfortable.

In order to carry out the comparison, a survey was carried out on the two approaches under consideration and TOPSIS decision tool used thereafter to determine the best approach.

3.5.1 TOPSIS method

According to Srikrishna et al., (2014) from their study of car selection, TOPSIS procedure is based on an intuitive and simple ideal. The optimal ideal solution is one with the maximum benefit and is obtained by selecting the best alternative which is far from the most unsuitable alternative that has minimal benefits. The ideal solution should have a rank of '1'(one), while the worst alternative should have a rank approaching '0'(zero).

As the ideal net metering compensation mechanism is not probable and each alternative approach would have some intermediate ranking between the ideal solution extremes. Regardless of absolute accuracy of rankings, comparison of the approaches under the same set of selection criteria allow accurate weighting of relative car suitability and hence optimal compensation mechanism selection.

Mathematically the following steps were followed in applying TOPSIS

Step 1: A decision matrix was established between the alternative approaches and the selected criteria from Curran & Clarke, (2012)'s report of Namibia's net metering practices. As elaborated in Eqn. 1

$$DM = \begin{bmatrix} L_1 \\ L_2 \\ \vdots \\ L_m \end{bmatrix} \begin{bmatrix} C_1 & C_2 & \cdots & C_n \\ X_{11} & X_{12} & \dots & X_{1n} \\ X_{21} & X_{22} & \cdots & X_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ X_{m1} & X_{m2} & \cdots & X_{mn} \end{bmatrix} \dots \dots \qquad Eqn. 1$$

Where 'i' is the criterion index (i = 1 . . . m); m is the number of potential sites and 'j' is the alternative index (j= 1. …n). The elements C_1, C_2…, C_n refer to the criteria: while L_1, L_2…, L_n refer to the alternative locations. The elements of the matrix are related to the values of criteria i with respect to alternative j.

Step 2: A normalized decision matrix was calculated. This normalized value denotes the Normalized Decision Matrix (NDM) which represents the relative performance of the generated design alternatives as show in the Eqn. 2 below.

$$NDM = R_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^{2}}} \dots \dots \dots \dots . Eqn. 2$$

Step 3: The weighted decision matrix was determined. Not all of the selection criteria may be of equal importance and hence weighting were introduced depending on literature to quantify the relative importance of the different selection criteria. The weighting decision matrix is simply constructed by multiply each element of each column of the normalized decision matrix by the random weights. See Eqn. 3 below.

$$V = V_{ij} = W_j \times R_{ij} \dots \dots \dots Eqn. 3$$

Step 4: The Positive and Negative Ideal Solutions were identified. The positive ideal (A^+) and the negative ideal (A^-) solutions are defined according to the weighted decision matrix via equations (4) and (5) below.

$$PIS = A^{+} = [V_1^{+}, V_2^{+} \dots V_n^{+}], where: V_j^{+} = \{maxi(V_{ij})\ if\ j \in J); (mini\ V_{ij}\ if\ j \in J^1)\} \dots . Eqn. 4$$

$$NIS = A^{-} = \{V_1^{-}, V_2^{-} \dots, V_n^{-}\}, where: V_j^{-} = \{(mini(V_{ij}) if\ j \in J); (maxV_{ij}\ if j \in J^1)\} \dots . Eqn. 5$$

Where, J is associated with the beneficial attributes and J' is associated with the non-beneficial attributes.

Step 5: The separation distance of each competitive alternative from the ideal and non- ideal solution was calculated according to the expressions below.

$$S^{+} = \sqrt{\sum_{j=1}^{n} (V_j^{+} - V_{ij})^2} \quad i = 1, \dots \dots, m \dots \dots \dots \dots \dots \dots \dots Eqn. 6$$

$$S^{-} = \sum_{j=1}^{n} \left(V_j^{-} - V_{ij}\right)^2 i = 1, \dots \dots, m \dots \dots \dots \dots \dots \dots \dots \dots \dots Eqn. 7$$

Where, i = criterion index, j = alternative index.

Step 6: The relative closeness of each location to the ideal solution was measured. For each competitive alternative, the relative closeness of the potential location with respect to the ideal solution is computed.

$$C_i = S_i^{-} / (S_i^{+} + S_i^{-}), 0 \leq C_i \leq 1 \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots Eqn. 8$$

Step 7: The approaches were ranked according to the value of C_i; the higher the value of the relative closeness, the higher the ranking order and hence the better the performance of the alternative.

3.6 Energy bill saving with and without net metering

Comparison of two different scenarios was carried out using year 2015 as the base year for the analysis. The scenarios were; depending on the designed energy system connected to the grid but without net metering in place, and net metered energy system. The monthly electricity bill, tariff rate and the average daily PV production after conversion from DC to AC by the inverter were used for this analysis. Monthly electricity bills for 2015 were obtained from the management of KCL, the tariff rate for the same year was picked from the Electricity regulatory authority, and PV production is from HOMER simulations. Although time of use rates exist, a flat rate tariff was adopted for simplicity of the analysis.

3.6.1 The analysis

The monthly electricity bill in Uganda shillings (UGX) is converted into US dollars which is internationally recognized by dividing it with the exchange rate for the year 2015 obtained from the central Bank of Uganda. The number of units (kWh) used in a particular month are also obtained from this bill. Then the PV share for a particular month was calculated based on the number of days in the month and the mean inverter output. This was first considered for the hybrid system without net metering and later with net metering. Without net metering, Sunday and national public holidays were excluded owing to the fact that on such days there is no factory production hence PV production on such days is just forfeited. However, with net metering in place, all PV production no matter which day is considered useful since it's stored with the grid and used on any other day with low production. Subtracting PV production (kWh) for that particular month from the total consumed energy (kWh) gives you the net grid consumption (kWh). This is multiplied with the tariff rate to obtain the electricity bill that a customer would receive in the presence of the alternative energy system. Thus, the difference between the two bills (with and without the alternative energy system) gives the savings that a customer would receive. The same procedure is repeated for a net metered PV/diesel hybrid energy system considering PV production on all the days of the month to be useful.

3.6.1.1 Facts and assumptions about the analysis

KCL operates from Monday to Saturday for 24 hours with the availability of coffee. In off seasons, only a general shift (8 am – 6pm) operates. Sunday and the rest of the national public holidays are rest days no processing takes place. Besides the above facts, the following assumptions aided the calculations to include; (i) no serious mechanical breakdown that can last the whole day was catered for, (ii) no work is done on any national public holiday and Sunday no matter any emergency. So, all the PV production on such a day is regarded as excess generation and therefore can only be considered under net metering, (iii) changes in the weather partners are disregarded. Therefore, the simulated HOMER PV production is used throughout, (iv) PV production declines by 1% every year from the year of installation, (v) there is availability of the raw material (Coffee) throughout the year, (vi) on a non-work day there is zero load, not even lights are considered to use the PV power generated, (vii) for simplicity, it's assumed that there is coffee throughout the year. So, a 24 hours production from Monday to Saturday is considered.

3.6.1.2 The mathematical expression of the analysis

Let the;

Monthly electricity ($) bill be,$B_m$

Monthly electricity Units (kWh) used be, $U_{e(m);}$ from the electricity bill obtained

Tariff rate of electricity be, $ T_e

Daily PV output (kWh) through the inverter be,O_{pv}

Without net metering, let the;

Monthly PV production (kWh) through the inverter be,$O_{pv(m)}$

Monthly grid purchase (kWh), $G_{pc(m)}$

Monthly electricity bill ($) without net metering be,$Eb_{pv(m)}$

Savings ($) due to non-net metered PV be, $\boldsymbol{S}$

Conversion from monthly to annual will be given by $\sum_{1}^{n}(\boldsymbol{parameter})$**;**

where n = 1,2,3………….12; number of months in a year

Therefore;

Monthly PV production (kWh) through the inverter would be given by, $O_{pv(m)} = N \times O_{pv}$

where N = 1,2, 3……...m; days in a month;

Monthly grid purchase (kWh), $G_{pc(m)} = (U_{e(m)} - N \times O_{pv(m)})$

Monthly electricity bill without net metering ($), $Eb_{pv(m)} = G_{pc(m)} \times T_e$

Monthly savings due to non-net metered PV, $S = \$(B_m - Eb_{pv(m)})$

With net metering in place, let the;

Monthly PV production (kWh) through the inverter be,$O_{pv(m),net}$

Monthly grid purchases (kWh) be,$G_{pc(m),net}$

Monthly electricity bill ($) with net metering be, $Eb_{pv(m),net}$

Savings (\$) due to net metered PV be, S_{net}

Hence;

Monthly PV output (kWh) through the inverter would be given, $O_{pv(m),net} = N \times O_{pv,net}$

Monthly grid purchases (kWh), $G_{pc(m),net} = (U_{e(m)} - O_{pv(m),net})$

Monthly electricity bill (\$) with net metering $Eb_{pv(m),net} = G_{pc(m),net} \times T_e$

Monthly savings due to net metered PV,$S = \$(B_m - Eb_{pv(m),net})$

CHAPTER 4: DATA COLLECTION AND ANALYSIS

Outline

4.1 Net Metering Survey

A survey was carried out amongst energy experts from research institutions CREEC and PAUWES, utility company UMEME and energy regulators from ERA. A total number of 50 emails were sent. Out of the sent emails only 25 people responded. In addition to the above, 10 people were physically interviewed from CREEC making a total of 35 responses. The questionnaire was prepared and pretested at CREEC prior to sending it out (see appendix b).

The parameters considered for investigation include; customer satisfaction, implementation costs, administrative costs, utility company satisfaction regarding the impact on their revenues. These parameters were obtained from Curran & Clarke, (2012)'s report and they deemed them important. Out of the 35 responses, only 9 participants had high knowledge about net metering while the rest expressed moderate levels according to the question asked about the same in the questionnaire. From the survey, no body expressed ignorance about net metering neither was there a participant who had never heard of net metering. The figure below illustrates the responses.

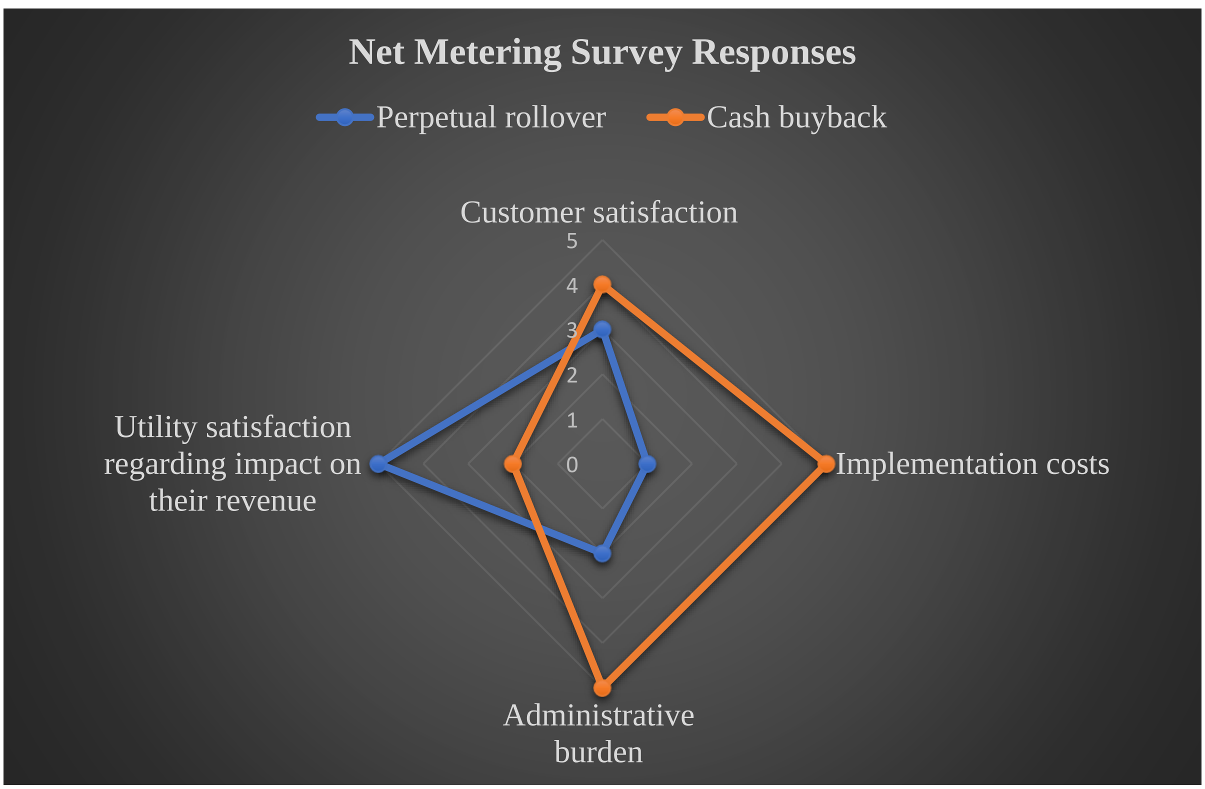

Figure 4.1: Net metering survey responses

4.2 KCL's Load Profiles

The analysis in this research relies on the load data collected using a Power Quality Analyzer (PQA 824) at an integration time interval of 30 minutes for a period of one week. From the collected load data in Appendix A., Table 2, an average hourly consumption is calculated as a total sum of the two transformers divided by the number of days (7). As shown in Figure 4.2, a base load of approximately 39 kW occurs in the evening hours of the day while peaks of around 320 kW in the morning hours. This hourly consumption is used by HOMER software to generate the average monthly load profile for the facility as illustrated in Figure 4.3. The total daily average load as calculated by HOMER is 4,294.6 kWh while the peak demand is 590.7 kW. This is susceptible to a demand charge by the utility at a rate of $3.2 per kWh.

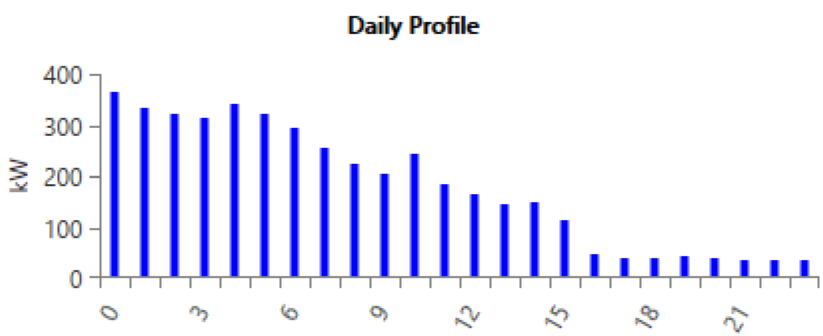

Figure 4.2: KCL's daily load profile

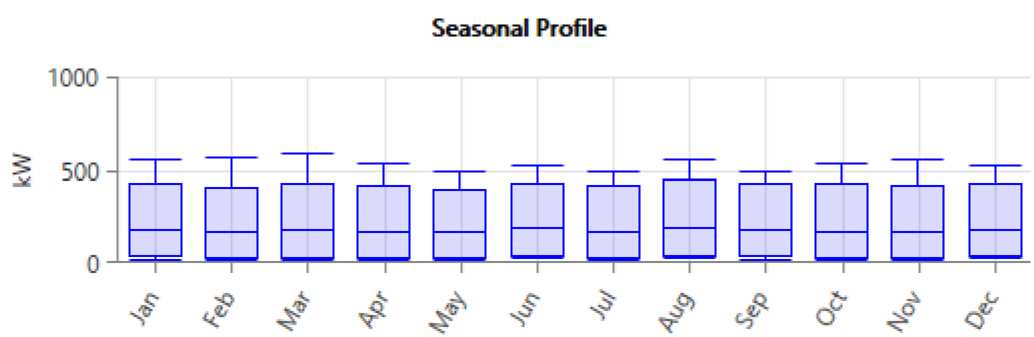

Figure 4.3: Monthly load profile for KCL

4.3 Solar Radiation Profile

The solar resource data obtained from NASA surface meteorology and solar energy website (NASA, 2016) is shown in Figure 4.4 below as a solar resource profile for a period of one year. The nearby location to KCL's site (latitude: 0.3575 and longitude: 32.694167) is Kampala (latitude: 0.3476 and longitude: 32.5825) whose data was used.

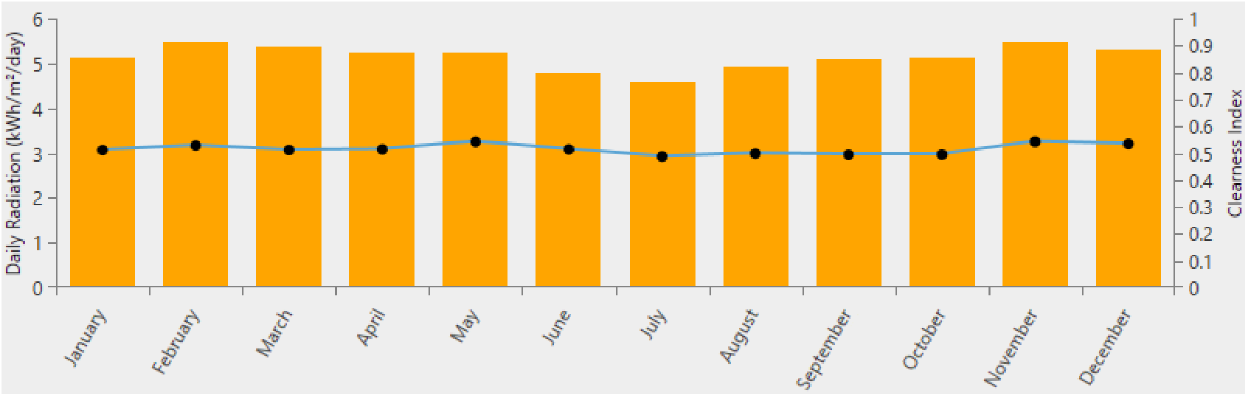

Figure 4.4: Solar Global Horizontal Radiation Profile for KCL
Source: (NASA, 2016)

4.4 Economic Analysis for KCL's Energy Use

For this study, an annual interest rate of 11% was considered from Bank of Uganda(BOU) website BOU (2017) and a project lifespan of 25 years. The exchange rate used is $1 to 3500 UGX for HOMER requirements while $1 to 3200 UGX for net metering calculations since the year under consideration was 2015 and thus the corresponding rate. The tariff rate for industries from ERA, is $0.14, $0.11 and $0.07 per kWh for peak, shoulder and off-peak respectively. Due to the ever-changing industrial loads, the maximum capacity shortage as a constraint is set at 5 % for all systems under consideration to satisfy. From the energy bills of KCL, the consumption varies from month to month depending on peak and off-peak seasons of coffee within the year. The monthly average consumption based on the available data is 31427.9, 143209.4 and 33778.67 kWh for off-peak, shoulder and peak periods respectively. This translates into $2199.95, $15753.04 and $4729.01 for the respective periods, totaling to $22682 per month. Annually KCL spends $272184 which is equivalent to $6804601 for the twenty-five years of consumption.

CHAPTER 5: RESULTS AND INTERPRETATION

Outline

5.1 Introduction

This section looks at results from the survey of net metering as well as the ones obtained from HOMER analyses and explicitly interprets them. Different energy systems to include; grid and/or with a backup generator, since these are the systems most industries in Uganda depend on, KCL inclusive; grid tied solar and the solar hybrid connected to the grid are reported from the analysis and savings due to them in comparison are noted. Savings due to net metering are fully presented and recommendations made thereof.

5.2 Net metering survey results

Out of the seven parameters in the questionnaire, three were representative of the utility company (implementation costs, administrative burden and utility company satisfaction regarding impact on revenues) while one was for the customer. This is because the utility has a lot to do with the establishment of the policy. The overall score from the raw data was in favour of perpetual rollover of RECs although not by a big margin as seen in Figure 4.1 above. Applying TOPSIS decision making tool to the responses, perpetual roll over of credits still had the best closeness value compared to cash buyback as shown in the figure below.

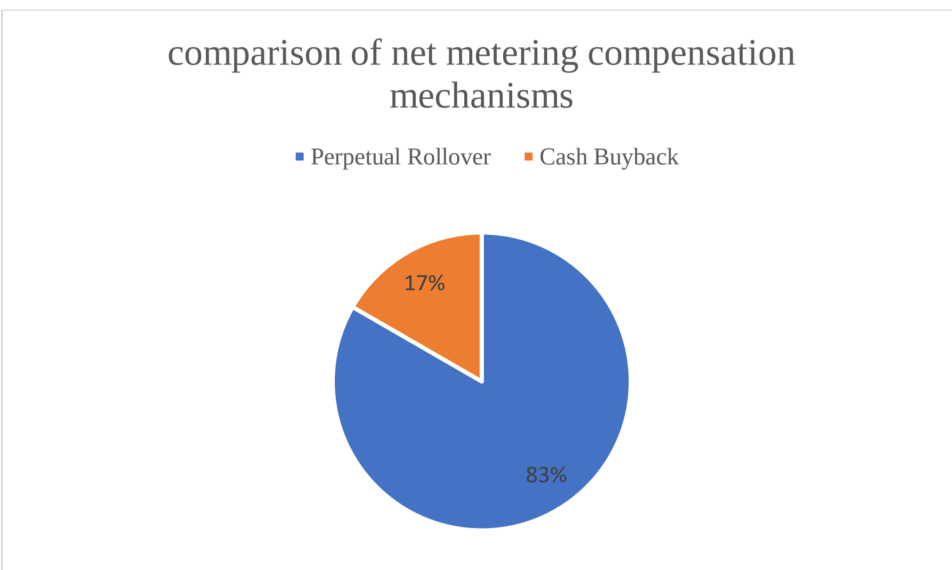

Figure 5.1: comparison of net metering compensation approaches

5.3 HOMER Implementation Outcome

5.3.1 System equipment configuration

A hybrid energy system consisting of solar PV and diesel generator was designed based on the loading system of KCL using HOMER. The equipment also includes a converter, and it's connected to the grid as can be seen in Figure 5.2. Although according to the software's rank of the systems simulated positioned grid connected solar PV alone as the most applicable alternative system for the factory based on NPC as its rank criteria, this study opted for the second ranked system (grid/PV/generator) for issues of grid unreliability.

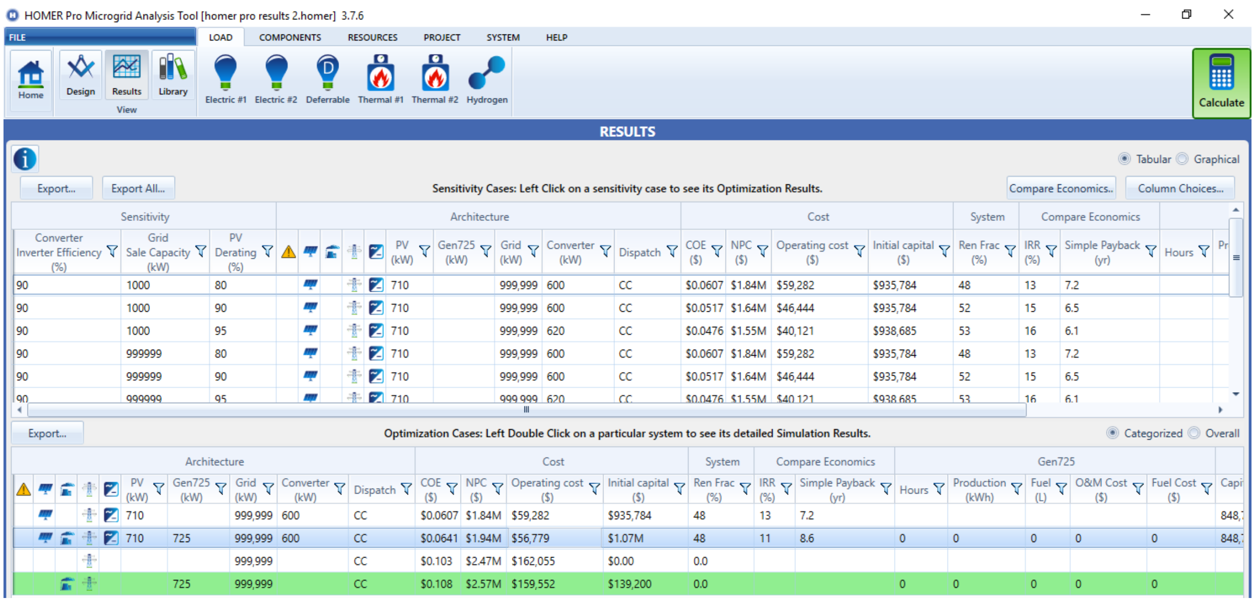

Figure 5.2: HOMER energy system' rank

Although the generator set is on the system, it's optimized to only operate in absence of PV and the grid power. The PV derating factor is set at 80% while the inverter efficiency stands at 90% according to HOMER sensitivity analysis. The system connected to the grid with net metering, therefore, there is sell back and purchase of electricity from the distribution network. This is set at a ratio of one to one (1:1) since there will be no physical monetary exchange but instead excess power is converted into renewable energy credits (RECs) of kilowatt-hours that are subtracted off from the monthly consumed units. These excess credits are valid indefinitely based on the net metering program chosen for this study. That is to say unused electricity in one banking period is transferred to another over and over again. The billing period was set for one month in HOMER.

5.3.2 PV system performance

The simulated annual PV system output is 1,066,478 kWh/year. With an average daily output of 2,921.86 kWh/d. See Table 5.1 and a monthly illustration in Figure 5.3 below. Maintenance of the PV wasn't considered because little or no maintenance is need for the panels (K. Ajao et al., 2011).

Table 5.1: PV production

Quantity	Value	Units
Rated capacity	710	kW
Mean output	122	kW
Mean output	2921.86	kWh/d
Capacity factor	17.15	%
Total production	1066478	kWh/year
Minimum output	00	kW
Maximum output	683.34	kW
PV penetration	68.03	%
Hours of operation	4380	Hours/year
Levelized cost	0.052	$/kWh

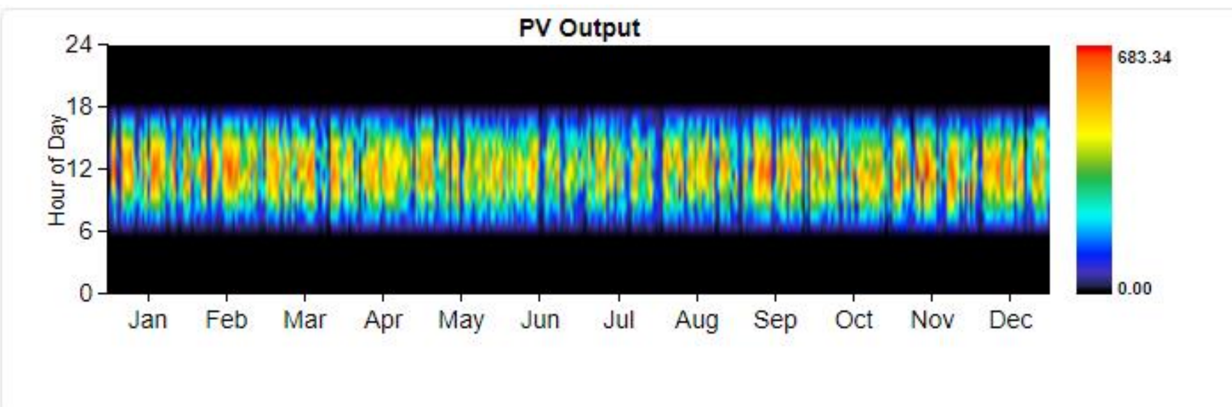

Figure 5.3: PV output throughout the year

5.3.3 Converter

Since KCL's load is for alternating current (AC), the inverter helps to convert the produced direct current (DC) from the panels to AC. The process of conversion comes with losses thus less of the produced PV electricity serves the load as shown in the Table 5.2 and elaboration of the inverter output in Figure 5.4 below. Again, no maintenance was considered just like for the PV (K. Ajao et al., 2011), only replacement after its specified lifetime of 15 years within the project life is considered. The efficiency of 90 % was assumed for the inverter.

Table 3.2: Inverter output

Quantity	Value	Units
Capacity	600	kW
Mean output	110	kW
Minimum output	0	kW
Maximum output	600	kW
Capacity factor	18	%
Hours of operation	4380	Hours/year
Energy in	1066426	kWh/year
Energy out	959783	kWh/year
Losses	106643	kWh/year

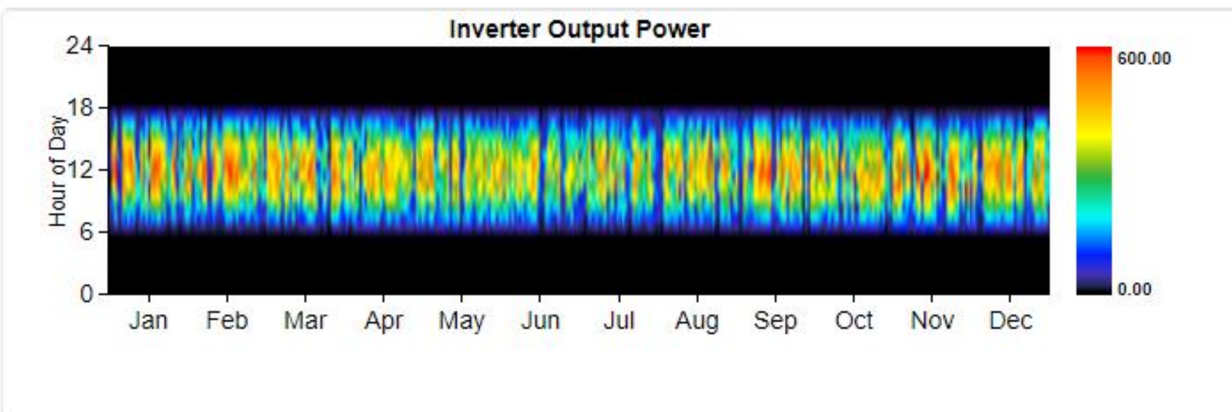

Figure 5.4: Inverter output throughout the year

5.3.4 PV and grid interaction

According to the simulation, the sized PV system serves approximately 50% of the monthly load and the rest of the electricity will be from the grid purchases as in the Figure 5.5 below.

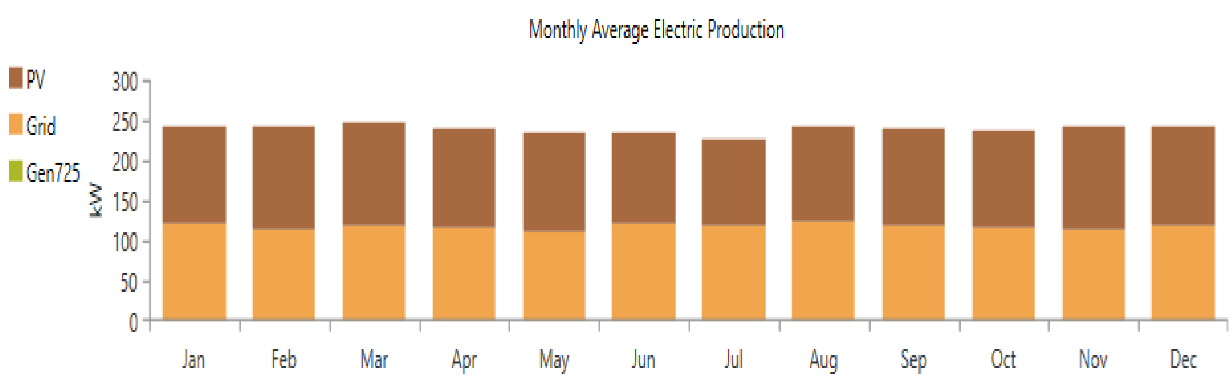

Figure 5.5: Monthly electricity share by source

5.3.4.1 Load offset

Figure 5.6 below is an hourly time series analysis detailing how PV production offsets most of the load. It clearly shows that if it wasn't for the losses due to the converter, much more load would be offset throughout the year. With a DC load, PV production would offset almost 70% of the load compared to the AC load in this analysis.

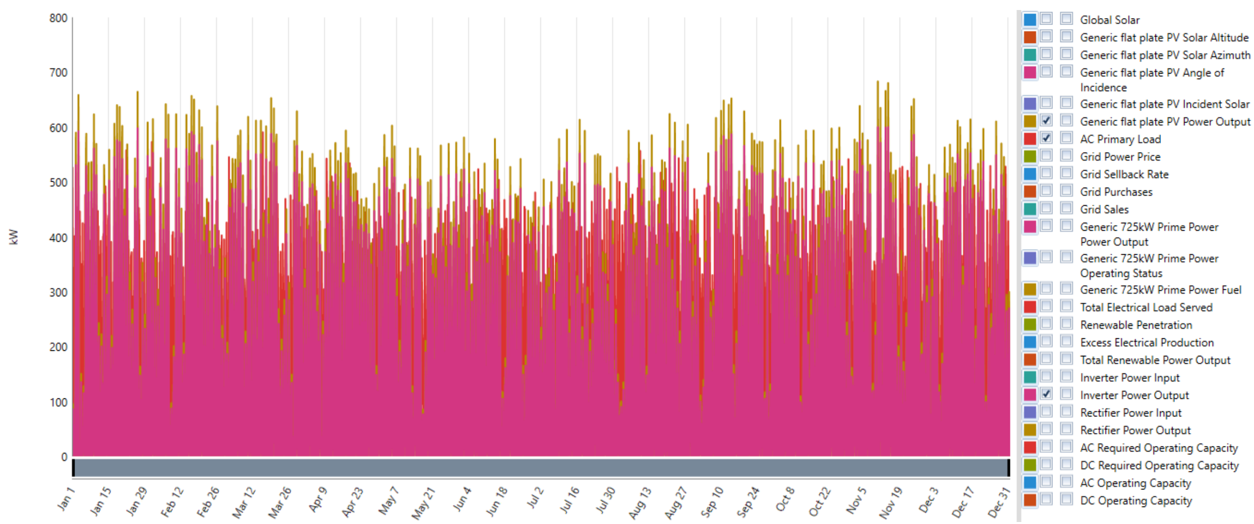

Figure 5.6: Analysis of PV system production versus the load

5.3.4.2 Grid sales and purchases

The grid sales and purchases with the designed system are shown in Figure 5.7 below. Annually, PV production stands at 51% leading to grid purchases of 49%. According to HOMER only 21% will be sold to the grid in year. Although purchases exceed the sales in the figure, there is more to save the customer than depending on the grid alone. Perpertual net metering as a supporting tool puts to use all the PV production. Therefore sales in the Figure 5.7 are in form of renewable energy credits that are rolled over indefinitely without physical exchange of money. Excess credits in form of kWhs are reduced from the consumed kWhs for a specific month

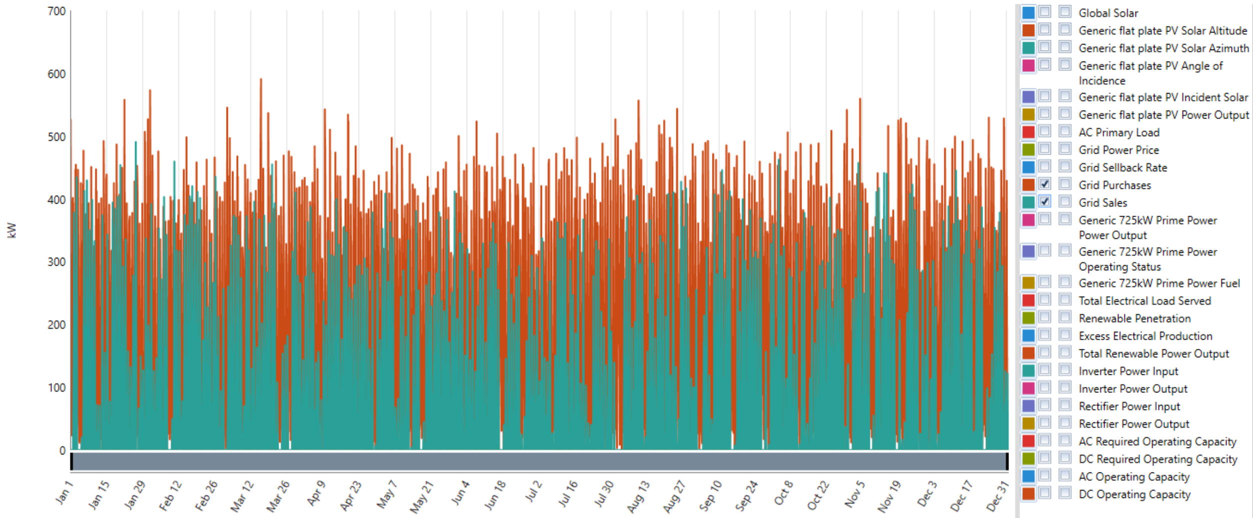

Figure 5.7: Analysis of grid purchases and sale

5.3.5 Comparison of solar hybrid energy system to the grid and/ or backed up with the generator

The selected alternative energy system (Grid/PV/diesel) has a total NPC of $194,1240, with a levelized cost of electricity (LCOE) $0.06407/kWh and an annual operating cost of $56,779.34 compared to the grid alone with NPC $2472,391, LCOE $0.1034/kWh, annual operating cost of $162054.6 and NPC $2573410, LCOE $0.1076/kWh, and annual operating cost of $159,552 for the grid with a backup generator. When the system is compared to the two systems based on econometric parameters in Table 5.3, it saves the customer $567,014 and $668,033 throughout the project life with grid alone and grid backed up with the generator respectively. The internal rate of return (IRR) is 10.3% and 11.4%. The simple and discounted payback periods of the solar hybrid energy system as compared to the grid alone and grid with a backup generator are as well shown in the Table 5.3.6 below.

Table 5.3: Comparison between solar hybrid system and grid alone and / or with a backup generator.

Metric	With grid alone	With grid backed up with the generator
Present worth ($)	567,014	668,033
Annual worth ($/year)	67,327	79,322
Return on investment (%)	10.3	11.4
Internal rate of return (%)	8.8	10.5
Simple payback (years)	9.89	8.57
Discounted payback (years)	13.08	10.86

5.4 Energy Bill Saving with Net Metering (validation)

Based on the simulated data from HOMER, the average daily PV production is 2921.86 kWh. However, since our primary load requires AC and PV produces direct current (DC), the inverter is used to convert this DC to AC. With the inverter's efficiency standing at 90% from HOMER, this means only 2629.54 kWh of the produced PV power serves the load. Therefore, using the monthly electricity bills collected from the grid customer (Kyagalanyi coffee limited) for the year 2015, net metering would save KCL up to a total of $195,484.6 in that year compared to $173,026.8 from PV without net metering program in place. Figure 5.8 shows the savings accrued in a particular month for the two cases while Appendix A., Table 3 shows the detailed calculation. If the trend is to remain the same throughout the project lifetime (25 years), the net metering case presents similar results of the payback period with HOMER's 9.9 years based on the total NPC of the system for the grid alone comparison. Considering only the system's capital investment, the simple payback reduces to 5.5 years. Taking 1% annual reduction in solar PV panel production due to aging and soiling (Severin Borenstein, 2008) while keeping all other factors constant, the payback period becomes approximately 10.4 and 5.6 years using total NPC and initial capital investment for the system respectively. All this validates the results from HOMER and justifies investment into this project instead of the customer depending on only the grid for all their energy needs. More benefits befall the grid customer than the utility itself when this net metering approach is implemented. Comparing the economic analysis of KCL's energy use in section 4.4 to the net metering scenario for the whole project life would save the grid customer, $488,7100.

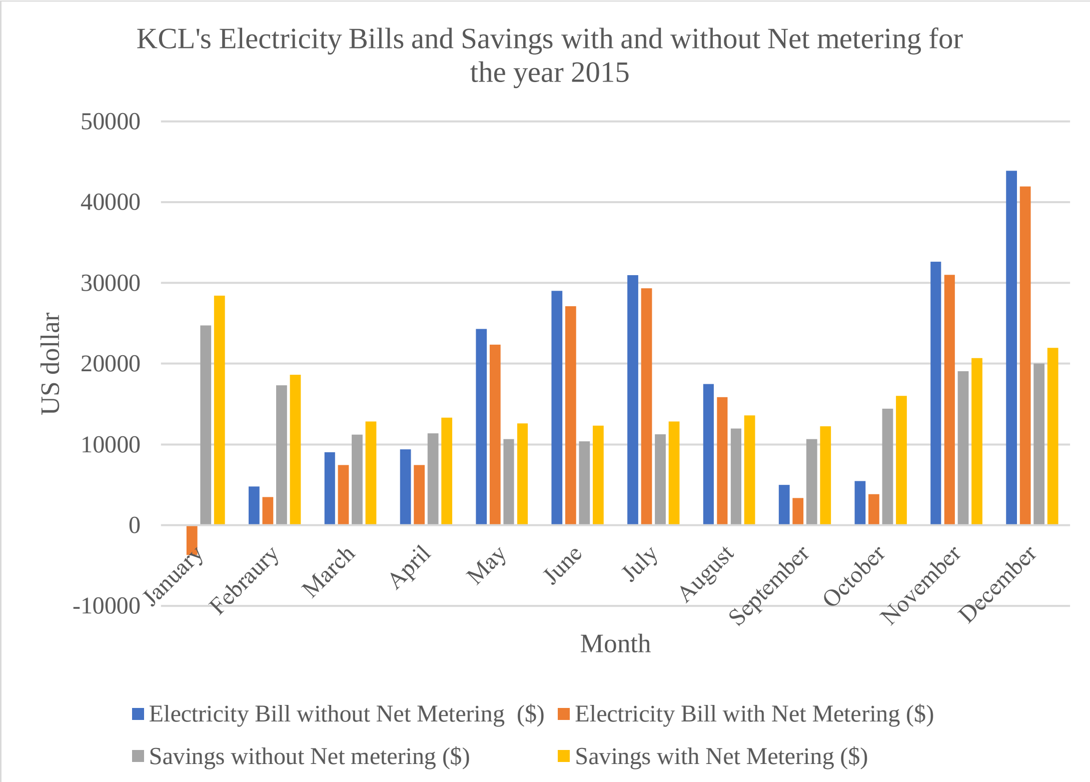

Figure 5.8: KCL electricity bills and savings with and without net metering

From the above Figure 5.8, taking 2015 as our base year and keeping other factors constant throughout the project life, KCL would generate more savings on electricity in January, followed by December, November, February, October, August, April then July, March, May, June and lastly September with net metering program in place. This is with respect to the seasons of coffee. In off seasons like January less electricity is required thus the load can be totally offset by PV production. With net metering in place, the same month would come with excess generation that can be used in the next month hence the negative sign of the bill as shown in the figure. Without net metering, the load will be offset, however, the excess is just forfeited to the grid if the system is connected to it. In case the system is not grid connected, storage units like batteries can be used, however, this would lower the affordability of the system since storage units are so expensive and last for a limited timeframe with in the project life. For batteries, they may require to be replaced approximately four times within the project lifespan of 25 years (Madani et al., 2015). Therefore, this would increase the operation expenses of the project leading to almost a negative cash flow.

CHAPTER 6: DISCUSSION OF RESULTS

The percentage tariff rate increment in Uganda reached its highest peak in 2006 when UMEME had just won its 20-year concession and then shooting high again in 2012 according to Figure 1.6. This increment is majorly due to the increasing inflation rate in the country that makes the currency so unstable, high marginal costs for electricity generating projects since more concentration has for the past years been majorly on large scale power generating facilities particularly hydropower, increasing operation and maintenance costs, and distribution and transmission losses. Until Uganda starts thinking small scale power production for example encouraging distributed generation, the electricity end-users are still suffering with this increasing tariff rate. The tariff rate changes four times in a year according to UMEME and ERA [ERA, (2017), UMEME, (2017)]. The year is divided into quartiles i.e. first, second, third and fourth quarters. The probability of rates increasing in any quartile is higher than an expectation of a decrease. Therefore, commercial and industrial electricity users who wish to remain relevant and competitive in the business are better off thinking self-consumption since it comes with more merits in addition to energy bill saving optimized with net metering policies.

From the data analysis and collection, Figure 4.2 shows that KCL employs a load management technique called load leveling in which it shifts its load to the valley times during off peak hours and shoulder periods of the day and very limited during peak periods.

The Ugandan electricity grid's reliability is unpredictable. This is majorly caused by dependence on one source (hydro) for power production and use of old technology. Any fluctuations in the volumes of water causes a reduction in power generated compared to the installed capacities. This situation was at its worst in 2012 [UEGCL, (2013), Tungaraza et al. (2012)] when water levels in Lake Victoria reduced due to a prolonged drought. Currently, though there has been improvement in the reliability of the grid to a limited extent in a few places in the country, there is still much more need to have a backup plan in place especially for businesses. Therefore, an alternative energy system needs to front the reliability factor by having a backup plan hence the choice for the second positioned HOMER simulated energy system with an optimized generator instead of the first one with grid connected solar panels only.

Solar hybrid system when compared to the grid and /or backed up with the generator, it's much better and saves the customer money, $567,015 and $668,033 respectively. This proves this study's hypothesis that distributed generation is a better energy system for large scale consumers than the centralized system in Uganda. The system's simple annualized payback period as well as its discounted payback periods are relatively shorter for business investment. The 9.9 and 8.6 years for simple payback, 13.1 and 10.9 years for discounted payback period for grid and grid backed up with generator respectively are just reasonable enough for investment. Therefore, based on the current Ugandan situation, it's better for a business to run on a solar hybrid alternative power generating system than on only the grid/ and or backed up with a generator system that most factories are employing currently. To medium and small factories like maize and coffee milling, the systems can even be much cheaper and affordable. Large industries which may require systems with very high upfront capital, can opt for loans since it's much simpler for them than residential owners.

From the net metering survey responses as well as the analysis of results, perpetual roll over of credits is the best Ugandan contextual approach for implementation compared to buyback mechanism. This is because the approach requires less monitoring and books of accounts compared to the other alternative. Also, the customer loses no excess electricity produced no matter when. All these factors combined makes the approach a preferable tool. In order for customers to optimize their savings as far as the energy bill is concerned, there is need for them to be part of a net metering program. This is because, from the analysis in section 5.4, it's validated that a net metered system would pay back after 9.9 years on a project life of 25 years. Considering only the initial capital investment, the payback period reduces to 5.5 years. This makes the project worthy investing into. Net metering yields more savings within a year ($195,484.6) than distributed generation without net metering. Therefore, this proves the hypotheses that net metering produces more savings for large energy consumers in Uganda than any other system, and as well reduces electricity bills.

CHAPTER 7: CONCLUSION AND RECOMMENDAIONS

KCL's efforts of reducing its energy consumption accompanied by the ecological mindset behind most of its projects can best be achieved through energy integration and net metering as the results of this study have demonstrated. With the generator set already in place as their backup energy source, this proposed system becomes even more achievable in terms of cost. This will improve the reliability of the system whenever PV production and the grid are unavailable.

As the aim of this study, the best way in which grid customers can reduce their energy expenditure is through energy integration and net metering compared to depending on only the grid as their sole energy provider or backed up with the generator. Distributed generation with a major focus on self-consumption according to Hugo & Juan, (2017) has a lot of advantages. One of such advantages is reduction of energy expenditure that this study has demonstrated. Reliability, security, energy independence are all factors that grid tied customers should think about to undertake embedded generation projects like solar PV. The government can as well induce these industrial customers into distributed generation for self-consumption through introduction of emission charges and rewards for less polluting customers.

Net metering is one way how such customers can optimize their savings so it's just appropriate if the government establishes it. However, since policies can either be through a top-down or bottom up approach, electricity end-users can a well influence ERA to establish the policy in place. Among the various advantages of net metering, acting as an additional capacity to the utility without incurring any cost of investment in generation, distribution and transmission or purchasing power from the external market is so relevant to the current electricity situation of Uganda. This is because the above avoided costs have a direct impact on the tariff design for any utility, therefore net metering will help to stabilize the escalating tariff rates in the country.

The net metering policy that can suit the Ugandan context according to this study should allow for indefinite roll over of renewable energy credits. This will easily be adopted by the network distributor UMEME since it requires limited administrative procedures and there is no physical monetary exchange. In most cases utility companies are hesitant in accepting the net metering programs because they don't wish to give out what they have collected. To the customers, it will keep them in check in order not to oversize their systems for benefits' sake especially if the program covers residential too. Additionally, since there is no credit that goes unused, it saves the customer from high electricity charges during times of high demand but with low PV production.

In order to encourage industries to take part in this net metering program, its size cap limit should be put to atleast 5 MW since these are large scale consumers. This will not only encourage more customers to join the program but will also make PV highly competitive on the electricity market.

The government can choose to limit the net metering program to the group of customers that it wants to support. This study recommends that the program covers all customer categories from residential to industrial customers. If residential customers are inclusive, third party ownership should be allowed to enable those without the initial capital to enjoy the benefits of the program.

I recommend use AHP to validate the results of this study. Use of different rates; peak, Off-peak and shoulder to expand the study as well as data (electricity bills) covering the whole project life to validate the method used here is recommended.

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Appendix

A.

Table 1: Tariff trends for different electricity customers

Year	Domestic	Commercial	Large Industries
2004	171.4	164.8	60.4
2005	202.225	194.5	69.025
2006	289.5	283.125	140.625
2007	361.775	359.7375	246.8667
2008	397.3875	393.2875	286.9
2009	403.2	400.1	296.0667
2010	393.075	390.925	296.4333
2011	395.3833	386.2	297.6
2012	436.6213	419.1833	353.6642
2013	473.0033	425.6583	360.3967
2014	512.1417	463.5343	368.4317
2015	540.3935	503.9468	393.3675
2016	595.061	565.144	413.0917

Table 2: KCL's load data

Time range	P _Avg. (kW)							
	19/05/2017		20/05/2018		21/05/2019		22/05/2020	
	Transf. 1	Transf. 2	Transf. 1	Transf. 2	Transf. 1	Transf. 2	Transf. 1	Transf. 2
0014-0114hrs	40.45	325.8	41.5	328.2	39.4	327	41.2559	323.65
0114-0214hrs	41.11	293.5	40.356	300.78	38.359	290.3376	35.58	295.61
0214-0314hrs	40.18	280	41.45	280.45	50.76	275.87	40.4999	283.7
0314-0414hrs	39.7	273.7	42.55	275.56	43.49	285.45	32.1403	280.35
0414-0514hrs	39.59	302.7	35.98	315.8	36.43	300.78	32.65	300.75
0514-0614hrs	38.74	284.1	45.65	296.5499	29.72	280.98	38.65	282.34
0714-0814hrs	37.3	256.8	38.78	265.7	39.23	260.5	35.67	255.49
0814-0914hrs	45.48	210.3	39.06	220.56	40.44	218.2322	42.56	195.72
0914-1014hrs	50.19	173.34	46.8	200.34	51.54	175.64	46.37	185.38
1014-1114hrs	53.44	151.62	50.45	163.5	43.44	155.32	50.46	154.35
1114-1214hrs	58.58	186.21	60.67	182.91	55.36	180.38	55.63	188.64
1214-1314hrs	60.45	125.35	57.234	129.23	56.76	130.378	49.65	115.458
1314-1414hrs	62.14	101.18	65.98	125.76	61.21	99.657	53.2	105.346
1414-1514hrs	42.89	102.19	45	115.85	42.8099	100.457	35.78	101.753
1514-1614hrs	29.69	119.19	25.1453	125.43	30.55	110.754	30.43	115.763
1614-1714hrs	29.04	84.4	33.56	80.1	25.22	79.3	30.977	83.44
1714-1814hrs	22.95	22.548	25.65	20.7	24.96599	25.443	20.59	23.58
1814-1914hrs	23.65	14.075	24.335	22.2	30.68	20.534	19.45	15.14

1914-2014hrs	26.65	14.049	27.112	28.29597	14.65	22.45	16.43	14.566
2014-2114hrs	30.7	14.037	33.65	15.79	25.86	19.563	25.47	15.123
2114-2214hrs	24.9	14.27	26.86101	13.53	23.34	18.564	23.54	14.546
2214-2314hrs	21.78	14.335	25.59502	14.32	22.17	18.465	19.112	15.03
2314-0014hrs	20.025	14.554	20.02	17.17	19.41802	17.467	14.36	32.574
0014-0114hrs	21.54	14.828	25.86	22.06	20.54	15.547	15.38	17.245

P _Avg. (kW)						
23/05/2021		**24/05/2022**		**25/05/2023**		**Day hrly Avg.**
Transf. 1	**Transf. 2**	**Transf. 1**	**Transf. 2**	**Transf. 1**	**Transf. 2**	
37.55	325.7743	38.72	326.64	40.36	327.45	366.25
39.3022	290.7	41.987	295.4	42.797	296.451	334.61
39.37	270.3	32.19	282.23	35.7	288.56	320.18
36.79	265.67	38.34	276.89	29.45	273.72	313.40
33.59	299.67	40.4	329.64	41.32	286.73	342.29
40.32	284.3	33.2	285.38	29.45	290.5	322.84
40.378	245.68	42.69	242.362	39.36	258.76	294.10
39.12	220.35	36.498	225.09	44.38	212.67	255.78
32.75	179.2601	36.82	171.47	38.35	176.46	223.53
55.67	161.42	52.746	150.346	45.86	146.798	205.06
73.2702	183.63	40.53	191.48	66.48	189.76	244.79
56.93	134.854	57.87	133.1283	69.65	123.658	185.80
62.89	110.654	53.97	80.3332	59.27	101.65	163.32
36.673	105.378	41.34	95.34	50.3	99.799	145.08
25.67	119.78	35.67	120.36	38.6	115.128	148.88
32.68	90.46	25.77	85.39	29.4	84.343	113.44
18.4	24.76	17.37	27.35	20.5	23.679	45.498
15.467	12.56	20.64	14.52501	16.16	14.659	37.725
19.687	16.55806	21.68	19.435	29.68	13.65	40.699
21.76	14.67	23.58	19.57	37.51	15.876	44.737
21.68	12.578	27.86	18.62	18.573	15.328	39.170
19.287	12.973	20.18	18.124	26.87	4.564	36.115
12.74	12.374	13.65	15.356	17.56	14.785	34.579
17.37	12.573	18.34	15.908	21.64	15.745	36.368

Table 3: Energy saving with and without net metering

Tariff Rate = $0.122927, Inverter Daily Output = 2629.54 kWh

Month	Monthly Electricity Bill (UGX)	Monthly Electricity Bill ($)	Total Units Consumed (kWh)	Useful PV Production Without Net metering (kWh)	Grid Purchases without Net Metering (kWh)	Electricity Bill without Net Metering ($)	Savings without Net metering ($)	PV Production with Net Metering (kWh)	Grid Purchases with Net Metering (kWh)	Electricity Bill with Net Metering ($)	Savings with Net Metering ($)
December	204533602	63916.75063	422755	65738.5	357016.5	43886.9673	20029.78333	81515.74	341239.26	41947.51851	21969.23211
November	165446378	51701.99313	331111	65738.5	265372.5	32621.44531	19080.54782	78886.2	252224.8	31005.23799	20696.75514
October	63569463	19865.45719	112731	68368.04	44362.96	5453.405584	14412.0516	81515.74	31215.26	3837.198266	16028.25892
September	49974350.53	15616.98454	106191	65738.5	40452.5	4972.704468	10644.28007	78886.2	27304.8	3356.49715	12260.48739
August	94206011	29439.37844	210522	68368.04	142153.96	17474.55984	11964.8186	81515.74	129006.26	15858.35252	13581.02591
July	135005483	42189.21344	320177	68368.04	251808.96	30954.12003	11235.09341	81515.74	238661.26	29337.91271	12851.30073
June	126104132	39407.54125	299332	63108.96	236223.04	29038.18964	10369.35161	78886.2	220445.8	27098.74086	12308.80039
May	111889428	34965.44625	263341	65738.5	197602.5	24290.68252	10674.76373	81515.74	181825.26	22351.23374	12614.21251
April	66457087	20767.83969	139625	63108.96	76516.04	9405.887249	11361.95244	78886.2	60738.8	7466.438468	13301.40122
March	64802803.32	20250.87604	141937	68368.04	73568.96	9043.611546	11207.26449	81515.74	60421.26	7427.404228	12823.47181
February	70690700	22090.84375	101933	63108.96	38824.04	4772.522765	17318.32098	73627.12	28305.88	3479.556911	18611.28684
January	79131367	24728.55219	51337	65738.5	0	0	24728.55219	81515.74	-30178.74	-3709.781972	28438.33416
Total	**1231810805**	**384940.8765**	**2500992**	**791491.54**	**1723901.96**	**211914.0962**	**173026.7803**	**959782.1**	**1541209.9**	**189456.3094**	**195484.5671**

B.

Net metering survey questionnaire

This survey is meant to understand the best net metering compensation approach applicable in the African/Ugandan context. Please assist the researcher to score the factors below in accordance to the subject above. Two minutes of your time will be highly appreciated.

Name (optional):

Years of experience in the energy sector (optional):

Question one: What's your knowledge level above net metering?

Score: ☐ High ☐ Moderate ☐ Not knowledgeable but heard of it

☐ Not knowledgeable and never heard of it

Please provide your score for the factors below, the numbers are represented as follows;

1- Very low 2- Low 3- Moderate 4- High 5- Very high

Factor	**Compensation mechanism**	
	Perpetual rollover	**Cash buy back**
Customer satisfaction		
Implementation costs		
Administrative burden		
Utility Company satisfaction regarding impact on revenues		