RESEARCH REPORT

Opportunities and Challenges for Distributed Generation with Rooftop Photovoltaic (PV) for Uganda: A case study of Crusader House, Kampala

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A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in fulfilment for the degree of Master of Architecture (Sustainable Energy Efficient Cities).

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DECLARATION

I, **Ceaser Migisha** declare that this report is my own unaided work except where otherwise acknowledged. It is submitted for the degree of Master of Architecture in the field of Sustainable Energy Efficient Cities to the University of the Witwatersrand, Johannesburg, South Africa. It has not been submitted before for any degree or examination at any other University.

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ABSTRACT

Distributed generation with rooftop PV technology is increasingly attracting attention as a strategy to enhance energy security for cities and as a critical climate-change mitigation intervention globally. In order to interrogate the strategy for a developing country context, the study applies a case study approach to explore responsive business models as well as related opportunities and challenges of DGRTPV deployment in Uganda, given the country's advantage of abundant solar radiation as a result of favourable location across the equator. The study substantiates on the research question which focuses on rooftop PV business models, policy and legislation environment, energy efficiency interventions and financial mechanisms for expedited adoption of the technological innovation for commercial buildings in Uganda. In order to substantiate on the working hypothesis, interviews were conducted with key informants from the case study building-occupants and property manager, MEMD, ERA, KCCA, and UMEME. Data were collected using semi-structured interviews as well as energy audits and energy performance simulations of the case study building based on Excel and Design-Builder Energy-Plus software in order to ascertain performance under alternative intervention scenarios.

The case study building consists of two blocks (the main block which is 5 storeys and the annex which is 4 storeys) and is grid-connected, but has standby generator with diesel consumption of up to 4,800 litres/year. The building was built in 1988 for the main block and 1993 for the annex and no energy efficiency interventions have been implemented so far. Overall, the baseline energy consumption is at 191,127.5kWh/year excluding diesel generation at 100,000kWh/year (2010 blackouts were 8 hours per day but at present, the generator is used for only 2 hours per day). Simulations, manual calculations, and economic feasibility appraisals were applied to guide on the viable energy efficiency and photovoltaic (PV) interventions. This resulted into viable energy reduction of 90,404.5kWh/year with a payback period of 0.6 months for lighting systems and additional energy efficiency interventions. Rooftop PV generation evaluation indicated an output of approximately 124,328.75kWh per year with the payback period of 7.6 years.

Overall the study finds that the roof space area (610m^2) of the building offers potential for generating surplus electricity which can be fed to the grid when responsive policy/regulatory environment is effected. The solar service business model is prioritised as the most viable given the current policy/regulatory landscape for Uganda as well as envisaged policy changes in the short term. Given Uganda's low-carbon electricity generation mix, the study finds that opportunity for carbon emission reduction for the building would mainly arise from the displacement of the standby diesel generator whose current emission is estimated at 4,000kg/year. The study therefore concludes that DGRTPV deployment is now mature for scale-up in commercial buildings for Uganda.

Keywords: Policy and legislation, business model, distributed generation, energy efficiency, CO_2, and rooftop PV

DEDICATION

In Virtute ET Sapientia (In virtue and wisdom), I dedicate this work to my dad Mr. Maxima Migisha. There is no precious gift than the love you have given me throughout my entire life and studies. You sacrificed all your projects and plans because of the love and zeal to ensure that I study this Masters in Architecture. There is no big reward I can give you but to pray to God such that He can open all the doors of all your endeavours.

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AEDC	Austrian Embassy Development Cooperation
BMs	Business Models
BSL	Bunyonyi Safaris Limited
CEO	Chief Executive Officer
CHOB	Crusader House Office Building
CFLs	Compact Fluorescent Light bulbs
CRT	Cathode-Ray Tube
DB	Design-Builder
DG	Distributed Generation
DGRTPV	Distributed Generation with Rooftop Photovoltaic
DSPV	Distributed Solar Photovoltaics
EE	Energy Efficiency
EER	Energy Efficiency Retrofits
EPBT	Energy Payback Time
EIA	Environmental Impact Assessment
EPC	Engineering Procurement and Construction
EPW	Energy Plus Weather
ERA	Electricity Regulatory Authority
ESCOs	Energy Service Companies
FIT	Feed in Tariffs
FMO	Financierings-Maatschappij voor Ontwikkelingslanden N.V
GDP	Gross Domestic Product
GETFIT	Global Energy Transfer Feed in Tariffs

GHG	Greenhouse Gas
IFC	IFC - International Finance Corporation
IEA	International Energy Agency
IPPs	Independent Power Producers
IRENA	International Renewable Energy Agency
JFD	Judiciary Family Division
KCCA	Kampala Capital City Authority
KfW	Kreditanstalt für Wiederaufbau
km^2	Square kilometre.
kWh	Kilowatt hour
LCA	Life Cycle Assessment
LCD	Liquid Crystal Display
LCOE	Levelised Cost of Electricity
LED	Light-Emitting Diode
kWp	Kilowatt peak
m^2	metres squared
MEMD	Ministry of Energy and Mineral Development
MEPS	Minimum Energy Performance Standard
MFP	Multi Functional Printers
MFPED	Ministry of Finance Planning and Economic Development
MTN	Mobile Telecom Network
MW	Megawatts
NEP 2002	National Energy Policy of 2002
OECD	Organization for Economic Cooperation and Development

PPAs	Power Purchase Agreements
PPP	Public Private Partnership
PROFIRA	Project for Financial Inclusion in Rural Areas
PSFU	Private Sector Foundation Uganda
PSH	Peak Sun Hours
PV	Photovoltaic
R&D	Research and Development
RE	Renewable Energy
REP 2007	Renewable Energy Policy 2007 of Uganda
RET	Renewable Energy Technology
RETD	Renewable Energy Technology Deployment
REFIT	Renewable Energy Feed-in Tariff
RIA	Regional Investment Agency
ROI	Return On Investment
SLA	Service Level Agreements
Sq.m	Square metres
SPE	Special Purpose Entity
UGX	Uganda Shillings
UECCC	Uganda Energy Credit Capitalisation Company
UETCL	Uganda Electricity Transmission Company Limited
UIA	Uganda Investment Authority
UNEP	United Nations Environmental Program
USEA	Uganda Solar Energy Association

CHAPTER 1 INTRODUCTION

1.0. An overview of Uganda's solar potential

Uganda is a landlocked country located in the great lakes region of East Africa and along the equator between latitudes 4°N and 2°S and longitudes 29º and 35°E. The country's total land area is approximately 213,000 km^2 (Twaha *et al*, 2016:788).

The country has for long been dependent on hydropower as the main source of electricity. The level of electricity supply and access by the population (estimated at 38 million people) remains low and consumers connected to the grid are faced with frequent power outages. Twaha *et al*., (2016) state that "the total installed generation capacity of Uganda is around 820.5MW and the available (usable) generation is 558.5MW, peak demand is about 487MW and the annual average load growth is 10%." In addition, the authors state that the country's power sector is suffering from a shortage of generating capacity due to lengthy droughts and inadequate investment in the least-cost generation capacity. The power deficit is estimated at 130MW. The 2005/2006 massive energy crisis (which served as a critical driver for government to support renewable energy (RE) generation) made the country realize that it cannot entirely depend on hydropower for its economic development and access to electricity for all. Hence, it was a call for exploration of renewable energy technologies (RET) such as distributed generation with rooftop photovoltaic (DGRTPV) which offers an opportunity to enhance electricity supply and affordability.

The country is gifted with abundant energy resources such as solar, peat, bagasse (thermal), wind and hydropower which can be considered as an opportunity for generating sufficient capacity to meet the energy demands of its growing population and especially for the commercial sector (Twaha *et al*., 2016). According to the Uganda National Meteorological Authority reports and Twaha *et al*. (2016), the central region (where CHOB case study building is located) of Uganda has solar radiation range of 4.8-5.6kWh/m^2/day on the horizontal surface and the country has peak solar radiation of 5-6kWh/m^2/ day on the horizontal surface. This signifies an outstanding solar energy resource. The mean solar radiation of 5.1kWh/m^2/day on the horizontal surface implies the country has a gross solar energy potential of about 11.98x10^{8}MWh/year. At an estimated conversion efficiency of 10%, Twaha *et al*. (2016) observe that these rates would yield electricity generation of 3,422kWh per capita per year once all these abundant natural resources such as solar are utilized.

Despite these resource opportunities, they are not fully utilized, thus rendering the country with only 12% of the population having access to grid electricity by 2010. Currently, Electricity Regulatory Authority (ERA) of Uganda state that 23% of the population have access to grid-connected electricity and this drops to about 10% access in rural areas. According to Murphy, Twaha, and Murphy (2014:523), "Lack of access to affordable energy hinders economic growth and human development, and that increased energy consumption correlates with increased GDP (gross domestic product) and HDI (human development index) scores."

On the broader economic development perspective, Uganda's economy has been predominantly supplemented by budgetary resources from donor funds. The discovery of oil in the western rift valley (around Lake Albert) has increased the revenue base which thus addresses the country's budget deficit to some extent. Whereas this entails an increase in revenue, it comes at a high environmental cost because of the related carbon emissions. There is a great opportunity to channel the revenue drawn from the non-renewable resource towards generating clean energy on the basis of distributed generation with solar rooftop photovoltaic investment (Twaha *et al.*, 2012).

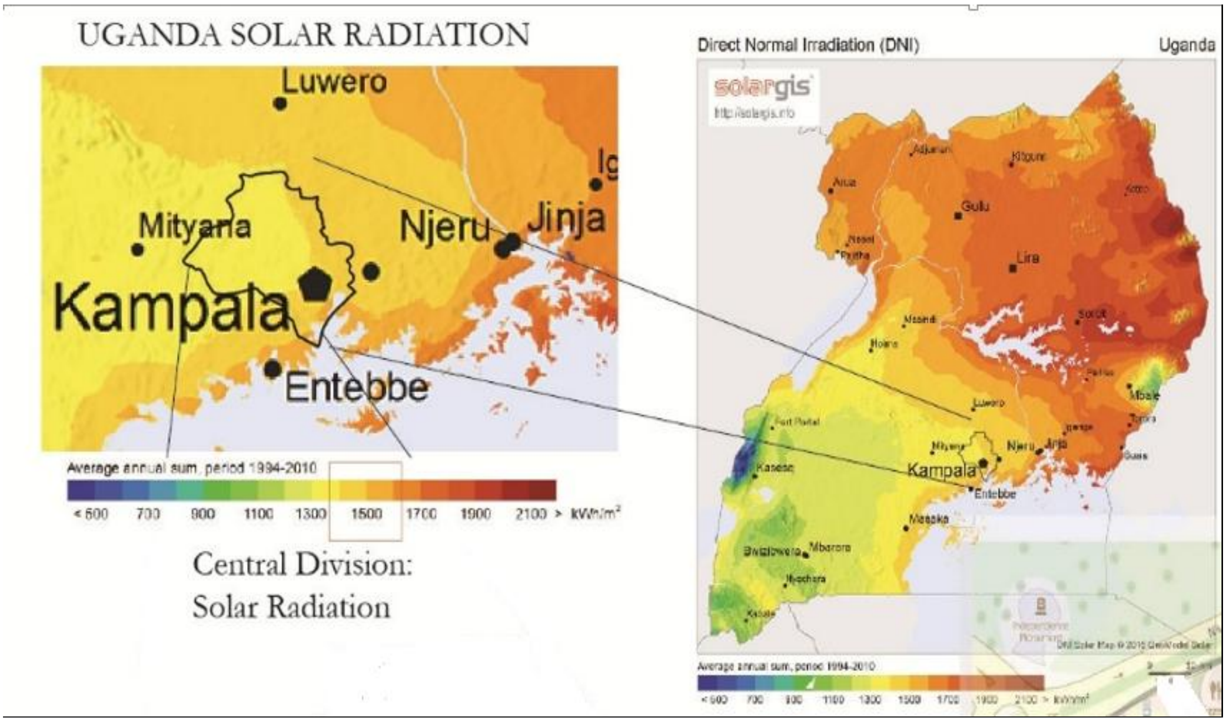

Figure 1: Uganda's solar resource: **Source:** solargis (2015)

1.1 Background and context

Photovoltaic (PV) solar energy is one of the fastest growing energy-sector industries globally. This growth of the PV market is driven by increased oil prices and rapidly falling PV module costs due to ongoing innovations completed by economies of scale as increased volumes in production materialise in response to growing demand globally.

1.1.1 Solar in developed countries

Goel (2016) states that the United States of America (USA), Canada, European Union (EU), Japan, China and India were the early starters and leading countries in solar energy research and development between 1960-2005. Currently, Germany, China, Italy and USA are leading in solar capacity as at March 15, 2016 (*ibid.*). China was heavily dependent on coal (68.75%) for electricity before they introduced the Renewable Energy Law in 2005 to facilitate renewable energy generation. The law was supported by regulations and guidelines adopted from the German renewable energy policies. For RE technology diffusion, the Chinese government ensured public participation, training of manpower skills, as well as ongoing research and development.

1.1.2 Solar technology adoption in developing countries

According to Aslani and Mohaghar (2013); Balachandra *et al.* (2010); Martinot *et al.* (2002); Reddy and Painuly (2004) and Zyadin *et al.* (2014) (cited in Gabriel and Kirkwood (2016)), there is a considerable demand and research interest towards increasing the uptake of renewable energy technologies (RETS) such as solar distributed generation with rooftop photovoltaic (DGRTPV). However, the commercial use of RETs remains largely restricted to niche markets (Balachandra *et al.*, 2010) and (Martinot *et al.*, 2002). The diffusion status of most RETs is described as being in the 'pre-commercial' and 'support commercial' stages of growth (Balachandra *et al.*, 2010), as they still lack systematic institutional support. Developing countries still lack the strong regulatory support necessary to facilitate technologies such as DGRTPV uptake (Jackson (2011); Walsh (2012)). Consequently, there is a slow uptake and adoption of RETs in those countries.

In order to keep the pace with developed countries, Wiginton *et al.* (2010) state that understanding the rooftop PV potential is critical for utility planning, accommodating grid capacity, deploying financing schemes and formulating future adaptive energy policies. Balachandra *et al.* (2010) cited in Gabriel and Kirkwood (2016) observe that the efforts to commercialize RETs in developing countries has largely remained as stand-alone government-sponsored initiatives.

However, the experience with such government driven strategies in developing countries over the past three decades is not so encouraging. There is an urgent need of the private sector involvement in the commercialization efforts of RETs (commercialization refers to the creation of self-sustaining markets that thrive without any kind of favour and within a level playing field with other competing technologies). Huijben and Verbong (2013) and Johnson (2010) suggest that innovations in business model scenarios are essential drivers for renewable energy technologies like DG with rooftop PV in the market as they serve as a guide to management tools to change, operate, implement and control a responsive business in the market/sector.

1.1.3 Solar market segments in Uganda

The solar market in Uganda can be segmented into five categories which are:

- Solar home systems (SHS) for households
- Institutional PV systems mostly applied in schools and hospitals
- Telecommunication satellites systems
- Utility scale such as the recently commissioned Soroti solar grid-connected plant
- Mini-grids and micro-grids in the northern Uganda and Lake Victoria islands

The solar energy market has steadily grown over the last 15 years with new players, both local and foreign investors such as B box (British) company and MKOPA (Kenya), gaining attraction into the market with their ‘pay as you go’ business model for solar home system application mostly targeted at rural areas. Currently, Uganda has nine electricity distribution companies across the country with UMEME company limited being the main distributor of hydropower in the city. West Nile Rural Electrification Company (WENRECO) and Kalangala Infrastructure Services are the only companies dealing with grid-connected solar energy and off-grid for Northern Uganda and Central region on Bugala Island in Kalangala District respectively. These organizations generate and distribute solar power for both urban and rural areas in those regions. Regulations guiding the operations of these companies could therefore be reviewed to guide projects for DGRTPV for existing office buildings. Despite the foreseen challenges that would be posed by UMEME's market dominance, an appropriate business model coupled with responsive regulatory framework could enhance full deployment of rooftop PV.

It is estimated that only around 1.1MW of solar PV capacity is currently installed off-grid across the country (Twaha *et al.,* 2016:792). This includes both institutional and solar home systems. According to ERA (2016), a total of 40MW of solar energy projects have been licensed and will be commissioned to supply the national grid once completed. These include 10MW in Tororo District, 10MW in Soroti (commissioned in 2016 and financed by Global Energy Transfer Feed-in Tariffs (GEFiT)) and 20MW in Kabulasoke in Mpigi District. It is reported that the Tororo private investor had applied for 50MW and the proposal was rejected over the concerns on grid instability, and especially with solar generation being intermittent in nature. Despite the solar intermittence, the Feed-in Tariff of USD 11 cents per kWh for grid-connected solar energy (as approved in 2014 by ERA) is expected to drive several rooftop PV investors and therefore likely to constitute a strong incentive for full deployment of DG with rooftop PV, net metering adoption and an increase in Uganda's Gross Domestic Product (GDP).

1.1.4 Energy efficiency and retrofit concept

According to Ma *et al.* (2012) and Rysanek and Choudhary (2013), adoption of DGRTPV systems is often enhanced by energy efficiency and retrofit policies such that retrofitting of existing buildings offer significant opportunities for reducing energy consumption and greenhouse gas emissions. Therefore, the effectiveness of a building retrofit depends on building-specific information such as geographic location (and related climate regime), building type, size, age, occupancy schedule, operation and maintenance, energy sources, utility rate structure, building fabric and related service systems. Lastly, experts report that buildings without the required intervention negatively impacts on occupants' productivity and performance at their workstations especially within poorly ventilated spaces.

1.1.5 Carbon emission in commercial/institutional facilities in Uganda

There is limited data on carbon emission in existing commercial buildings of Kampala (especially on the energy mix which includes mainly hydropower and use of standalone diesel generators). However, Lwasa (2013) notes that energy generation indirect carbon emission in commercial/institutional facilities of Kampala is 10,972.5 tonnes of carbon dioxide equivalent (tCO_2e) while the direct emission is 797,821tCO_2. In 2014, it is reported by Knoema (2017) that the carbon dioxide emissions as result of energy consumption in Uganda is 4 million metric tons. The country's emissions increased from 1 million metric tons in 1995 to 4 million metric tons in 2014 growing at an average annual rate of 9.07 %. In 2016, the study reports that Uganda's carbon emission per capita is 0.12 metric tons and the carbon intensity is 0.07kg per 1000 dollar GDP.

1.2 Problem statement.

Uganda's population increase (38 million as of 2015 population census) and ongoing economic growth (GDP growth rate range for 2013-2017 is 5.0%-7.5%) as demonstrated by a boom in the construction of commercial buildings in Kampala has contributed to excess demand on limited hydroelectricity supply thus impacting on all consumers. Several consumers have therefore resorted to combustion of fossil fuels for generators as an alternative source of power during the prolonged outages, thus contributing further to greenhouse gas emissions, climate change and air pollution (Hootman, 2013; Twaha *et al*., 2016; Sampaio and González, 2017). Therefore, there is an urgent need for renewable energy technologies such as DGRTPV towards ensuring energy security as well as mitigating GHG-emission and air pollution.

The continued underutilization of solar energy technologies such as DGRTPV signifies a lack of innovative business models for diffusion of the technology. Historically, high capital costs have been a major impediment to PV adoption. Whereas solar PV module prices have dropped globally, several stakeholders still view the upfront costs of the technology as prohibitively high, thus deeming the system to be unaffordable. Szabó *et al*. (2011) argue that it is the lack of adequate technological skills/knowledge as well as political, environmental and socio-economic barriers that have hindered the use of solar energy thus slowing down the opportunity of exploiting the abundant solar resource.

Furthermore, Tobias and Vavaroutsos (2012) posit that 2% of the worlds' diseases are caused by indoor air quality especially due to unhealthy gaseous emissions generated from nearby buildings emitting carbon dioxide as well as traffic and congested room occupancies/fittings with inadequate levels of ventilation. Consequently, building occupants and urban residents are at risk of chronic and viral-borne diseases such as influenza, cough and asthma among others.

Lastly, several existing commercial office buildings in Kampala face increased energy costs. While some building owners blame the government for the annual electricity tariff escalations, several studies argue that it is the lack of awareness and absence of energy efficiency culture (such as using green Star Energy rated appliances and equipment) which contributes to the cost-escalation.

1.3 Rationale of the study

In light of the escalating demand for electricity and slow uptake of solar PV DG due to the effect of socio-economic and technological barriers, the primary focus of this study is to explore on a responsive business model towards the full-scale-up of DGRTPV technology with the target of enhancing energy security as well as contributing to climate change mitigation at building scale level. In addition, the study aims to identify energy efficiency interventions for retrofitting into existing office buildings. In line with this, the study appraises feasible financial mechanisms, policies and legislation that could contribute to acceleration of the diffusion of rooftop PV technologies and energy efficiency. The study findings are targeted towards informing the commercial building owners, policymakers, regulators and stakeholders on the viability of DG with rooftop PV as a solution towards enhancing energy security, as well as mitigating greenhouse gas emissions caused by the combustion of fossil fuels (especially from diesel/petrol generators). Instead of designing spaces for generator rooms and fuel storage, it is anticipated that a shift towards PV generation for buildings would support rooftop PV technology as the more viable option.

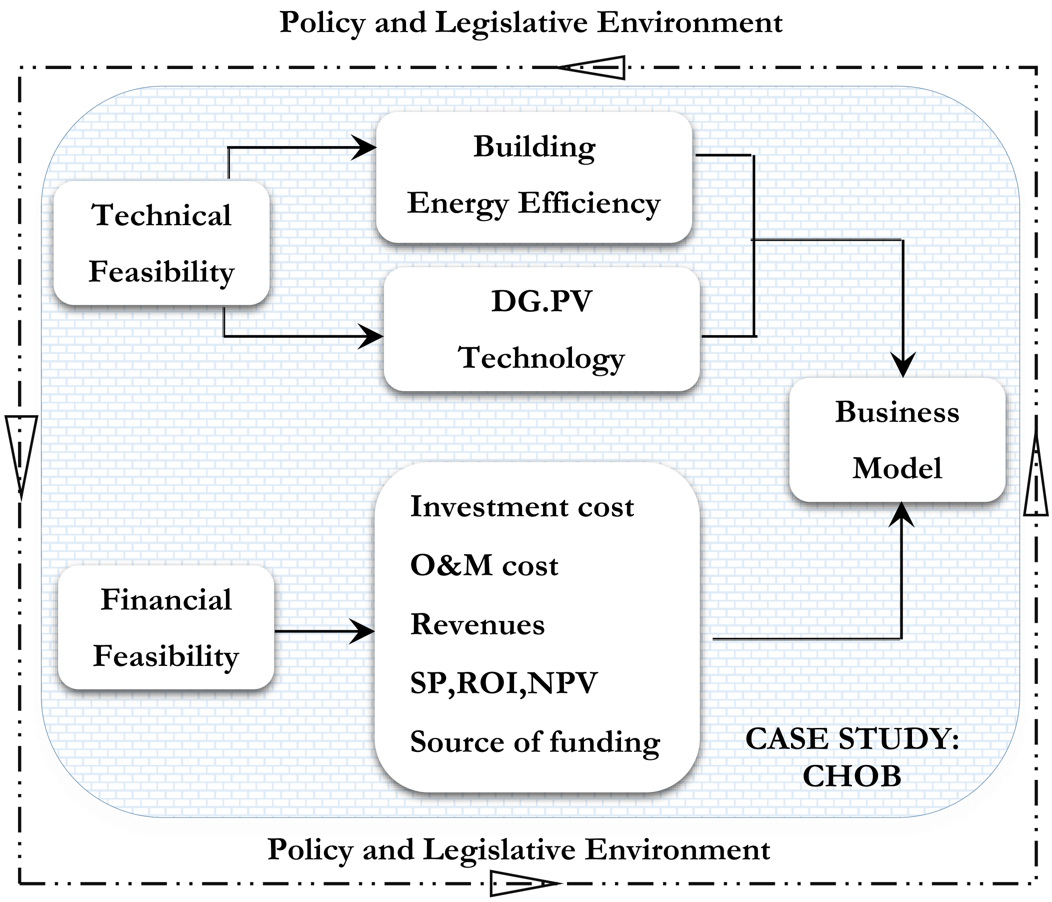

Figure 2: Conceptual framework of the study

Figure 2 shows two key components (technical and financial feasibility) employed towards the assessment of the DGRTPV responsive business model for the case study building. The case study (CHOB) findings on EE and potential of DGRTPV technology, and the related financial viability assessment was applied to guide the conceptualisation of a responsive business model. The procedures and findings are cross-referenced to the RE policy and legislative environment boundary (as illustrated in Figure 2) of Uganda, and also highlights critical policy reforms in support of the relevant models.

1.4 Research Questions.

In order to meet the objectives highlighted in Sub-section 1.3, the study is guided by the main research question and sub-questions as follows:

1.4.1 Main question

What would be the responsive business model scenarios for distributed generation based on rooftop PV technology as an opportunity towards energy security and climate change mitigation intervention for Crusader House Office Building (CHOB) in Kampala, Uganda?

1.4.2 Sub-questions

1) What are the policy/legislative opportunities and challenges for distributed generation with rooftop photovoltaic for CHOB?
2) What are the cost-effective energy efficiency interventions for retrofitting into CHOB ?
3) To what extent can distributed generation with rooftop PV guarantee energy supply for CHOB ?
4) What is the financial viability of distributed generation with rooftop PV for CHOB?

1.5 Working hypothesis

The current levels of innovations in the building and energy sector, as well as the projected escalation in electricity tariffs, offer significant revenue opportunities to underpin a responsive business model aligned with the emerging opportunity in Uganda. In addition, a viable business model for DG with rooftop PV technology for CHOB demonstrates a significant potential towards enhancing energy security as well as contribute significantly to climate change mitigation for Uganda, while at the same time boosting reliability, affordability and economic growth from the scale-up of the opportunity. CHOB therefore serves as a relevant prototype for other existing commercial office buildings in Uganda with regard to the diffusion of DGRTPV in the country's economy.

1.6 Research approach

Based on the overall research question and sub-questions, a case study approach was adopted to guide the study. Introduction letters from the University and appointment letters for participants were drafted in order to facilitate access to the case study building and also introduce the researcher to the participants who were interviewed for primary data of the study. The participants included the occupants of the case study building and purposely selected key government officials who mainly deal with the issues highlighted in the research sub-questions. The key participants were interviewed face-to-face and the data captured were transcribed for analysis. In addition, the study carried out on-site observations/audit of appliances used in the case study building and its surrounding environment over three weeks.

Secondary data (including sources such as academic journal articles, newspaper articles, public-sector reports, textbooks and internet sites) were analysed in order to supplement the primary data. A qualitative research approach was prioritized as it was the best suited for a clear understanding of the opportunities and challenges for DG with rooftop PV. The analysis was complemented with data from energy simulations for CHOB based on dynamic Design Builder Energy Plus simulation software as presented in Chapter 5.

1.7 Delimitations and limitations of the study.

The study is delimited to technical and financial feasibility appraisals of DGRTPV technology in order to ascertain a responsive business model for the case study building. Responsive policy and legislative frameworks appraisal is considered to be a secondary component of the study.

Moreover, the appraisal of Uganda's opportunities and challenges in using DG with rooftop solar PV is identified as an intervention for the escalating electricity demand in CHOB and similar commericial buildings. DGRTPV technology has also been noted in several previous studies as a solution towards mitigation of excessive carbon emissions that lead to climate change and global warming.

The second delimitation is on financial feasibility. The study is delimited to discounted cash flow approach. Internal rate of return, risk assessment, options analysis and other accounting financial analysis methods are not applied. The analysis in the study is therefore limited to net present value, return on investment, simple paybacks, investment costs, operations, maintenance costs, and related revenues.

The study is limited by lack of systematic data and literature on Uganda's solar market. Most of the information was obtained from institutional reports and three academic papers of three different years from the same author. However, academic literature from other countries such as China, USA, Netherlands, Thailand, India and Germany were appraised in comparison to Uganda's institutional reports information.

The study applies a case study approach as the primary framework for consolidating both primary and secondary data for analysis and findings. Whereas the findings can be used to infer scale-up opportunities at conceptual level, more such studies would be required in order for a detailed and representative view to emerge. In light of this, Crusader House office building as the case study currently has six tenants (Newplan Limited, Cowi

Consultants, Project for Financial Inclusion in Rural Areas, Austrian Embassy Development Cooperation, Bunyonyi Safaris Limited and Judiciary Family Division office). As another limitation to the study, Bunyonyi Safaris Limited and the Embassy did not respond to the request letters for interviews. However, spatial configurations of their occupied spaces were assumed and sketched out as input data for simulations based on what was evident from an informal visit. In addition, the equipment and appliances of the office spaces were assumed in relation to the tenant offices that were formally audited thus taking consideration of equipment and appliances running 10 hours a day.

These observations were validated through cross-referencing to the full architectural drawings of the whole building, which in turn facilitated a few assumptions such as the type of printers, photocopiers, and lighting and room layout/partitions. In addition, the researcher observed some similarities across the case study participant responses which also allowed for re-assessment of the assumptions on the tenant usage where interviews could not be undertaken. Moreover, supplementary data on appliances and equipment wattage values used for energy optimization were obtained from online sources/ websites which thus compensated on the limited access to the spaces where tenants did not consent for interviews/visit-audits.

Another limitation was availability of accurate building information (such as full electrical drawings) as the property manager was unable to trace where theyhad been stored since 1987. However, given the single sheet of the electrical drawing, the researcher was able to count the number of the lighting systems since the architectural drawings were typical on the office space levels of the building.

The fourth limitation to this study was the unoccupied office on the second floor of the main building. There was no partition or activity in the building hence equipment and other loads were considered to be zero.

Lastly, the Design-Builder simulation software had limitations with inputs for exact weather data. However, the variation in actual weather data versus the default Design-Builder weather data for Kampala were considered negligible. For instance, if Uganda's hottest month is January with about 34^{o}C, the design-builder inbuilt temperature was about 32^{o}C for the same month (Climate-data, 2017).

1.8 Outline of the study

The report is structured into eight chapters as follows:

Chapter one gives an overview of Uganda's solar potential, background and context of the study, the research problem, the purpose of the study, the research question and sub questions, working hypothesis, research approach, delimitation and limitations and lastly an outline of the research report.

Chapter 2 comprises the literature review which starts with the appraisal of studies in policies and legislative environment for DGRTPV technology at global scale and in Uganda. This is followed by studies in energy efficiency, distributed generation with rooftop PV, financial feasibility and business models followed by consolidation conclusion on significance to the rest of the study.

Chapter 3 describes the processes of data collection and how the data were transcribed and coded for qualitative analysis approach in order to derive sub-findings and overall finding based on the conceptual framework shown in Figure 2.

Chapter 4 addresses the first sub question through analysis of policy and legislation environment for DG with solar PV technology in Uganda. It is subdivided into four sub-sections starting with findings from interviews conducted with government representatives in the MEMD, ERA, UIA, KCCA (see abbreviation full description in the list of acronyms page xiv) and solar market/business stakeholders. In addition, the chapter presents findings on the solar PV business in the country, possible solar PV financing mechanism, and related regulations that govern electricity generation either through mini-grid, off-grid and grid-interactive applications. Lastly, the chapter gives a brief overview on the country's planned energy efficiency policy.

Chapter 5 presents findings of the case study building towards addressing sub-question 2 and 3. The chapter is sub-divided into seven sub-sections which highlight the building description, occupancy, and building envelope and information, Crusader House drawings and photographs, baseline energy audits, electricity bills, appliances, lighting systems loads and building simulations. In addition, energy efficiency measures are analysed and energy efficiency feasibility is also appraised and related sub-findings presented.

Chapter 6 presents the financial analysis for DGRTPV investment towards addressing sub-question 4. Sizing of the PV systems and financial analysis tools such as the return on investment, simple payback period and net present value are applied towards deriving the viability of investing on rooftop PV systems based on the case study building.

Chapter 7 presents an appraisal of responsive business model options for DG with rooftop PV while Chapter 8 consolidates the analysis and sub-findings in Chapters 1 to 7 in order to derive overall findings to the overall research question.

CHAPTER 2 LITERATURE APPRAISAL

2.1 Introduction

In the pursuit towards resolving the main research question, and guided by the working hypothesis as described in Section 1.5, the literature appraisal reviews readings around responsive business models for renewable energy so as to explore the appropriate model for Crusader House Office Building (CHOB). In the first place, readings on technical aspects such as distributed generation (DG) and energy efficiency (EE) are appraised to provide a clear understanding of opportunities and challenges of DG with rooftop PV for CHOB. In addition, the readings on financial aspects as well as the policy and legislative environment issues are reviewed.

In light of this, the chapter is subdivided into seven sub-sections. The first sub-section highlights the existing PV system policies and legislation environment at global scale. This is followed by appraisal on energy efficiency and retrofit concept for existing buildings and DG with rooftop PV under sub-section 2.4. Review on opportunities and challenges is then presented in sub-sections 2.4. Readings on financial aspects and business models are discussed in the sub-sections 2.5 to 2.7. Lastly, the literature appraisal and significance for the study is consolidated in sub-section 2.8.

2.2 Existing policies and legislative environment for PV systems at global scale

According to Solanki *et al.* (2011:2150), energy policy is "a strategy in which government decide to address the issues of energy development along with the development of the energy industry to sustain its growth including energy production distribution and consumption." Therefore, in policy the government can make use of demand and supply-side instruments in order to harmonise the market.

2.2.1 Demand-side policy instruments

Zhi *et al.* (2014) highlight that the demand side instruments include FiTs, subsidies, net metering, green tags, RE portfolios, financial support, public investment, tax credits (consumer subsidies), government mandates and regulatory provision. The policy instruments can be used to foster solar energy-use market. The Feed –in Tariffs (FiTs) instrument is adopted in more than 75 jurisdictions around the world including Germany, China, Uganda, Netherlands, South Africa, Thailand and USA among others. The FiTs facilitates for long-term financial stability for investors, which in turn improves the financial viability assessment.

Subsidies are another widely adopted policy instrument. The demand side subsidies include the direct and indirect subsidies for installation of solar energy hardware. Such subsidies include investment grants, capacity payments, output or production based payments and soft loans.

Green tags (also known as RE credits) and net metering are two trading based policy instruments that use energy market to promote the application of solar energy. Green tags are trading mechanisms, which have been adopted by nine EU countries which include Germany, Malta, Sweden and Netherlands. Depending on the policy changes, this study observes that green tags are privately managed as opposed to FiTs which are mostly managed by the government. For instance, property rights to environmental benefits from generating rooftop solar electricity can be sold and traded (between private RE producers at their own negotiated cost) and the owners can legally demonstrate they have purchased renewable energy. Net metering allows households and commercial establishments to sell excess electricity generated from the distributed PV system to the grid. According to Zhi *et al.* (2014), the electricity customers are able to offset their electricity consumed with the small-scale power over the entire billing period using the power at a different time than it is produced, without considering when it is consumed or generated, and storing it in the utility's grid. In otherwords, if in Uganda my UMEME (main electricity distributor) bill is 50 USD, and my small rooftop power generated is worth 50USD or more, I can offset that cost, though I may or not make profit in terms of cash at hand as a solar energy producer but benefit the storage facility. In light of this, a comparison of FiT, green tags and net metering policies depend on the implementation methods and processes which can influence the economic efficiencies of the policies.

Renewable energy portfolio is another trading regime that sets standards for small-scale solar energy producers without (or with low) renewable electricity content in their overall supply portfolio to buy from large-scale producers with high renewable electricity content and vice-versa depending on the location of consumers. This policy has been adopted by more than 14 countries including the USA. The policy can be merged with the FiT to promote diffusion of PV systems. For instance, if RE plant 'A' generation levels drop down to the required capacity to supply its consumers, and RE plant 'B' is at excess generation levels (generated more capacity than what is consumed by its consumers), plant 'A' can buy top up power for its consumers from plant 'B'.

Lastly, Financial support is used by governments in form of low-interest loans. Such loads could facilitate the diffusion process of DGRTPV and a full scale-up of the technology.

2.2.2 The supply-side policy instruments

Zhi *et al.* (2014) appraise several supply-side policy instruments, which include research and development grant, financing support for manufacturing (low-cost loans), investor subsidy, subsidized support infrastructure and tax concession/ exemptions. Such instruments are regarded as 'push-side' by the government and are further argued to have less attention in the literature compared to the demand-pull policies.

Table 1: Policy instrument adopted by large PV market investors: **Source:** adopted from Zhi et al. (2014)

	Policy instruments	**United States**	**Germany**	**Japan**	**China**
Supply-side	Research and Development Grant	√	–	√	√
	Financing support for manufacturing	√	–	√	√
	Materials and Equipment Duty-free		–	–	√
	Tax concessions/exemptions	√	√	√	√
	Investor subsidy	–	–	–	√
Demand-side	Feed-in-tariff	–	√	√	√
	Net metering	√	–	–	–
	Interconnection Standards	√	–	–	–
	Renewable Portfolio Standard (Renewable Energy Standard)	√	√	√	√
	Consumer Subsidy (tax credit)	√	–	√	–
	Public investment (demonstration project)	–	–	√	√
	Performance-based incentives	√	–	–	–
	Government mandates	–	–	√	–
	Financing support (for consumer)	√	√	–	–

Table 1 shows Policy instruments that could be considered for Uganda full-scale roll out of DGRTPV for CHOB.

2.2.3 China RE policies

Zhi *et al.* (2014) note that the German Renewable Energy Act influenced Chinese PV industry and policy formulation. The German policy and FiT also facilitated acceleration in the PV market of several European countries. The detailed appraisal of the evolution and adaptation of the policy in China is presented in the subsequent sub-sections.

2.2.3.1 On-grid tariff, subsidy financial and fiscal incentives.

Zhi *et al.* (2014) points out that in 2006, the Chinese government issued an on-grid tariff and subsidy of CNY (currency of China called Yuan Renminbi) 0.42 per kWh for output from distributed solar photovoltaic (DSPV) projects in order to promote the development of solar PV industry in China. According to Zhang (2016:93), 1CNY=0.1613USD. The subsidy is administered by China Renewable Energy Development Fund (CREDF) and allows for a 20-year lifecycle PV system projects. In this subsidy policy, the grid company pays for any surplus power generated by the PV system and exported to the grid at a local benchmark price range of CNY 0.25/kWh to CNY 0.52/kWh (fixed rate throughout the years). This depends on the location of the project. As a result, the prosumer (person who consumes and generates power) receives CNY 0.42/kWh from the government for power generated and avoids power bills (*ibid.,* 2014).

Moreover, Zhang (2016) comments that subsidies are suitable for local government and always available for rooftop investors. However, in order to access these subsidies, Zhang (2016) highlights that DSPV project-investors are required to register with the local energy administration. The provincial level government oversees the detailed registration process. Permitting process for DSPV is streamlined and requirements are waived for generation business licenses, planning and site selection, land pre-approvals, water conservation, environmental impact evaluation, energy conservation evaluation and social risks evaluation (*ibid*). Further, China has a scale control policy (a solar energy generation capacity ranging from 5kW to 300MW required by individuals/investors to qualify for financial support) under the national subsidy. Zhang (2016) notes that not all DSPV projects enjoy the national subsidy, but some developers receive local policy incentives, which are not subject to the scale-control policy. Moreover, in China, DSPV fiscal incentives include government RE surcharge exemption and 50% VAT (Value Added Tax) exemptions for projects whose monthly income of power sales is less than CNY 30,000 (approximately 5000 USD).

2.2.3.2 Power grid, connection, measurement and settlement policy

Power grid, connection, measurement and settlement policy is for communities and homesteads and it is often integrated with the FiT scheme. Under this policy, investors are motivated through waiver of services and engineering fees by the government. The permit process is streamlined (individuals are able to ascsertain the necessary requirements for PV investment and implementation), distributed projects are exempted from the need to hold generation license and grid connection integration charges of DSPV projects into the public grid and reinforcement charges are incurred by the grid utility rather than the investor/developer. Zhang (2016) highlights that all these waiver incentives by the utility are covered by the grid connection tariff and subsidy. Surplus power is sold to other power consuming enterprises by the government. According to Zhang (2016), the Chinese government set up this policy to discourage individual building-scale/ homestead from power-export to the grid in order to preserve the grid security but rather motivate household and community self-generation and self-consumption.

2.2.3.3 Other DSPV policies and regulations in China

In 2014, the Chinese government announced policy changes where all banks and financing agencies were required to provide preferential loans to 'property relief DSPV projects in China' through lease fund and individual credit financing models. Several banks, to some extent, were unfamiliar with DSPV projects. Later these banks gained interest after central government intervention. In light of this, Uganda can adopt such scenarios to boost full deployment of DGRTPV projects in the country.

2.2.4 Italy RE policies and regulations that can be adopted by Uganda

Italy has FiT policy where there is an incentive called, "Conto Energia" (translated as photovoltaic-electricity bill). Spertino, Di Leo, and Cocina (2013) highlights that the incentive is paid based on the electricity produced/generated by the PV system. The incentive period is 20 years as it is fixed at a constant rate for PV system electricity produced. However, small domestic plants in building integration benefit from a higher rate while larger plants which are not architecturally integrated receive lower rates.

"Ritiro Dedicato" (Dedicated Delivery) is the other incentive under the FiT policy in Italy. In this incentive, electricity generated is fed into the grid on the electricity market through the Italian Energy Service Operator (utility). The utility recognizes the producer for the electricity generated at €/kWh variable in the range between 0.07–0.105.

2.2.5 Uganda's energy sector: existing policies/regulation environment

Twaha *et al.* (2016) point out that Uganda's energy sector is undeveloped and characterized by extremely low levels of modern energy consumption and heavy reliance on biomass energy that accounts for up to 93% of the total energy consumption.

In reference to the Constitution of the Republic of Uganda (1995:13), it states the need to promote and implement energy policies that can address the people's 'basic needs' and 'protect the environment' while ensuring 'a widespread access to affordable modern energy services' so as to improve the standard of living for all people in Uganda.

In 1999, Uganda's energy policies started on a transformation path following the enactment of the Energy Act of 1999. This resulted in the establishment and reinforcement of the energy sectors of the country which are categorized as

- Electricity
- Petroleum
- Nuclear
- Renewable energy

Moreover, under the Ministry of Energy and Mineral Development (MEMD), the Electricity Regulatory Authority (ERA) was established in order to regulate the electricity sector across the four fields of generation, transmission, distribution and rural electrification. Further, the establishment of ERA resulted in unbundling of the Uganda Electricity Board (UEB) coupled with the establishment of different business entities for the generation, transmission, and distribution with a target for a single buyer business model for any electricity sale. These entities include Uganda Electricity Generation Company Limited (UEGCL), Uganda Electricity Transmission Company Limited (UETCL) and Uganda Electricity Distribution Company Limited (UEDCL) (Energy Policy, 2002:14). According to the 2002 energy policy, distribution and generation business is targeted to be leased out to private operators on long-term concession while transmission remains as a public function in the medium term (NEP 2002).

Twaha *et al.* (2016) observe that under the *Promoting Renewable Energy and Energy Efficiency Program* (PREEP), the MEMD, in collaboration with Gesellschaft für Internationale Zusammenarbeit (GIZ) formulated the National Energy Policy (NEP) 2002 to enable the energy sector to contribute to the economic and social welfare of Uganda's population in a friendly and sustainable manner. In 2007, the Ministry once again announced the Renewable Energy Policy 2007 (REP 2007) and the Multi-Generation Type Renewable Energy Feed-in Tariff Policy (MGTREFiTP) with the aim of promoting small-scale renewables, increasing the use of modern renewable energy (RE) from 4% to 61% of the total energy consumption (excluding hydropower) by the year 2017. The other aim was to support the provision of sustainable and reliable RE services accessible to the population in pursuit of poverty eradication *(ibid.)*. "It was in this policy that the Feed-in Tariffs (FiTs) for RE and Standard Power Purchase Agreement (SPPA) was established. Key targets included increasing solar water heater installations to 30,000 m^2 and applying industrial energy appraisals while awarding certificates of performance to outstanding industries and distribution of efficient equipment to industries" (*ibid*.:794).

2.2.5.1 FiT policy

According to Adaramola (2015), a feed-in tariff (FiT) is a policy mechanism designed to support the growth of renewable energy conversion systems. This FiT comprises of generation cost (which is levelised cost of electricity) and the premium (bonus). The FiT is estimated based on the following approaches:

- Cost of generation
- Avoided cost and
- Electricity tariff

Furthermore, Twaha *et al.* (2016) and ERA (2016) report that Uganda took an early lead in East Africa to implement the FiT system (others being Tanzania, Kenya, Mauritius, Rwanda, South Africa, Algeria and Egypt). The government anticipated that the FiT would attract private investors for renewable energy (RE) as envisaged under the REP 2007. However, this did not materialize until 2013 when the Global Energy Transfer Feed-in Tariff (GET-FIT) was launched as a solution for REP 2007 with FiT clause. According to Twaha *et al.* (2016:795), the GET-FIT program "is an arrangement intended to help the advancement of RE in developing countries through the creation of international public-private partnerships. International AAA rated donors such as national governments, development banks, and international climate-related funds contribute to premium payments for RE projects in partnership with developing country governments valid for 20 years." In Uganda, the energy resource technology tariffs are set in US dollar cents per kilowatt hour, levelized cost approach with the consideration of electricity generation costs incurred by the RE energy operators.

2.2.5.2 Subsidy policy instrument

Twaha *et al.* (2016) mention that the partnership between the Private Sector Foundation of Uganda, the government through ERA and nine donor agencies led to an offer of a 45% subsidy on solar power equipment. This was aimed at encouraging private suppliers to invest in solar products that would increase access to electricity in rural areas. These subsidies were planned and guided by the Rural Electrification Strategy Plan, which was covering the period of 2005 - 2011. This strategy aimed at attaining unbiased regional supply of energy, exploiting the environmental benefits of rural electrification subsidies and promoting grid expansion alongside developing off-grid electrification in remote areas. As a result, Twaha *et al.* (2016) report that the government heavily subsidised the electricity and the Ministry of Energy and Mineral Development (MEMD) has spent over 390 million euros on power subsidies. It is anticipated that these subsidies will be scrapped and electricity prices will hike thus motivating private sector investment in the power supply sector and enabling the Ugandan government to invest in large hydropower projects (*ibid.,* 2016).

2.2.5.3 Recommended policies to improve RE exploitation in Uganda

Twaha *et al.* (2016) acknowledge the fact that Uganda was among the first countries in Africa to adopt FiTs but recommends that the policy should be well managed and activities should be closely monitored in order to attract potential investors. In addition, well-trained personnel in the government or private audit organizations should be assigned the responsibility of handling this process in order to facilitate the smooth operation of the REFiT program.

Moreover, Twaha *et al.* (2016) aregue for a net-metering plan to aid the FiT to be utilised in providing electricity in different regions of Uganda. However, given that funding is anticipated to be an obstacle for that innovation, the study suggests that net-metering should be incorporated in REFIT policy in order to motivate Independent Power Producers (IPPS) fund power projects with the goal of selling generated electricity to the government through Power Purchase Agreements (PPAs).

Besides grid-connected PV systems, regional-based micro grid DG systems should be adopted for remote areas that are far away from the national grid. This would be advantageous as there would be reduced blackouts from the main grid, high-efficiency performance, environmental stability and also being economical for the government, especially in remote areas where the cost of grid extension is unaffordable.

In spite of the fact that the Ugandan government has heavily and continuously subsidized electricity, the subsidy schemes have failed to improve the electricity supply situation in the country. Twaha *et al.* (2016) anticipate that this could be attributed to the channels and ways of subsidising used by the authorities and yet constrained by the depreciating Uganda Shilling against the Dollar. As a solution, Twaha *et al.* (2016) recommend provision of incentives to individual households or communities in order to encourage them to install small-scale RE systems on their premises.

2.3 Energy efficiency and retrofit appraisal for existing buildings

Ashrafian *et al.* (2016) state that energy efficiency retrofits for existing buildings play a crucial role towards reaching critical worldwide energy consumption reduction and environmental mitigation targets. Buildings are responsible for a large proportion of energy consumption and have tremendous energy saving potential.

Kaygusuz (2012:1121) note that "Improving energy efficiency is the cheapest, fastest and most environmentally friendly way to meet a significant portion of the world's energy needs. Improved energy efficiency reduces the need for investing in energy supply. Many energy efficiency measures are already cost-effective, and they will pay for themselves over their lifetime through reduced energy costs."

Tobias and Vavaroutsos (2012) state that energy efficiency for existing commercial building stock in the cities today is critical. Air conditioning and powering of the buildings is only second to manufacturing and production sectors as the key contributors to global emissions of greenhouse gases arising from the combustion of high-carbon fossil fuels for heating, cooling and generating electricity used in building operations.

2.3.1 Cost-effective energy efficiency measures for existing office buildings

In order to incentivise energy efficiency interventions, governments should employ the range of available policy instruments, including regulations and standards, fiscal incentives, public information campaigns, labels, and public-sector leadership in procurement. These can be deployed across multiple government sectors (Kaygusuz, 2012).

According to Hootman (2012); Tan *et al.* (2016) and UNEP (2009), energy use in commercial buildings is one of the most significant contributors to greenhouse gas emissions worldwide. In addition, it is reported that the building sector offers mitigation strategies where carbon dioxide emissions reduction can be pursued at relatively low costs through retrofit interventions. Building owners always see this as an obstacle because of the related upfront investment costs for installing and replacing of new energy-efficient technologies.

Several studies such as Wang, Ding, Geng, and Zhu (2014); Tobias and Vavaroutsos (2012); Labanca *et al.*, (2015); and Griego *et al.,* (2015) suggest the following energy efficiency measures that should be implemented in order to improve the energy performance of existing commercial buildings.

- ❖ Adding effective sun shading systems (to control internal heat gains and losses), taking full advantage of natural ventilation and day lighting (to minimize the need for artificial lighting during daytime and to avoid the use of forced air heating and cooling)
- ❖ Adopting responsive glazing measures such as double pane glazing, double pane-low transmissive glazing, single pane low transmissive glazing, low emissivity glazing and low solar gain low emissivity glazing
- ❖ Adopting responsive equipment measures such as surge protector power strips for each workstation and also replacing individual inkjet printers with multi-function copy machine in common office spaces and replacing the old CRT computer monitors with LCD monitors
- ❖ Installing intelligent control systems such as daylight sensors, motion sensors, ventilation controllers (carbon sensors) to optimize fresh air levels based on occupancy and the interior conditions
- ❖ Installing energy saving lamps such as the light-emitting diode (LEDs)
- ❖ Tenant energy management web-based systems to enable monitoring and adjustment of energy consumption levels

- Application of renewable energy such as solar energy. Substitutions of traditional energy by installing photovoltaic panels and solar water heaters constitute additional opportunities for retrofit
- Optimization and retrofit of the existing HVAC systems in order to improve the energy utilization ratio and thus decrease the waste of input energy

Griego *et al.* (2015) states that the most cost-effective measures for existing office buildings is the reduction of equipment and lighting loads since they have the greatest annual energy consumption. The annual energy saving percentage in existing commercial office buildings would be reduced significantly enough to allow for the application/ introduction of the rooftop photovoltaic distributed generation with a view towards achieving a net zero energy building.

In order to implement and evaluate viable energy efficiency (EE) measures in existing buildings, Tobias and Vavaroutersos (2012) states that the four stages outlined below need to be adopted.

- At the preliminary stage, energy use is based on the review of utility bills
- Walkthrough analysis stage combines site inspection and interviewing building owners and managers in order to evaluate energy performance and low-cost areas that need improvement
- The energy survey and engineering analysis stage involve employing a qualified engineer to analyse the whole system
- The capital-intensive modifications and architectural building energy efficiency analysis stage, involves review of the building components such as insulation, windows, doors, roofing and other exterior conditions that may affect energy efficiency of the building (*ibid*)

In addition, the study states that other factors such as market and property specific criteria need to be considered as part of EER investment assessments. The market-specific criteria involve identifying the market and submarket conditions such as value and competitiveness, rents and occupancy rates, regulatory policies that may affect the building use, tenant demand of green space in the building and reviews of tenant lease structures where the building owners have options to pass costs of building improvements to tenants while the property specific criteria involve determining the indoor environmental quality and occupant comfort, building energy reduction, maintenance and operational cost implications (*ibid.*).

Labanca *et al.* (2015) similarly argues for detailed energy audits to estimate typical operation schedules, seasonal occupancy variations, construction materials, lighting power density and office equipment power density in order to determine the energy consumption and performance in existing commercial buildings. In addition, policy measures to drive the commercial energy efficiency market need to be established. Policies that stimulate energy savings such as energy performance standards for both new and old buildings, minimum efficiency standards for appliances, labelling of buildings and appliances, subsidies or favourable loans or tax-deductions, voluntary agreements, taxes on energy consumption or on CO_2 emissions and certification of energy efficiency implementers or entrepreneurs would motivate full-scale-up of energy efficiency applications in existing commercial buildings (*ibid.*, 2015). Tobias and Vavaroutersos (2012) highlight that consideration of policy-based initiatives such as tax deductions, investment subsidies, promotion of energy service companies, increased government research and development budgets for improved technologies, creating awareness through demand-side management programs and use of improved appliance standards could contribute towards reduction of greenhouse gas emissions, net cash flow, and long-term asset value of retrofitted premises.

Ruparathna *et al.* (2016) point out that improving energy efficiency in existing buildings is a vital step towards mitigating climate change as well as achieving energy independence through net-zero energy buildings. Energy efficiency of existing buildings contribute to both environmental and economic benefits such as reduction of greenhouse gas emissions and operational-cost savings.

Building energy performance can be improved through a wide variety of strategies such as energy management, creating awareness among the building users (influencing behaviour change) as well as the incorporation of technological measures for energy efficiency and use of renewable energy. Figure 3 illustrates strategies that should be considered in an attempt to improve energy efficiency in existing commercial buildings.

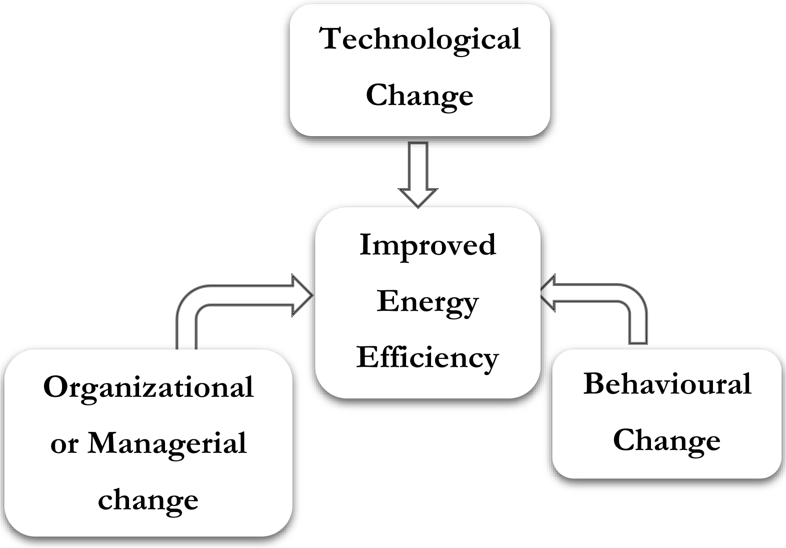

Figure 3: Theoretical framework for energy efficiency interventions. **Source:** Adopted from Ruparathna et al. (2016)

2.3.1.1 Technological changes

Technological change involves the mechanical components, lighting systems, building envelope, energy retrofit and performance assessment and renewable energy micro-generation. Mechanical equipment such as heating, ventilation and air conditioning (HVAC) systems consume a lot of energy, especially depending on the indoor thermal comfort set point, air infiltration, window- wall ratio, window type, internal loads, building type and outdoor climate. In addition, passive and active measures highlighted by Griego *et al.* (2015); Labanca *et al.* (2015); Tan *et al.* (2016); Tobias and Vavaroutsos (2012) and Wang *et al.* (2014) fall under technological changes towards energy efficiency in an existing building. The assessment process can be based on actual energy consumption analysis (based on utility bills) or performance simulation. However, barriers such as lack of funding, constraints in interoperability of systems and unstructured decision-making have inhibited retrofitting scale-up globally and within countries.

2.3.1.2 Organizational and management changes

Organizational and management changes constitute a vital component in energy efficiency interventions for both new and existing buildings. This involves real-time monitoring, energy metering for lifecycle management through the use of sub-meters (record keeping of exact operational energy usage), energy codes (energy consumption monitoring) and energy benchmarking (such as utility bills) for baseline comparisons

(Ruparathna *et al.*, 2016)..In addition, building energy labelling (LEED and energy star) under various rating systems can be reinforced through a systematic operation and strategic maintenance regimes. However, barriers such as volatile energy prices, failure to implement the best-operating practice and failure to identify a responsive business case based on monetary impact (especially on returns) have hindered energy management as a critical component of facilities management (*ibid.*).

2.3.1.3 The behavioural change

Behavioural change and lifestyle choices are additional interventions for reducing the building energy demand. Creating energy efficiency awareness and communication between the managers and building users constitutes some of the key interventions under this category (Ruparathna *et al.*, 2016:1038).

2.3.2 Energy efficiency retrofit challenges/barriers for existing buildings

Social and cost barriers include lack of public acceptance, financing, information, education or proper incentives. Ashrafian *et al.* (2015) claim that limited financial resources of building owners and high levels of initial investment cost are some of the significant barriers to existing building energy efficiency retrofit. Property owners make decisions based on initial capital costs instead of long-term costs and benefits. In addition, lack of involvement in retrofit actions, lack of practical understanding about energy efficiency and other benefits of green retrofitting hinders mitigation interventions for greenhouse gases as building owners feel that related returns are negligible and thus not worth the bother. The lack of experienced service providers further raises the cost of GHG emission reduction measures and interventions in the sub-sector (*ibid.*).

In rented buildings, building owners argue that tenants are the beneficiaries. This raises the split-incentives concern where the investor who pays for the upfront costs for RET and EE measure is often not the same entity who reaps the benefits of lower energy costs. Conversely, the tenant may not be interested in an investment into RET either, as he/she may move out before the end of the payback period. Kaygusuz (2012) observes that facilities managers tend to give energy efficiency a low priority in decision-making. Yet, Ashrafian *et al.(*2015) observe that EER not only affects the energy usage of buildings but also impacts on occupants' productivity and performance, especially for buildings which are poorly ventilated and where workstations are at low daylight levels as artificial lighting increases internal heat gains.

In light of this, countries need to pursue EE policies more diligently as less attention is paid to EE measures as compared to RE policies despite all having similar benefits in terms of energy security and climate change mitigation.

2.4 Distributed Generation (DG) rooftop photovoltaic technology

Solar PV systems offer unique benefits in distributed power applications. Goel (2016) points out that distributed generation (DG) with rooftop PV require interventions such as policy restructuring in order to motivate grid-connected solar installations, off-grid solar installation with battery backup system and net metering.

2.4.1 Distributed Generation (DG)

El-Khattam and Salama (2004) highlight two types of distributed generation which are fossil-fuel and non-fossil fuel based generation. Fossil fuel examples are combustion engines such as natural gas turbine and other micro turbines while non fossil-fuel examples include storage devices such as batteries, flywheel, and renewable energy technologies. This chapter prioritizes on non-fossil fuel type such as the renewables and battery storage devices.

Abdmouleh *et al.* (2017:269) define DG as "a small-scale generation source of electricity connected usually to the distribution level". The International Energy Agency (IEA) quoted in Abdmouleh *et.al.* (2017:270) define DG as "a generation plant serving a customer on-site or providing support to a distribution network, connected to the grid at distribution-level voltages."

DG with rooftop PV technology application is rapidly gaining attraction globally such that an increasing number of consumers have become prosumers (individual/entity who produces electricity for self-consumption and possible export surplus to the grid) (Camilo, Udaeta, Gimenes, and Grimoni, 2017). Pepermans *et al.* (2005:788) acknowledge that DGRTPV systems are flexible and thus allow for developers to respond easily to changing market conditions. Secondly, DGRTPV system power is reliable and of good quality supply. The operations and size of the system motivate the developers to scale DG technologies to suit their needs and would thus perform well in liberalized electricity markets. However, Carley (2009) notes that barriers such as lack of national procedures and technical standards for grid interconnections, lack of standard tariff schemes, lack of insurance inhibit large-scale DG technology deployment.

Zhang (2016), states that DG power is either located on rooftops or ground mounted. The solar energy generated electricity can either be fed to the grid (depending on the region policy and business model) or supplied to a local distribution network (micro-grid) rather than to a high voltage grid. This contributes to reduction in grid peak demand and increases electricity access opportunity for consumers within their proximity.

There are four categories of DG capacities highlighted by Zhang (2016). These include micro (range from 1W-5kW), small (range from 5kW-5MW), medium (range from 5MW-50MW) and large (range from 50MW-300MW). These categories depend on the user type and levels of demand/consumption. Depending on a country's policy tools on energy security, Goel (2016) acknowledges that venturing into micro and mini-grid development for distributed generation applications of up to 2MW with storage facility would be suitable for many commercial buildings in urban areas.

Camilo *et.al.* (2017) points out that in order to benefit from DG application, it is important to address and ascertain the following issues:

i) Regulations and frameworks in support of or constraining DG deployment
ii) Utility's demand or grid operator's requirements for grid access
iii) Financial aspects that are of utmost importance towards implementation of carry out DG projects.

Camilo *et.al.* (2017) note that DG investors need to assess the respective market policy and legislation environment before investment. Investors should ascertain the legality to connect oneself to the distribution grid as mini/micro-generator or if there are compensations for such interconnections or benefits for prosumers (one who produces electricity for self-consumption and is also capable to supply to the grid) and the utility.

The grid operator requirements regarding protection, control, and energy quality need to be clear on who would be responsible for all the technical compliance and commercial issues/related costs. Finally, financial analysis is important for any DG investment. The local market prices for both the energy bill and the PV generation system constitute key considerations for any decision-making. For PV generation, Camilo *et.al.* (2017) suggest this formula, '$\boldsymbol{E = A \times r \times H \times PR}$' where;

E = Energy (kWh) –annual generation capacity of the plant

A = Total solar panel Area (m^2)

r = solar panel yield (%)

H = Annual average solar radiation on tilted panels (kWh/m^2) (assuming no shading)

PR = performance ratio (%) of the system

For the financial analysis, Camilo *et.al.* (2017) acknowledge that a simple monthly Net Present Value (NPV) or similar method can be applied.

2.4.1.1 Other costs to consider for DG

According to Deichmann *et al.* (2011), meeting the energy demand of an existing commercial building requires a system sizing for either stand-alone or mini-grid option that depends on RE potential. Mini-grids have a larger capacity to serve over 50 or more communities or commercial buildings at a time. Therefore, to calculate the costs for DG, levelized costs per kWh need to be taken into account. These include capital costs, operation and maintenance costs.

Levelised costs of electricity.

Levin and Thomas (2012) define levelized costs of electricity (LCOE) as an indicator that encompasses all costs of electricity generation into a unit cost. It is a ratio of the present value of all costs associated with electricity generation to time-discounted lifetime output of a generation system as indicated in the equation below.

$$\text{LCOE}=\frac{\text{PV (costs)}}{\text{Life time electricity generated}}$$

Factors that influence the cost of electricity (include labour, materials, the location of the project (during installation and maintenance) and fuel) must be factored into LCOE. Depending on the type of technology either via off grid or grid interactive, storage costs and related maintenance costs would influence the costs of electricity (See chapter 6 for related calculations and replacements costs)

2.4.2 Rooftop PV opportunity

According to Fthenakis and Kim (2011:1609), photovoltaics (PV) are made from semiconducting materials (such as silicon) which convert solar radiation photons into electricity. "When sunlight hits the material, photons with certain wavelength trigger electrons to flow through the materials to produce direct current (DC) electricity." Parida, Iniyan, and Goic (2011) state that PV systems are rated in peak kilowatts (kWp) which is "the amount of electricity that the system is expected to deliver when the sun is directly overhead on a clear day" (*ibid.:* 1626).

Camilo *et.al.* (2017) highlights that the concept of a PV system is divided into two major parts which are the PV panel and frequency converter. The PV panel is composed of PV cells which are commercially grouped into three categories as follows:

i) Monocrystalline silicon,
ii) Polycrystalline silicon
iii) Thin film technologies, such cadmium telluride (CdTe) and copper indium diselenide (CIS)

The frequency converter allows for the conversion of direct current (DC) into alternate current (AC) which can be fed to most load-types or to the grid. According to Goel (2016) and Ferreira *et al.* (2018), rooftop PV is a smaller system compared to utility-scale or ground mounted systems and mainly consists of PV modules, mounting systems, DC-AC converter and electrical connections.

The battery bank set up helps to avoid isolation phenomenon. Isolated or independent PV systems are often installed in areas with no access to grid power such that the PV system is the only source of electricity. In such a scenario, the battery storage facility is crucial in order to allow availability of electricity beyond sunshine hours when solar radiation is available.

Rooftop PV installation technology in urban or rural areas require solar installation solutions with battery backup in areas faced with frequent power outages. According to Parida *et al.* (2011) grid-connected system are large independent grids through which power generators can be able to export/supply surplus electricity to the national grid. Moreover, grid-connected systems vary in size from a kWp (household purposes) to GWp (solar power stations). Electricity generated from rooftop PV systems can be fed into the grid at a regulated feed in tariff (FiT) or used for self-consumption based on a net metering approach. The net metering mechanism allows for a two-way flow of electricity wherein the consumer is billed only for net electricity (total consumption minus own PV production). On the other hand, Singh (2013) points out that the majority of the PV technology applications are off-grid (stand-alone) systems especially in remote homes, terrestrial communications sites and in urban centres faced with frequent grid power blackouts. In order to alleviate prolonged grid power outages, Deambi (2012:154) suggest that adopting grid-interactive rooftop solar PV systems with full load battery and partial load battery backup is an invaluable connection scheme for rapid electricity demand in residential, commercial, industrial and institutional sub-sectors.

2.4.2.1 Rooftop PV financing

Goel (2016) notes that demand side policy instruments such as soft loans, tax credits, municipality roles and market based mechanisms have played a critical role in the accelerated adoption of DGRTPV technology especially in countries such as China, USA and Germany. For instance, the governments of India, China, and some EU countries introduced several policies and subsidies such as direct and indirect sales tax, excise and custom duty tax exemptions to promote adoption of solar energy.

Spertino *et al.* (2013) highlights that the most important cost items for a PV plant are: the PV module costs which ranges between 40–55% of total cost, inverter/cable/protection costs (10%), building-integration costs (10–15%), installation costs (10–15%) and design/bureaucratic-documentation costs (5–10%).

2.4.3 Opportunities in DGRTPV technology application

Asmus (2008) observes that the use of semiconductors to generate electricity directly from sunlight is the fastest-growing power source in the world. Solar power promises reliability, local economic development and national energy security. The PV industry has been focusing on innovations to reduce the cost of solar panels and cutting consumption of expensive silicon in the manufacturing process through increasing the conversion efficiency of available solar radiation to electricity.

According to Rüther and Zilles (2011), as cited in Ferreira *et.al.* (2018); Sampaio and González (2017), PV systems integrated into buildings and connected to the distribution system offer several advantages such as:

- ❖ Mitigating on high electricity bills
- ❖ Reduces power losses due to transmission and distribution of energy as electricity generated is consumed close to where it is generated
- ❖ Buildings integrated systems do not take separate (or dedicated) physical area/space
- ❖ Reduces investment costs for transmission and distribution lines
- ❖ When strategically distributed, PV generators offer ideal generation capacity due to its great modularity and short-term installation opportunity.
- ❖ DGRTPV system offer high levels of reliability
- ❖ Low cost of operation and maintenance
- ❖ Potential to mitigate greenhouse gas emissions

Sampaio and González (2017) note that the past years of DGRTPV appearance in the markets of China, United States and Europe have propelled many investors, politicians and industry leaders to gain interest and understanding of the economic viability of the PV technology. Globally, DGRTPV power and other renewable energy technology have the most attractive market. This is because it does not require to be extracted, refined, or transported to the generation site and does not contribute to serious environmental impacts such as climate change due to global warming or air pollution and acid rain primarily caused by conventional power generation sources that use fossil fuels. Huijben and Verbong (2013) acknowledge PV technology as a proven system that can contribute to the energy security of many countries. They further note that PV technology does not produce harmful emissions during the operation phase. DGRTPV reduces the need for investments in centralized fossil alternatives and decreases the stress on the grid in crowded areas especially during peak loads. Engelken et al. (2016) observe that connecting businesses from industrialized to developing countries constitutes an important opportunity for DGRTPV which can in turn boost partnership opportunities through micro-finance and social entrepreneurship thus motivating technological change and transfer of technical expertise.

2.4.4 Challenges and barriers of DGRTPV technology

Whereas PV systems offer several advantages, Sampaio and González (2017) argue that during the solar PV life cycle and processing, large amounts of energy is consumed. Greenhouse gases are emitted at some stages of the manufacturing process of solar cells, assembly of photovoltaic modules and transport of material, among others (*ibid*., 2017). Peng *et al.* (2013); Sherwani and Usmani (2010) and Nawaz and Tiwari (2006) posit that during the PV system life cycle, a large amount of energy is consumed and some GHG are emitted especially during solar cells manufacturing processes, PV module assembly, balance of system production, material transportation, PV system installation and retrofitting and system disposal and recycling.

However, PV technology generates electricity from solar energy and would therefore be free from fossil energy consumption and GHG emissions (sometimes related to energy consumption) during its operations. Peng *et al.* (2013) and Nawaz and Tiwari (2006) study highlights that the energy payback time and GHG emission rate are good indicators to actually evaluate the sustainability and environmental performance of the PV system based on life cycle assessment (LCA) methodology. Within the LCA approach, the energy payback time (EPBT) is "the number of years required for a PV system to generate a certain amount of energy (converted into equivalent primary energy) for compensation of the energy consumption over its lifecycle, including energy requirements in PV modules' manufacturing, assembly, transportation, system installation, operations and maintenance, and system decommissioning or recycling" (*ibid*: 256). The study further highlights that estimating EPBT and GHG emissions of a PV system in a specific region would be difficult because there are so many parameters to consider such as a product manufactured in China and it is used in Uganda (PV modules place of origin), local weather conditions, electricity mix of PV modules, local irradiations and life cycle energy requirements. In light of this, Peng *et al.* (2013) and Nawaz and Tiwari (2006) note that the EPBT of a rooftop system could range between 4 years to a maximum of 8 years because of the steel and aluminium supports embodied energy ("the amount of energy required to produce the material in its product form"(Nawaz and Tiwari (2006:3145)). The GHG emission rate of PV system, assuming a 30-year life cycle, could range between 48-83g CO_2-equivalent/kWh, the energy requirement of a rooftop PV system is about 700mJ/m^2. Therefore, this study can conclude that PV technology GHG emissions, balance of system embodied energy (including inverters, batteries, cables, controller, array support, junction box etc.) and other environmental impacts can be effectively compensated through significant life-cycle emissions-reduction as demonstrated by the short EPBT.

Besides, Ferreira *et al.* (2018:182) state that several potential investors and producers in the energy sectors of different countries such as Brazil lack experience, as well a scientific background (information and expertise) about DGRTPV. As a result, they tend to slow down their interests in the development of related projects.

Goel (2016) highlights the barriers that often hinder full deployment of DGRTPV systems as follows.

- High upfront costs
- The lack of awareness among consumers on viability and technical performance of PV technology
- Lack of local manufacturing facilities which necessitates imports thus escalating upfront costs
- Lack of skilled workforce
- Restrictive procurement rules and building permit process
- Lack of clear business models and outdated regulations.

Engelken *et. al.* (2016) outline additional barriers to deployment of DGRTPV as follows:

- Lack of management skills
- Low security of supply
- Price distortions
- Corruption
- Shortcomings in legal frameworks in various countries
- Lack of entrepreneurship and skilled personnel/labour
- Lack of long-term security/reliability due to changing approaches and framework conditions
- Lack of knowledge and information about markets for renewables and potential customers
- Incentives are not designed to align with the locally varying contexts

These barriers severely constrain the adoption of rooftop PV deployment in many developing countries like Uganda (Goel, 2016; IRENA, 2016).

Abdmouleh *et al.* (2017) appraises the structure of the electricity market especially with regard to the challenges it poses for private sector investors. Goel (2016), states that this is mainly due to the excessive bureaucratization of authorization processes for PV installations. The study draws on from the PV market in Germany and Italy where initial production and the promotion of new commodities constrained many developers/investors in those countries before the issues were later addressed and streamlined (Goel, 2016; IRENA, 2016). Spertino *et al.* (2013) further note that this kind of constraining mindset and behaviour is gradually improving globally and many investors/developers in solar energy businesses are getting to understand better on how to engage with the processes. However, there are some countries that are still undergoing severe constraints. Nonetheless, Goel (2016) highlights that low consumer-awareness of DGRTPV and its weak market acceptance still prevail as the most significant challenges towards promoting solar energy in general and DGRTPV in particular.

Zhang (2016) further points out insecurity of rooftop PV ownership as one of the challenges facing full deployment of DGRTPV in China. In addition, the owner of the land is not necessarily the owner of the building and ownership of commercial buildings is limited to 50 years. The study further elaborates that there are legislative risks for long-term investment when linked to such short ownership periods, and especially for large-scale distributed solar PV systems. In addition, protecting the project developers' right when their customers move out (with the risk that new property owners could refuse to continue purchasing the rooftop solar energy) is another challenge associated with rooftop PV ownership.

Ramli *et al.* (2017) state that DGRTPV systems in many countries are often exposed to harsh weather conditions such as temperature fluctuations, humidity, corrosives and dust which affect the reliability of PV power and the overall performance of a PV system even though mitigative data aggregation and responsive design features are being innovated and implemented.

Sampaio and González (2017:597) states that "the cost aspect of photovoltaic electricity is influenced by the location, i.e., less sunny locations require larger systems to generate the same amount of electricity that a smaller system in a sunny location can produce, and more distant places require longer transmission lines to connect the power produced to the grid." Other constraints outlined in the study include:

- ❖ Limitations due to constrained supply of systems in the market which reinforces dependence on imports at additional costs.
- ❖ Needs a relatively large land/roof area for installation

- ❖ High dependence on technology development
- ❖ Geographical conditions such as levels of solar irradiation

According to the IEA-RETD (2013) report, there is inadequate information on financing options available to developers for investments in EE or RET. Potential building owners willing to implement EE measures or RET often find it hard to obtain not only qualified personnel but also independent and objective advice from financial experts. Financiers often have no specific knowledge on EE and RET, and are therefore inadequately prepared to fairly assess viability and risks of such projects. This is especially common with the local financial institutions and banks which normally assume a more conservative approach.

Financial barriers such as long payback periods, perceived high costs and challenges in access to capital, as well as high transaction costs for small-scale generation are all unattractive to most commercial banks and Energy Service Companies (ESCOs) (*ibid.*, 2013). Moreover, lack of knowledge and competence of professionals involved in the installation and maintenance of RET limits the diffusion of RET (*ibid.*).

Globally, inadequate market capacity for local manufacturing of the solar cells, and constraints towards research and development for DGRTPV is a big challenge. Goel (2016) suggests that more countries need to have the capacity and capability to manufacture solar cells, inverters and storage systems which thus highlight the need to invest in related research and development (R&D).

2.5 Energy demand and supply factors

In cross reference to the study objective and problem statement described in Chapter 1, Florio et al. (2008) highlight two key considerations (which are energy production, storage, transport, transmission and distribution as well as consumption energy efficiency) for energy-project investments. Florio *et al.* (2008) further point out the following factors (outlined below) that influence energy demand and supply of an economy.

- ❖ Demographic dynamics
- ❖ Economic trend (gross domestic product-GDP, growth and per capita)
- ❖ Weather and climatic conditions
- ❖ Tariff system

- ❖ Energy efficiency developments in energy transportation/transmission and/or energy consumption

The factors that influence energy supply are noted as follows:

- ❖ National and international socio-economic and political factors influencing the fuel price dynamics
- ❖ Political decisions about the discontinuation of certain types of energy sources and fuels (e.g. nuclear power)
- ❖ System of incentives on certain types of energy sources and fuels (e.g. subsidies on renewable sources)
- ❖ Environmental requirements imposing additional costs to energy production
- ❖ Structure, territorial size, degree of integration and performance quality of the energy system (both production facilities and the transportation and transmission/distribution networks)
- ❖ Market structure, particularly related to the number of competitors and the degree of market openness and integration into other markets.

2.5.1 Financial analysis for DGRTPV

Florio *et al.* (2008) note that financial analysis guides project cash flows forecast in order to determine suitable net return indicators such as Net Present Value and the Financial Internal Rate of Return (FRR). Time discounted cash flow approach is often applied for financial analysis of DGRTPV projects with the following assumptions taken into account:

- ❖ Only cash inflows and outflows are considered (depreciation, reserves and other accounting items which do not correspond to actual cash flows are disregarded)
- ❖ Determination of the project cash flows is based on the incremental approach (the differences in the costs and benefits between the PV system scenarios and counterfactual scenarios especially the business-as-usual scenario.)
- ❖ Aggregation of cash flows occurring during different years requires the adoption of an appropriate financial discount rate in order to calculate the present value of the future cash flows

2.5.1.1 Investment costs

Florio *et al.* (2008) note that in addition to planning and design, construction, engineering and operations, additional investment costs for energy projects typically include:

- ❖ Land acquisition and purchase of rights of way
- ❖ Decommissioning/dismantling/demolition costs borne when rehabilitating old energy-generation facilities
- ❖ Technological plant installations and equipment
- ❖ Mobile equipment required for operations
- ❖ Connections to the relevant utility networks
- ❖ Road access
- ❖ Skilled and non-skilled labour costs
- ❖ Information technologies, particularly relevant in case of smart grid projects
- ❖ Mitigation measures for environmental protection
- ❖ Testing and training of operational staff before start of operations

2.5.1.2 Operation and maintenance costs

According to Brijesh and Semida (2013:303), operations and maintenance costs are the costs incurred during the life-time operation of the system. This includes the recurring costs for staffing, repairing and maintaining the components in order to ensure continued technical performance.

Florio *et al.* (2008) posit that operating and maintenance (O&M) costs of energy projects can be differentiated between variable and fixed costs, depending on whether they vary with the quantity of energy produced/distributed or not. Fixed O&M costs, (whose magnitude depends on the type of project) usually include:

- ❖ Cost for public concessions fees or other permits
- ❖ Insurance costs
- ❖ Labour costs
- ❖ Periodic fixed maintenance and repairing costs

Variable operating costs include

- ❖ Energy fuel costs
- ❖ Variable overheads and utility costs

- ❖ Other goods and services for energy production or transportation/transmission/distribution

Revenues (inflows)

Revenues include accruals from the following:

- ❖ Energy or fuel sales (a unit price/sales, paid by consumers of the energy supplied by DGRTPV system)
- ❖ Transport or other service sales (a tariff or a price paid by consumers for energy transport via off-grid, grid interactive, ancillary services (measurement, supply adjustments, balancing, capacity payments, etc.)

2.5.1.3 Simple payback, return on investment cost and net present value

Simple Payback

Florio *et al.* (2008) defines simple payback as a tool used in financial analysis to indicate the period it takes for accrued revenues to balance out the initial investment outlays of the project without regard to profitability. The method also ignores all revenues and cost after the payback period. In addition, it does not recognize the time value of money, though that can be remedied by using the discounted payback method. Due to these drawbacks, the simple payback method, though commonly used, is not comprehensive. It primarily serves as a quick tool to assess the financial feasibility/economic viability of a project or programme in conjuction with otjher more reliable tools.

Return on Investment (ROI)

Wiehle *et al.* (2006 cited in Björnsdóttir, 2010:16), defines ROI as "a profitability ratio that, when taken over time, helps in measuring the performance of the capital employed." The ROI is a key indicator for investment decisions and helps to compare profitability of alternative investment options. The study defines the derivation of ROI as follows:

$$\text{ROI} = \frac{\text{Earnings before interest rates and taxes}}{\text{Total liabilities and shareholder's equity}}$$

To determine the ROI in Chapter 6, the study adapts/translates the ROI formula into the following formula.

ROI= Total net cash flow divided by total project investment cost expressed as a percentage (source: Krarti (2016:65))

Net present value

According to Florio *et al.* (2008:48) net present value is defined as "the sum that results when the expected investment and operating costs of the project (suitably discounted) are deducted from the discounted value of the expected revenues" This can be calculated by the following formula (*ibid*:48).

$$\text{FNPV} = \sum_{t=0}^{n} a_t S_t = \frac{S_0}{(1+i)^0} + \frac{S_1}{(1+i)^1} + \dots + \frac{S_n}{(1+i)^n}$$

Where,
$\mathbf{S_t}$ is the balance of cash flow at time **t**

$\mathbf{a_t}$ is the financial discount factor chosen for discounting at time **t**

t is the time between 0 and ***n***

n is the time horizon (months/years)

i is the discount rate for the investor concerned

In order to determine the profitability of an investment in the PV plant over its full life, Spertino *et al.* (2013; 2014) recommends the use of Net Present Value (NPV) and Internal Rate of Return (IRR). The parameters that influence the NPV calculations include installation cost of the PV, rated power of the PV system, annual revenues, annual operations and maintenance costs and the interest rates.

Spertino *et al.* (2013: 535-536) further argue that "NPV of a time series of cash flows is defined as the sum of the present values of the individual cash flows of the same entity. The interest rate takes into account the alternative uses of capital or the minimum return that an investment must generate in order to equalize an investment of equal duration and risk on the financial market. Therefore, NPV takes into account the lacking revenues arising from the alternative use of money." If an investment is associated with a positive NPV, it is not only profitable from the economic and financial point of view but also more profitable than other investments with similar characteristics. A negative NPV means the investment return is less than other available alternatives (*ibid.*).

The present value factor (for the investment years) can be determined as

A= (1/ (1+d) ^*t*) where, A is Present value, d is discount rate and *t* is time

Internal rate of return (IRR)

IRR is a financial viability indicator that represents the yield of an investment. This can be used to facilitate for comparison of projects targeted for investments. IRR is an annual compounded rate of the real return on investment. Spertino *et al.* (2013:536) further explains that "An investment should be pursued when IRR is greater than the minimum Attractive Rate of Return (MARR), which coincides with the normal rate of return for an investor or a company." Mathematically, IRR is defined as the interest rate that would make the NPV of a series of the related cash flows equal to zero.

2.5.1.4 Sources of financing

Nevitt and Fabozzi (2000 cited in Björnsdóttir, 2010) state that it is rare to have projects financed independently on their own merits without credit support from sponsors who, in long run, may benefit from either interest rates or exchange of services. The authors outline the following financing sources of project investments:

- International agencies (such as the World Bank, International Finance Corporation, area development banks, etc.)
- Governments
- Commercial banks
- Institutional lenders
- Money market funds
- Commercial finance companies
- Individual investors
- Sponsors loans and advances

2.5.2 Economic analysis of potential PV projects

Economic analysis appraises a project's contribution to the economic welfare of the region or country it is located in. In order to determine the economic viability of implementing a PV system, Koo *et al.* (2016) highlight that the whole life-cycle cost and benefits of the potential PV project should be established. Moreover, the authors outline the following impact factors that can be considered for a targeted solar project location.

- ❖ Regional climates (i.e. geographical factors such as latitude and monthly meridian solar altitude as well as the meteorological factors such as average daily solar radiation and monthly temperatures),
- ❖ Building characteristics (i.e. azimuth of the installed panel, slope of the installed panel, budget limits, the roof area limit and other on-site installation factors)
- ❖ Regulations such as mandatory renewable energy installation program (which could make it compulsory to supply a proportion of energy consumption in a public building as the minimum electricity generation requirement.)

Building characteristic impact factors are divided into three categories as follows:

- ❖ Defined parameters such as region where the building is located and the azimuth of the installed panel
- ❖ Adjustable parameters such as the slope of the panel, type of the panel, the number of installed panels along the length and width of the roof area
- ❖ Constraint parameters such as rooftop length and width, minimum electricity generation capacity should be excluded in the possible scenarios for the rooftop PV constraints

From a life cycle perspective, the economic and environmental assessment is essential in order to evaluate the effects of rooftop PV systems. Assumptions such as the overall analysis approach, the real discount rate, the analysis period and the cost of ownership are important in determining and influencing the implementation of rooftop PV system.

A lifetime of PV systems is normally considered to be 20-25 years. The assumed project life can have a significant effect on the levelised cost of electricity (LCOE) especially if the project is partially or fully financed through a loan. Secondly, using a discounted cash flow approach allows for the future cost of electricity to be derived without requiring separate methods to account for the effects of inflation. For small-scale systems, the annual operation and maintenance costs can be assumed to be 1% of the initial cost plus installation cost of the system.

Even though it is normally assumed that the PV system produces the same amount of electricity for each year of its life (useful/technical lifetime), it should be noted that due to hourly, daily, monthly, seasonally and annual variability in solar irradiation as well as normal degradation in the PV modules, annual energy production should be expected to vary over the lifetime of the system.

2.6 Common global financing mechanisms for DGRTPV projects

According to Meier (2014), the following financing options have proven to be a success in the United States and other European countries like China and Germany.

- ❖ Emerging crowdfunding financing
- ❖ Third party ownership financing
- ❖ Conventional self-financing
- ❖ Utility and public financing
- ❖ On billing financing

Crowdfund financing

Under crowd fund financing, Meier (2014) states that investors are connected online with solar projects that need financing and are paid back their capital over an agreed period with interest. The developer works as a virtual renewable energy bank, soliciting investment for solar projects and making loans to be paid back over a period of around 10 years. Such loans can be secured through assets of the project owned by the Special Purpose Entity (SPE) or through contractual rights with respect to the sale of electricity.

Third party financing

Under third-party financing, the solar developer installs the PV systems on the building owner's or consumer's rooftop at his/her own cost. Later, the customer or consumer pays for electricity at a lower rate for an agreed period of time in order to finance the initial installation costs over time. This would come with an acceptable profit margin for the developer. Later on, the consumer may decide to buy back or pay for the system in order to own it with the possibility of the developer taking responsibility for maintenance and other technical services which would be paid for by the new owner or consumer of electricity generated from the solar system. This is facilitated through Power Purchase Agreements (PPA) and leases followed by Service Level Agreements (SLA) if the customer eventually buys back the system (Zhang, 2016).

Further, the developer or company installs, owns, and operates the solar PV system on the customer's site and either leases the PV system or sells the PV electricity to the building through a solar lease. Tongsopit *et al.* (2016) state that institutions and organizations such as Google, Citibank, and Bank of America are willing to finance rooftop solar through solar leasing companies or developers.

Conventional self-financing

Tongsopit *et al.* (2016) state that under the self-financing mechanism, building owners take full liability for the cost of installing and maintaining the solar PV systems. This constitutes high upfront costs which is a key factor that has prohibited the widespread adoption of PV rooftop installations.

Utility and public-sector financing

For utility and public financing, local governments and municipalities provide incentives such as low-interest loans, rebates, and subsidies in order to expedite the adoption of distributed generation with rooftop PV by property owners within their areas of jurisdiction.

On-billing financing

On-billing financing is similar to utility and public financing. Tobias and Vavaroutsos (2012) state that such financing mechanism provides low or no down payments or long-term loans to building owners desirous of installing the PV system on their roofs. The loans (from banks or government entity) are repaid through tax or utility bills per month or depending on the agreement between the parties. Tongsopit *et al.* (2016) highlight that the loans are secured by a property such as land with a land title. This enables the local government or municipality to finance 100% for the upfront cost of the PV system.

2.7 Business model scenarios for DGRTPV for existing commercial buildings

Specific studies on business models for DGRTPV for commercial buildings in cities are very limited. However, available information and data are primarily based on the review-reports of existing trade and industry practices rather than academic studies.

Slavik and Bednár (2014) observe that several authors (studies) define the term 'business model' as a system of creating value in order to make money. In their opinion, a business model is an economic concept, which entails 'producing' revenues and costs. Authors such as Afuah (2003); Debelak (2006); and Osterwalder and Pigneur (2009) quoted in Slavik and Bednár (2014:20) define business model as tabulated here below.

Table 2: Business model definitions

Author	Business model definition
Allan Afuah (2003)	"Business model is a framework for making money. It is the set of activities which a firm performs, how it performs them and when it performs them so as to offer its customers benefits they want and to earn a profit."
Don Debelak (2006)	"A business model is the instrument by which a business intends to generate revenue and profits. It is a summary of how a company means to serve its employees and customers and involves both strategy as well as an implementation."
Alexander *et al.* (2009)	"A business model describes the logic of how an organization creates, delivers and control value and how money are earned in a company."

Slavik and Bednár (2014:21), refined the definition of the term business model "as a system of resources and activities, which create a value that is useful to the customer and the sale of this value makes money for the company".

According to Huijben and Verbong (2013); Johnson (2010); Hamwia and Lizarralde (2017) business model (BM) scenarios are essential drivers for the deployment of renewable energy technologies (RET) such as DG with rooftop PV. Such models serve as management tools to change, operate, implement and control a business. Zhang (2016) gives an example of the Chinese government that formulated several incentive policies to promote distributed solar PV throughout the country. However, the study noted that these policies did not perform well primarily due to lack of innovative business models and financing mechanisms.

Hamwia and Lizarralde (2017) state that developing a suitable BM is often necessary for technological innovations such DGRTPV. Moreover, business models facilitate for the bringing of inventions to the market in order to satisfy customer needs. Correspondingly, technological innovation by itself does not guarantee business success. More so, estimating the customers and competitors behaviour-changes from initial conjectures makes the adopting of new business models essential. Employing product service system

(PSS) has the potential to increase efficiency by delivering functionality (e.g. pay-per-use) rather than selling ownership.

According to Asian Development Bank report (2015), business models should be designed in response to challenges such as:

- ❖ Lack of awareness and knowledge about energy efficiency and rooftop PV for existing commercial buildings
- ❖ Regulatory barriers leading to cumbersome procurement rules and permits
- ❖ Financial barriers which reflect poorly developed banking services and high upfront costs of investment and low initial returns

These challenges can be mitigated either by 'ownership business models' which focus on financing and risk concerns or service business models which focus on providing specified services and methods of operations and maintenance. The diverse range of related business models/scenarios are reviewed in Table 3.

Table 3: Business model and related financing mechanisms

Author (S)	Business model type and country applied	BM. description , drivers and merits	Source of funding	Utility and other issues
Huijben and Verbong (2013), Asmus (2008) Tongsopit *et al.* (2016) Spertino, Di Leo, and Cocina (2013) Mac-Schoettle and Ortega (2011) Zhang (2016)	**1)** Community shares model (solar city) **Applied in** Netherlands	❖ Buildings in a zone not exposed to the sun can draw power from buildings exposed to sun within that zone. ❖ Building owners, developers or tenants do not need to pay upfront costs, installation and maintenance costs but purchase shares of power generated by the system or total output of the system ❖ Designed for energy intensive buildings and aims to reduce electricity costs ❖ Customers pay a monthly fixed fee for shares in a local solar farm in exchange for credits that can be used to offset their electricity bills. ❖ PV electricity units are sold at a discount, typically 5–10% lower than the grid electricity tariffs to interested customers	❖ Building owners collective collaborations in a designed zone save money to invest for larger PV system and more efficient projects leading to upfront cost affordability ❖ Utility and public financing	❖ Utility becomes a critical player because of grid connections for own use. In the long run, the community will need to conduct a further research ❖ Fear of revenue loss as many zones may own PV systems ❖ Change in the load pattern due to change in building activity use or tenant

Author (S)	Business model type and country applied	BM. description , drivers and merits	Source of funding	Utility and other issues
		❖ Model based on cost due to economies of scale hence reduced installation cost, clean electricity production, job creation, technological innovation and safe investments ❖ The model addresses the technical complexity, economies of scale, capital costs, and funding challenges of renewable energy and energy efficiency projects ❖ This BM depends on the local actors, therefore the local and well-known mediators encourage behavioural changes due to a close and trustworthy relationship		
Overholm (2015) The Mac-Schoettle and Ortega (2011) SEIA (2015) Meier (2014) Zhang (2016)	2). Solar energy management service model or third party **Applied in** Netherlands USA China	❖ Solar power is offered as a service by a solar service company that builds, owns, and maintains solar panels on the premises of end-customers. ❖ Investors reep benefits of tax incentives ❖ Through PPA customers value is received through cheaper service and	❖ Service company has access to external funding like crowd funding ❖ Banks often finance 70% then 30% by the developer for security reasons.	❖ Fear of revenue loss as many building owners may opt to own PV systems ❖ Often relatively complex hence require frequent changes in regulation ❖ Lack of third party registration system for the solar

Author (S)	Business model type and country applied	BM. description , drivers and merits	Source of funding	Utility and other issues
		electricity tariff compared to utility tariffs ❖ Customers are guaranteed performance, engineering, operations and maintenance services upon signing solar lease or solar PPA contract for normally 10-20 years ❖ Under solar lease, customers pay a certain amount monthly and use electricity at their choice. They later decide to buy the system from service provider and hire him/her for services and engineering solutions when needed ❖ Model driven by regulation and policy changes and access to cash to finance the ownership is the strength of the model.	❖ Local or international investors depending on the PPA ❖ Third-party ownership financing ❖ Conventional self-financing	component can result to inferior products, poor energy quality and price distortions ❖ Defaults and non-payment affects loan reimbursements
Tongsopit, *et.al.* (2016)	2) Roof rental model	❖ Consists of three players; the developing company, the roof owner and the utility.	❖ Investors: community, global organizations or conventional self-financing	❖ Developer acquires 25 year PPA for this grid tied system installation

Author (S)	**Business model type and country applied**	**BM. description , drivers and merits**	**Source of funding**	**Utility and other issues**
Tobias and Vavaroutsos (2012)	**Applied in** Thailand and Netherlands	❖ Offered by countries with FiT incentive. The developing company rents the roof to install and operate a solar system and sells the electricity for the FiT ❖ After developer assessment of roof strength and size, roof owner signs contract with developer for 10-25 years to rent roof ❖ Roof owner receives roof rental payments. All power generated sold to the grid and not for own consumption ❖ Roof owner not liable for any solar PV system operation or investment. Hence, no participation at all stages of the project process or operation. Apart from receiving roof rental payments, additional benefit could be reduction of heat absorption through the roof	❖ Local bank and other financial institutions ❖ On-bill financing, loans repaid through tax or utility bills	❖ Roof damages such as roof leaks cause the roof to collapse thus this should be highlighted in the contract

Author (S)	Business model type and country applied	BM. description , drivers and merits	Source of funding	Utility and other issues
Huijben and Verbong (2013) Zhang (2016) Hamwia and Lizarralde (2017)	3) Customer own (Host owned) model **Applied in** China, USA and Netherlands	❖ The customer or consumer purchase the solar system and installs on their rooftops or other sites to generate electricity for own use and excess exported to the grid ❖ The host customer pays 80% upfront cost, and 20% comes from subsidy ❖ The host customer has to look for an EPC contractor (solar PV developer) to design, procure and install the solar PV system, as well as comprehensive O&M support ❖ Host customer assumes the risk of poor performance of the system ❖ The host customer has to bear the transaction costs associated with grid interconnection ❖ The market segments are the home owners and few commercial building owners with sufficient rooftops, willing to take risks and no significant shadows from neighbouring buildings	❖ Supported by national and local government in Netherlands after the country experienced policy uncertainties with FIT policy implementation ❖ Self-finance ❖ Access to government subsidy if 80% is self-consumed and 20% exported to the grid	

Author (S)	Business model type and country applied	BM. description , drivers and merits	Source of funding	Utility and other issues
Zhang (2016) Tongsopit *et.al.* (2016)	4) Solar Lease model **Applied** USA Thailand	❖ Allows the customer to pay for the solar system over an agreed period and avoids upfront costs ❖ Customer can decide to be a prosumer or sell electricity in order to receive revenue based on FiT ❖ The customer's monthly payment should not be higher than the benefit the customer earns from the leased system-i.e., energy savings. ❖ Model driven by demand side: untapped group of potential customers that typically would not be able to afford solar PV upfront	❖ Crowdfunding	❖ Lack of flexibility in small systems ❖ Lack of a third-party registration system for solar system components

2.7.1 Business model drivers for rooftop PV systems for commercial buildings

Several studies have reported different drivers for DGRTPV. Zhang (2016:802) for example argues that creating innovative business models constitutes an important driving force for DGRTPV industry. Engelken *et al.* (2016) posits that the exacerbating scarcity of oil has accelerated increases in fossil fuel prices. This has nourished energy security concerns globally and political intention to lower national dependency on oil. "The threat of devastating effects from climate change is globally recognized and drives political agendas to implement CO_2 reduction goals and to support measures to mitigate climate change." More so, Engelken *et.al.* (2016) highlights liberalisation of the energy sector, unbundling of energy systems' functions such as generation, transmission, distribution, and the change from large state-owned utilities to an increasing involvement of private-sector actors as having contributed and motivated companies to create new innovative business models in all countries worldwide.

Air pollution and health problems caused by conventional energy sources, steep learning curves regarding PV technology, the pursuit of sustainable lifestyle and intention to close urban-rural-divide, are also mentioned as key drivers. Huijben and Verbong (2013) further highlight that the continued grid electricity supply constraints has resulted into acceleration and diffusion of DGRTPV technology because of the emerging favourable government policies and market adoption strategies which are reflected in the innovative business models now emerging globally and especially in developed countries.

2.7.2 Sample conceptual frameworks for some business model types

Third party business model-conceptual framework

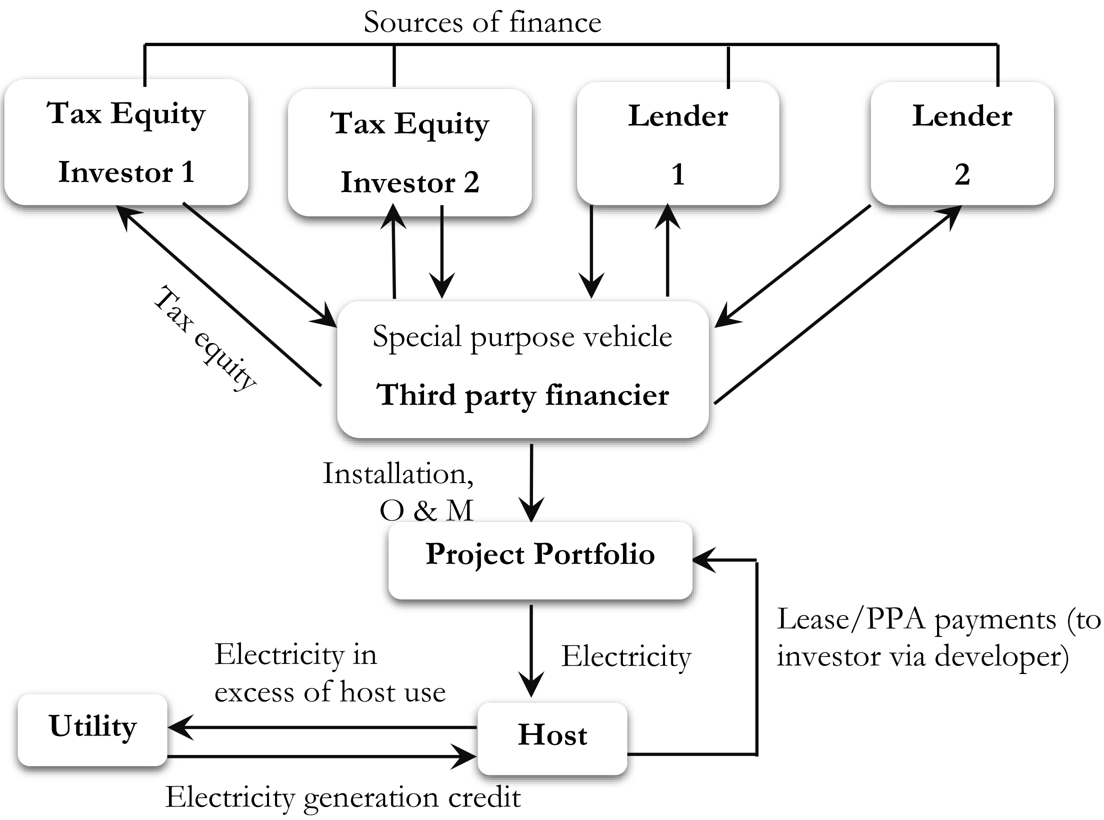

Figure 4: Third party owner financing business model. **Source:** Adapted from Zhlang, 2016: 460).

Figure 4, shows the third-party business model framework. The model is attractive to large external project investors, project finance lenders and tax equity investors who would not otherwise be interested in small projects on a once-off basis.

Roof rental business model conceptual framework

Figure 5, indicates the procurement processes after developer signs a contract with the roof owner. Investors fund the developer who then pays an engineering services company to design, operate, maintain and install the system on the roof procured by the developer. Electricity generated on the procured roof is sold to the utility and developer receives FiT payment. Developer reimburses the money borrowed from investors based on PPA and also pays roof rental fees to the building owner.

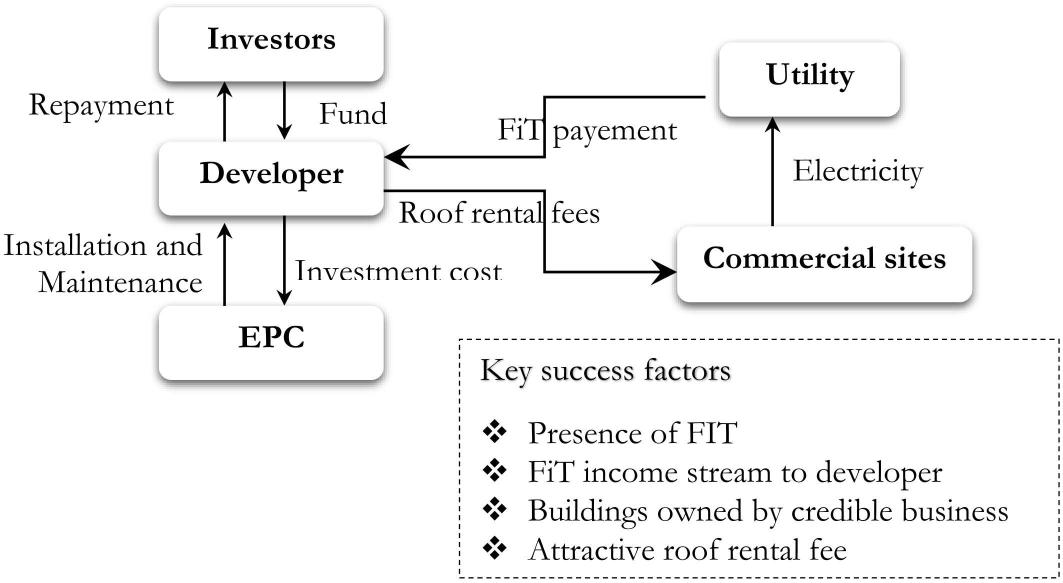

Figure 5: The roof rental business model structure. **Source:** Adapted from Tongsopit *et al.* (2016:452)

Solar lease business model conceptual framework

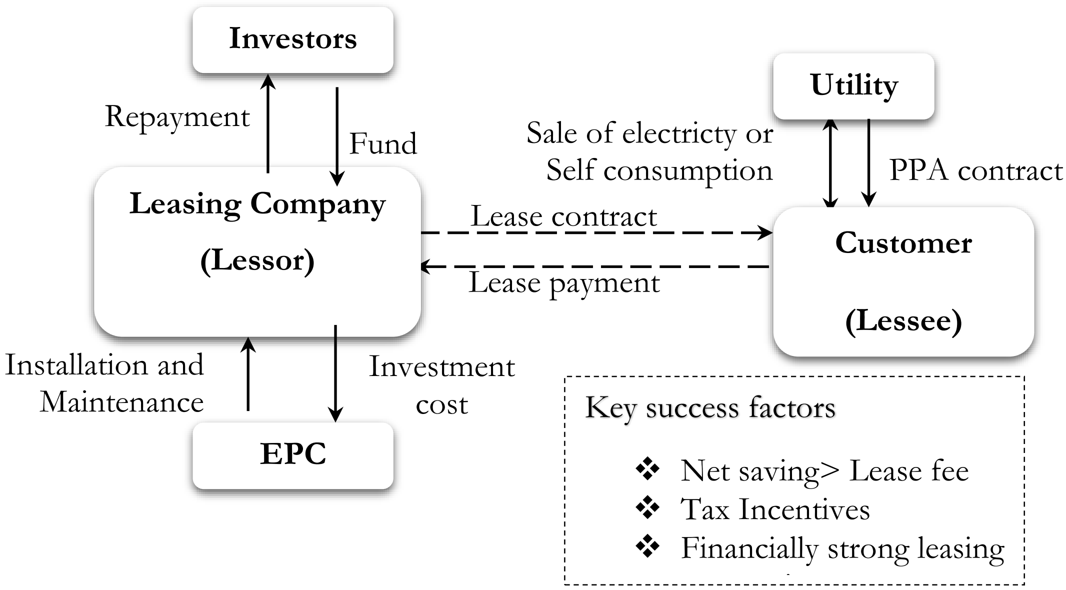

Figure 6: Solar lease business model. **Source:** Adapted from Tongsopit *et al.* (2016:453)

Figure 6, illustrates solar lease model where the customer does not have the capital to invest on the PV system. The customer therefore engages a leasing company with the system to install, operate and manage all necessary engineering solutions. The leasing company seeks funding from potential investors either through crowdfunding or international banks. Once the funds are received, the leasing company hires an engineering company (EPC) to provide the engineering solutions, operations and maintenance onto the customer's rooftop. The customer then enters a lease contract with the leasing company to make an affordable down payment for the system and the balance paid monthly. Failure to pay may result to electricity cut off or penalties as set out in the contract. Alternatively, all electricity generated may be sold to utility rather than self-consumption of the building owner/user. Part of the revenue received from the sale of electricity is then used to meet the lease costs.

2.8 Conclusion: An evaluation to motivate CHOB

This chapter has reviewed literature on policy and legislative environment for DGRTPV technology based on national (Uganda) and global scale. In addition, energy efficiency DGRTPV technology, financial feasibility for DGRTPV and rooftop PV business models applied worldwide were articles reviewed in order the conceptualisation of a responsive business model for CHOB rooftop PV deployment. The literature appraisal has highlighted several pertinent issues and ideas that Uganda can review and adopt towards the support of DGRTPV investment for CHOB. Drawing from Figure 2, in Sub-section 1.3, and insights from the literature review, indicated the need to find value for customers and the developers through application of DGRTPV technology. Given that several authors (studies) highlight the high initial capital cost of this technology, a responsive business model to be identified in the subsequent chapters needs to solve this problem of technology finance with less demand for government intervention while leveraging on the existing policies and legislative frameworks for RETs.

CHAPTER 3 RESEARCH METHODS

3.1 Introduction.

The previous chapter presented key insights for Uganda, opportunities and challenges of distributed generation (DG) with rooftop photovoltaic (PV) within a global context. This chapter presents the research methods employed during data collection and the analysis stage of the study. The final section of the chapter outlines the ethical considerations which guided the study.

3.2 Overall research approach.

In reference to the literature appraised in Chapter 2 and the research questions raised in Chapter 1, the study adopted a qualitative research method and also applied a case study approach in order respond to the research questions and sub-questions. Creswell (2009) states that in qualitative research, the researcher constitutes a key instrument of the study as he or she examines documents, observes behaviour and interviews participants and thus deals with text and image data collected with a variety of tools and techniques. Yin (1991:23) as quoted in Sarantakos (2005), defines a case study as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context when the boundaries between the phenomenon and the context are not clearly evident and in which multiple sources of evidence are used". In light of this, the study addressed the research questions and other pertinent issues that would contribute to the deployment of rooftop PV on CHOB. Through the case study approach, the study also addresses one of the country's objectives with regard to energy supply/security as well as mitigation of climate change. Figure 7 represents the conceptual approach that guided the study.

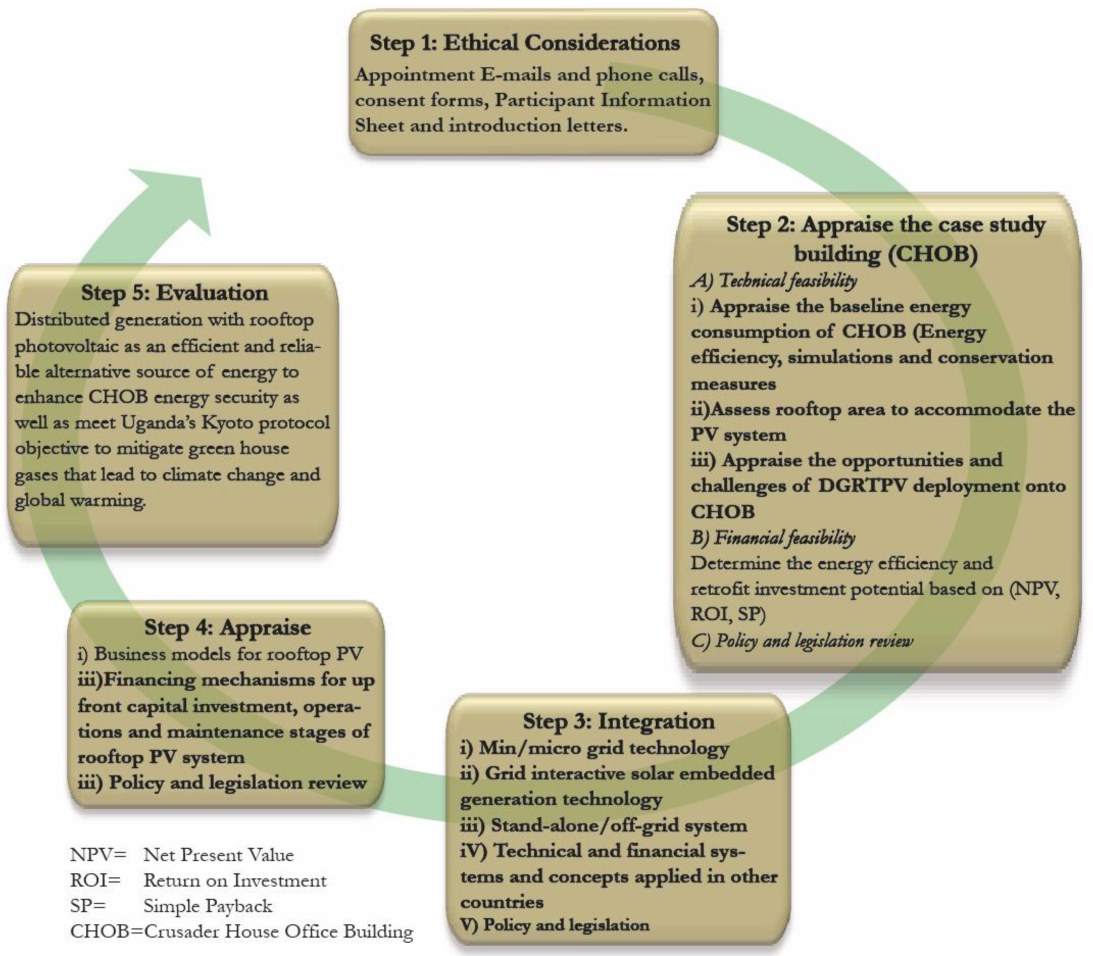

Figure 7: Research design and approach

Looking at the first step, the study was guided by the university ethics standards such that before undertaking fieldwork on appraising the case study, appointments with the government institutions in the field of this study topic were made. These institutions included Ministry of Energy and Mineral Development (MEMD), Ministry of Works and Transport (MoWT), Electricity Regulatory Authority (ERA) and Kampala Capital City Authority and Uganda Investment Authority (KCCA). The aim of the interviews was to get a clearer understanding of the policies, regulations and frameworks that would influence the deployment of DG with rooftop PV.

E-mails and phone calls for appointments were made to those institutions. In addition, an introductory letter from the university, the consent forms and participant information sheet were hand-delivered to the respective offices and via E-mail. Other interviewees, besides Crusader House occupants, included the entrepreneur of the year 2015 from UMEME and Konsult Limited respondent (a private firm dealing in solar products and related consultancy in Uganda) who is a committee member of Uganda Solar Energy Association (USEA) launched in 2015.

The interviews were scheduled with the entities' representatives. Semi-structured questions; pens and a voice recorder were used to conduct the face-to-face interviews. In addition, the study involved access to internet sites, for secondary data and to allow for cross-referencing of issues highlighted in the interviews. Focus group discussion of three case study building participants (representatives from Cowi Civil Engineers, Judiciary Family Division, and Program for Financial Inclusion of Rural Areas (PROFIRA)) were also conducted. As part of the direct observation, photographs of appliances, lighting systems, room partitions and other spaces that consume or use energy were taken. The data collection process also took notes on occupants not interviewed, as well as sketches of the office layout, type of lighting systems, appliances and equipment. The semi-structured interviews conducted addressed several issues such as appliances used in the respective offices, number of staff, energy consumption patterns, power outages, operations and maintenance of office equipment, opinions on rooftop PV and possible experiences with the DGRTPV innovation.

Finally, an energy audit of the case study building was carried out and observations on power ratings of lighting systems, appliances and equipment were noted. Measurements of the building windows and office spaces (to allow for cross-referencing to the architectural drawings as built) were observed and recorded. In addition, the split cooling and heating systems in the building were noted. More so, UMEME electricity bills for the building were reviewed and captured into Microsoft Excel software in order to allow for the calculation of the baseline energy consumption of the building. Data from the review of the architectural and electrical drawings were then entered into an energy performance simulation software called Design-Builder in order to simulate baseline energy consumption of the building (see Chapter 5 for simulation outputs).

Secondary data based on energy conservation measures, opportunities and challenges of distributed generation with rooftop PV, and Uganda's energy policies and regulations were collected and appraised in order to guide the interventions for CHOB. Financial analysis tools such as net present value, return on investment and simple payback period assessment was used to determine the economic viability of energy efficiency and retrofit intervention.

The third step was to appraise the opportunity of applying mini/micro grid technology or grid interactive embedded solar PV generation application for CHOB. Secondary data to assess the economic viability of the two applications were considered as key for the appraisal. Academic journals, textbooks, and other internet sites were accessed in order to gain insights on adaptation and application of the technology. Practices in terms of technologies, financial systems, policies and legislation environment of different countries were appraised in order to facilitate for a clearer understanding of the study and motivate recommendations that can be adopted for CHOB. Interestingly, the study gained insight (from the regulator's website) that feasibility studies for net metering policy for Uganda were already in process. This would significantly facilitate for grid interactive technology application for CHOB.

The fourth step necessitated the conceptualisation and appraisal of business model options and financing mechanisms for DG with rooftop PV for the case study building. The study carried out interviews with companies dealing in solar business and energy generation in order to ascertain the existing business models in Uganda. Secondary data from internet sources were also analysed in order to guide the conceptualisation of economically viable business models and viability of DGRTPV investment as well as identifying potential sources of funding for rooftop PV technology.

The last step of the research process was the simulated assessment of the performance of the DG with rooftop PV versus the energy demand of the building. Themes were adopted for analysis as well as consolidation of sub-findings obtained from both primary and secondary data in order to consiolidate overall findings to the research question.

3.3 Data analysis process and derivation of findings

The data analysis process and derivation of findings was based on the process map shown in Figure 8 below:

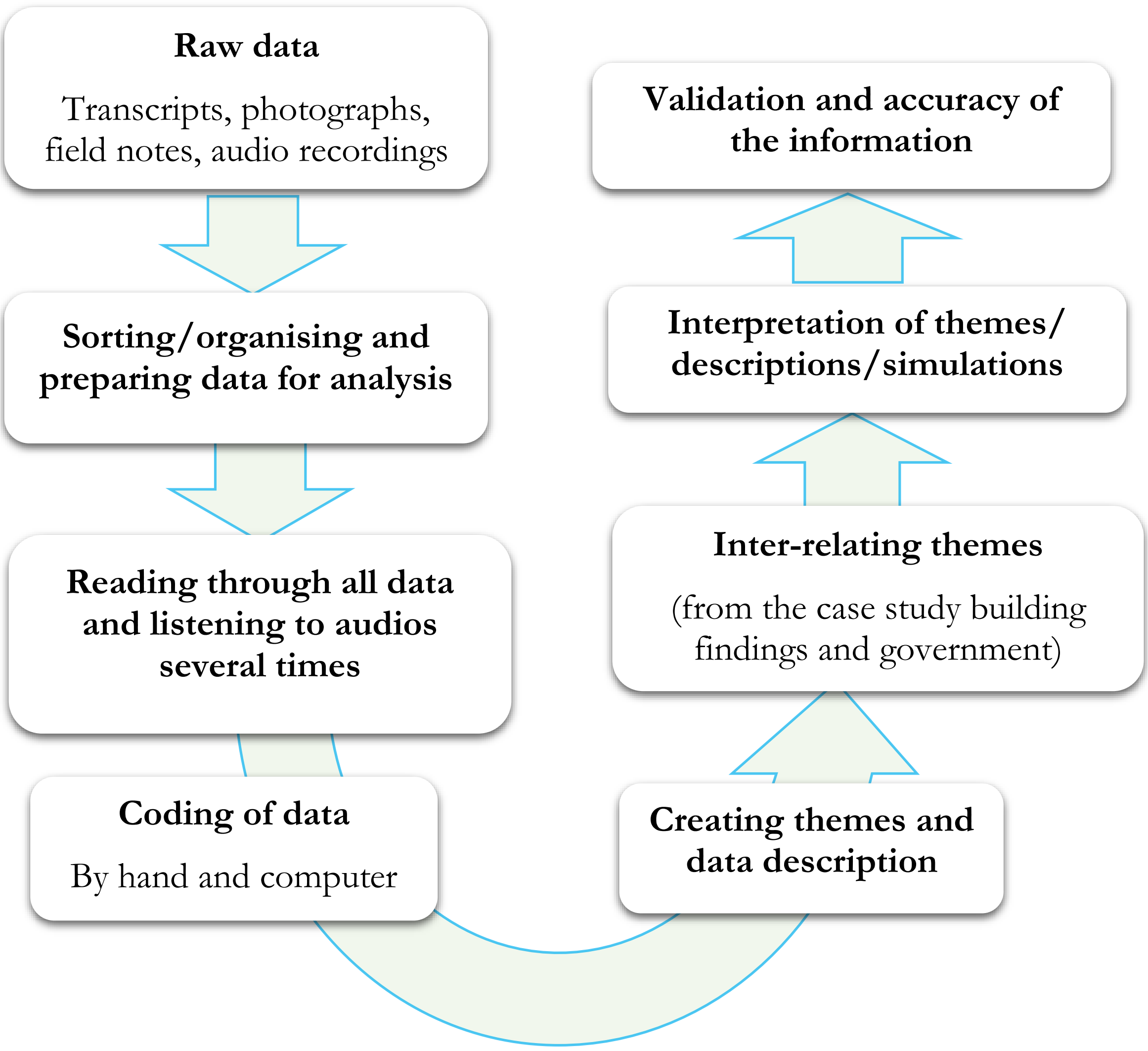

Figure 8: Data analysis and derivation of findings: **Source:** adapted from Creswell (2009)

The raw data included transcripts from audio recordings of interviews, field notes and photographs. The data were organised in accordance with the key themes applied in the semi-structured interview questions (see the questions guide in Appendix 1, Page 174). Audio recordings were transcribed and field notes were integrated into transcripts. The transcribed data were reviewed in order to co-relate with the research questions. Subsequently, key themes emerging from responses to the interview questions versus the research sub-questions were developed and applied towards deriving sub-findings of the study. The different themes were then coded in accordance with the research sub-questions and the interview questions. The amalgamated themes were then used to describe, narrate and interpret prevailing context/environment for DG with rooftop PV application for Uganda. Secondary data and legal documents (such as Uganda's RE Policy of 2002) from participants were reviewed and coded in order to guide the study towards overall findings on responsive business models and DG with rooftop PV technology application.

Table 4 below presents an overview of how the research questions were addressed based on the approach and methodologies described/narrated above.

Table 4: Data requirements, collection and analysis in relation to sub-questions of the study

Research sub-questions 1: Addressed mainly in chapter 4	**Data analysis and processes**
What are the policy/legislative opportunities and challenges for distributed generation with rooftop Photovoltaic for CHOB?	Field notes and transcripts were scanned Data collected were read through, reviewed and interpreted Audio recordings were listened to familiarize with the data collected and to detect issues regarding bias Data were transcribed and interpreted Data were coded using manual process then typed in computer for validation. A thematic and descriptive approach was adopted Data were analysed as described in Chapters 4 and 5, and interpreted in order to derive sub-finding
Interviewees: Purposely-sampled participants from ERA, Ministry of Energy and Mineral Development, Ministry of Works and Transport, Konserve Consult Ltd and UMEME respondent, CHOB property manager	
Primary data collected ❖ Information on policies and legislation on rooftop PV investment, grid interactive, mini/micro grids and off-grid applications ❖ Information on policies and legislation on retrofit and energy efficiency from Kampala Capital City Authority and Ministry of Works and Transport ❖ Accessibility; renting the rooftop for 20 years. Data were collected from CHOB property manager **Secondary data needed** ❖ Data on rooftop PV policies and regulations worldwide for existing office buildings ❖ Opportunities and challenges of DGRTPV diffusion worldwide and in Uganda	

<table>
<tr><td>Data collection tools and Instruments

❖ Semi-structured or open-ended interviews were used based on face-to-face oral questioning. Responses were recorded using the audio recorder and notes were taken
Online legal documents about rooftop PV policies and legislation were reviewed based on data captive notes/templates</td><td></td></tr>
<tr><td>Research sub-question 2: Addressed mainly in chapter 5</td><td>Data analysis and processes</td></tr>
<tr><td>What are the cost-effective energy efficiency interventions for retrofitting into CHOB?</td><td rowspan="3">Field notes, images/photographs and transcripts were scanned

Data collected were read through and interpreted

Audio recordings were listened to familiarize with data collected and to detect issues of bias

Data were transcribed and interpreted
Data were coded using manual process then typed in the computer for validation. A thematic and descriptive approach was adopted
Simulation using Design-Builder energy plus software was used to determine the baseline and simulated baseline to guide optimizations. Consequently, the energy efficiency and retrofits options were determined
Available drawings were interpreted and reviewed to guide retrofit simulations
Data were analysed as described in Chapters 4 and 5, and interpreted in order to derive sub-finding</td></tr>
<tr><td>Interviewees: the case study building occupants mainly the respondents, human resource managers and logistics and operations managers in the case study building.</td></tr>
<tr><td>Primary data collected include:

❖ Building energy audits: Energy consumption, appliances used in the building, lighting systems, size of the rooms, openings, ventilation systems, cooling and heating mechanism
❖ Hours of usage of the standalone diesel generators
❖ Expenditure on the use of both hydroelectricity and diesel electricity.
❖ Human behaviour and their environment (in and out) of the building.
❖ Landscape and parking spaces (traffic: peak days and off peak days).</td></tr>
</table>

<table>
<tr><td>Secondary data collected include:

Based on retrofitting of commercial office buildings performance, energy efficiency, and climate change mitigation interventions in relation to case studies from academic journals, and online reports by various organisations.

Data collection tools and instruments

❖ This was both direct and indirect. The researcher observed and made sketches using a tape measure, researcher diary (pen and paper) and a camera.
❖ Semi-structured or open-ended interviews were used and involved face-to-face oral questioning. Respondents were recorded using the audio recorder and notes were taken.
Policy documents on solar energy generation were reviewed using the eyes and senses.</td><td></td></tr>
<tr><td>Research sub-question 3: Addressed mainly in chapter 5 and 6</td><td>Data analysis and processes</td></tr>
<tr><td>To what extent can distributed generation with rooftop PV guarantee energy supply for CHOB?</td><td rowspan="3">Field notes and transcripts were scanned

Data collected were read through, reviewed and interpreted

Audio recordings were listened to familiarize with the data collected and to detect issues regarding bias

Data were transcribed and interpreted</td></tr>
<tr><td>Interviewees: ERA, UMEME respondent and CHOB occupants representatives (Managing directors, human resource managers and logistics and operations managers)</td></tr>
<tr><td>Primary data collected include:

❖ Available size of the roof
❖ Capability of tenants/owner to finance the facility.</td></tr>
</table>

❖ Available regulations and policies on DG ❖ Available subsidies and taxes ❖ Hours of hydroelectricity power outages. **Secondary data collected include:** ❖ Data about distributed generation technologies, and solar energy for commercial use. These data were collected from journals, textbooks, articles, reports and stories on D.G and rooftop PV Internet based sources were used as the researcher's tool to access and abstract secondary data. **Data collection tools and instruments** ❖ Both direct and indirect participant observation, use of tape measure, a diary (pen and paper) and a camera ❖ Semi-structured or open-ended interviews were used. This involved face to face oral questioning and the respondents were recorded using the voice/audio recorder and notes were taken Legal and policy documents on energy in Uganda were accessed and reviewed	Data were coded using manual process then typed using computer for validation. A thematic and descriptive approach was adopted Data were analysed as described in Chapters 4 and 5, and interpreted in order to derive sub-finding
Research sub-questions 4: Addressed mainly in chapter 6	**Data analysis and processes**
What is the financial viability of distributed generation with rooftop PV for CHOB?	Field notes and transcripts were scanned

Interviewees: UMEME respondent, Ministry of Energy and Mineral Development, ERA and Konserve Consult Ltd	Data collected were read through interpreted and transcribed Audio recordings were listened to familiarize with data collected and to detect issues of bias Data were coded using manual process then and typed in computer for validation. A thematic and descriptive approach was adopted Data were analysed as described in Chapters 4 and 5, and interpreted in order to derive sub-finding
Primary data collected include: ❖ Current donor requirements for potential investors ❖ Available commercial bank financing schemes linked to MEMD ❖ Capability of tenants/owner to finance the facility ❖ Owner/customer prefered model suggestions by researcher through interview ❖ Existing solar energy business models through interview of solar business companies **Secondary data collected include:** Data related to upfront capital investment for financing mechanisms for rooftop PV. The data were sourced from academic journals, textbooks and publications accessed through internet/google scholar. The data are based on commercial/ industrial and institutional business related case studies **Data collection tools and instruments** ❖ Semi-structured or open-ended interviews involved face-to-face dialogue and audio recorded with notes also taken. ❖ Review of legal and policy documents on energy in Uganda. ❖ Data collected were scanned and stored on a hard drive with a password-access restricted to the researcher only	

Overall research question: What would be the responsive business model scenarios for distributed generation based on rooftop PV technology as an opportunity towards energy security and climate change mitigation intervention for Crusader House Office Building (CHOB) in Kampala, Uganda?
Addressed through consolidation of sub-findings across the sub-questions in order to substantiate the overall findings, conclusion and recommendations

3.4 Ethical considerations

The study was guided by the research ethics requirements/standards of the University of the Witwatersrand (see ethics clearance certificate in the Appendix 2). Appointment letters, phone calls and emails were made in advance to the respondents in order to solicit prior consent and appointment. At the point of interviews, each participant was provided with information about the study and why they were identified as the relevant respondents. After taking the participant through the participant information sheet (PIS), the consent form was discussed and each participant was requested to sign the form.

In addition, the researcher obtained a formal permission letter from the case study property manager (Mercantile Properties Limited) which allowed the researcher to use the building as the case study building. Given the nature of the study, it was not possible to keep the building details anonymous. This is mainly because both specific location the as well as specific input data on nature of uses and related energy consumption were essential as primary data for inputs into the building performance simulation software. The permission letter was thus issued with an understanding that anonymity for the building cannot be guaranteed.

CHAPTER 4 POLICY AND LEGISLATION ENVIRONMENT FOR DG WITH SOLAR PV TECHNOLOGY IN UGANDA.

4.1 Introduction

One of the objectives of the study was to investigate the existing policies and regulations that would influence the scale-up in the deployment of DG with rooftop PV. This chapter presents the policy and legislation environment sub-findings for DG application with rooftop PV technology for Uganda. In addition, the study attempts to address the main research question in section 1.4.1 and sub-question 1.4.2, on the policy/legislative opportunities and challenges for distributed generation with rooftop PV for CHOB. The research sub-question was responded to through primary data from interviews and secondary data sourced from related policy and regulatory documents. The data collection involved interviewing respondents from the Electricity Regulatory Authority (ERA), Ministry of Energy and Mineral Development (MEMD), Kampala Capital City Authority (KCCA), Uganda Investment Authority (UIA), Konserve consultant and UMEME-Uganda's main electricity distributor, entrepreneur of the year 2015, who is also a shareholder in the 10MW utility-scale solar PV project in Tororo District.

4.2 Energy efficiency policy data and sub-findings

According to the MEMD respondent, the government is working on the energy labelling legal framework and the minimum performance standards for equipment and products, especially those imported into the country. Furthermore, the commissioner highlighted that the government of Uganda is planning to take record of all the large energy consumers such as organizations or industries/commercial businesses for easy monitoring and management by the ministry. The commissioner also pointed out that the high-energy consuming organizations or industries would have to carry out energy audits and report on their energy efficiency performance levels as well as strategies for EE improvement in cases where energy consumption is above the set standard.

Moreover, KCCA respondent confirmed that there is no legislation/regulations on energy efficiency either at national or local level. The council currently uses the Public Health Act of 1935 and building legislation of the 1950s when issues like EE were never thought about. However, the KCCA respondent pointed out that KCCA has been lobbying the policy formulators to include sections for energy efficiency. According to the Ministry of Works respondent, the ministry is conducting studies on EE categorization, classification management, regulation and implementation. According to the International Energy Agency (IEA), energy efficiency policies can be categorized according to seven economic sectors such as buildings, lighting, cross-sectoral, energy utilities, transport, industry, appliances and equipment. More so, the IEA posits that having mandatory Minimum Energy Performance (MEP) requirements and labels, test standards and measurement protocols for appliances and equipment, and final market transformation policies for appliances and equipment, would enable significant energy savings in the appliance and equipment category of an office building. Based on the interview data and sub-finding, EE policies are still at infancy levels and formulation development process under the Ministry of Works and Transport in collaboration with Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and UN-Habitat.

4.3 Renewable energy policies, legislation and distributed generation

4.3.1 Renewable energy policy and finance findings

Uganda has two energy policies that are currently operational. The first one is the National Energy Policy of 2002 (NEP 2002) and the second one is the Renewable Energy Policy of 2007 (REP 2007). According to interview with the ERA respondent, the REP 2007 aimed at increasing renewable energy generation in Uganda from 4% to 61% of total energy generated by 2018. Under this policy, ERA respondent highlighted that the initiators of this policy were looking at large scale hydropower generation. Therefore, if ERA is to follow the framers of the REP 2007, Uganda will have achieved 40% energy generation from renewables by 2018 from 17 small hydro projects totalling to 367MW, 81MW from bagasse (sugar cane waste burnt to generate energy) and 20MW solar energy generation. However, the ERA respondent elaborated that, these generation figures will further be increased with Isimba 183MW and Karuma 600MW of hydropower generation expected to be commissioned towards the end of 2018.

Furthermore, the ERA respondent mentioned that Uganda was among the first countries in Africa to adopt the Renewable Energy Feed in Tariffs (REFiTs) in 2007. However, the REFiTs did not attract investors as targeted by the REP 2007.

Consequently, reviews had to be done in 2009 and 2012 in order to motivate potential investors. In addition, the respondent mentioned that the review of 2012 largely removed solar PV technology from the policy because ERA took the decision to adopt a competitive bidding strategy for any further licensing of solar projects in the country. Besides the concern of not attracting investors, ERA respondent mentioned many other challenges faced by REP 2007 such as the massive load shedding at that time, failure of Uganda Electricity Transmission Company Limited (UETCL) to pay some of the Independent Power Producers (IPP) like Bugoye Power at that time, and end-user tariffs being subsidised at 46% by the government and yet only 14% of Uganda's population had access to electricity, especially in the urban areas. He also highlighted that in such a situation the high sought-after returns from the investors can put the country at risk of over-indebtedness if the government has to cover for the difference in tariff level.

As one of the interventions, the government abolished the end-user subsidies in 2012, which resulted in an increase of end user tariffs by 46% after ERA strongly lobbied for the complete removal of the subsidies. This was motivated on the fact that the subsidies did not reach the target group (poor people) in rural areas. Instead they went to people in areas already enjoying grid connection and especially those who can afford their electricity bills. According to ERA engineer, this was unfair to the people living in unelectrified rural areas who were also paying taxes. For the sake of equity, ERA proposed that subsidy-funds be used to invest in the transmission and distribution infrastructure as well as generation. The respondent explained that abolishing the end-user subsidies facilitated the release of funds towards development and the commissioning of Karuma and Isimba hydropower generation. Further, the respondent talked about the 23% current electricity access increase and stated that by 2020, 40% of Uganda's population is expected to have been connected to the grid.

On REFiT challenges, the respondent mentioned that ERA approached global development partners to financially support Uganda's energy generation sector and the development partners responded positively. The Global Energy Transfer Feed-in Tariffs (GETFiT) programme was proposed by the partners and approved by the regulator in 2013. This programme provided funds supported by the European Union, the government of Germany through Kreditanstalt für Wiederaufbau (KfW) development bank, the Netherlands, Norway and the UK as a top-up on the cost per kilowatt-hour (kWh) to what UETCL provided under the 2007, 2009 and 2012 REFiTs. In addition, this premium top-up was given as a grant to a few of the private-sector developers who were capable of raising half of their initial project investment costs. This grant was calculated on the basis of the expected generation of eligible projects over the lifetime of the 20-year standardised Power Purchase Agreement (PPA) which the developer was expected to sign with UETCL. The respondent further expressed that developers were paid 50% of the 20-year top-up on commissioning of the project and a further 10% was paid yearly for five years as the project performance increased.

In summary, the respondent pointed out that the GET Fit premium is entirely for the 20 year period but is paid within 5 years. This was aimed at helping the investors/ developers with the upfront capital cost that is needed for the RE projects. In addition, this type of repayment helps the private investors to have a front loading of cash flow such that when discounted over the lifetime of the PPA project, it becomes more viable economically. More so, the respondent highlighted that GETFiT programme helped the country to achieve the other aspect of the REP 2007 policy which was standardisation of documents and especially the Power Purchase Agreement (PPA) and the Implementation Agreement. The programme allowed ERA to hire some of the best lawyers in the world who guided on the process of consultations with major lenders such as IFC and FMO when the regulator was developing the standard agreement documents. Lastly, the respondent highlighted that another objective of REP 2007 was to facilitate a 20% increase in biofuel production by 2018, but this has not been pursued as yet.

4.3.2 Distributed generation with rooftop solar PV

In order to get a better understanding on the current status of rooftop solar PV in Uganda, the study used a semi-structured interview process with the following themes:

- ❖ Solar PV energy production in Uganda
- ❖ Solar PV market and applications
- ❖ Opportunities and challenges of DG with rooftop PV
- ❖ Opinion about DG with rooftop PV

- ❖ Opinion about mini-grid/micro grid or grid interactive rooftop PV
- ❖ Regulations and taxes for DG with rooftop PV
- ❖ Recommendations for rooftop PV with DG.

For solar PV generation in Uganda, the principal project engineer of Electricity Regulatory Authority Technical Regulation (ERATR) and the respondent at Ministry of Energy and Mineral Development (MEMD) talked about the licensed grid-connected solar projects which included the 10MW plant licensed in Soroti District in Opuyo (Eastern Uganda) and was to be commissioned in December 2016 but only commissioned later as discussed in Chapter 1. The engineer explained the Soroti project was procured through ERA tender process carried out in November 2014. The developer of the project had to complete full-scale Environmental Impact Assessment (EIA), solicit financing and was also subjected to additional approvals. The construction started in February 2016. It is reported by Regional Investment Agency-COMESA that the total project cost was USD$19 million. The European Union was the largest financier with a contribution of approximately 8.7 million Euros and FMO (a Dutch development bank) financed the project at about USD$5.35 million (RIA, 2016). According to RIA, the 33-acre site project is to provide power for about 40,000 households.

ERA respondent pointed out that the 10MW licensed solar project in Tororo (Eastern Uganda) is located near the Tororo substation, and the project construction kicked off in November 2016. Other licensed projects in the country (as the ERA respondent outlined) include the 20MW in Kabulasoke-Gomba-Mpigi District in the central region of Uganda) and a 10MW project in Mayuge District (Eastern Uganda). A further 20MW wind projects located in Tororo and Karamoja in the northern region of Uganda have been guaranteed licence and are at feasibility study stage.

The ERA respondent explained that the Tororo solar project-developer had applied for 50MW, but due to the national grid stability constrains, there is a limit for power capacity to be fed into the national grid for intermittent power. The ERA respondent highlighted that a study to determine the capacity of renewable energy that can be fed into the national grid was conducted by ERA and the system operator (Uganda Electricity Transmission Company Limited -UETCL). ERA and UETCL established that the national grid capacity could only accommodate 89MW maximum load of renewable energy generation. Consequently, ERA took a decision that any further licensing of any renewable energy generation was to be subjected to a competitive bidding in order to better manage the available but limited grid capacity. The respondent highlighted that a total of 60MW (10MW in Soroti, 10MW in Tororo, 20MW in Mayuge and 20MW in Mpigi) was licensed to various developers through unsolicited bidding. The authority has therefore aborted further applications for unsolicited project bids especially for the wind and solar projects as currently licensed projects were totalling to over 100MW, a figure way above the maximum available grid capacity for the intermittent renewable energy, and yet in addition, the authority had also licensed wind projects which are at feasibility study stage.

Despite the limited space on the national grid for intermittent power, the respondent stated that the authority is open to off-grid technology applications and own use projects. In addition, he talked about mini-grids that are licence exempted, especially if they are less than 2MW and designed to be installed more than one kilometre from Uganda's main power distributor footprint. The engineer also highlighted that mini-grid tariffs are often higher than grid tariffs because mini-grid project developers do not enjoy economies of scale. In light of this, the researcher disclosed the case study building name to the respondent. He narrated that the CHOB is located in the city centre, which is within UMEME concession footprint. Therefore, rooftop PV energy development or investment on CHOB, would not be permitted to sell electricity to neighbouring buildings or to the grid, but such investment is permitted for own-use generation via off-grid or standalone application. The respondent further explained that to do a business with such a system (off-grid scenario), an investor has to design the system such that the regulator (ERA) can licence it for operation. The respondent based his justification for not selling power to neighbouring buildings by quoting the Electricity Act 1999, which states that all power, when generated, can be consumed for own use but can not be sold to the neighbouring buildings. However, in case the developer or building owner wants to sell power, it can only be sold to UETCL as the only buyer of electricity and only seller to distribution companies in the country. According to Uganda Investment Authority (UIA) respondent, the idea of having a sole energy buyer and seller is good. He argued that the RE producers are likely to unfairly overcharge or overshoot the price of electricity generated from the system.

Regarding partnerships, the ERA respondent clarified that the authority (ERA) permits investors or developers interested in a joint venture with the already licensed companies operating under unsolicited bidding system. However, joint ventures/ partnerships with licenced companies under the competitive bidding process will not be permitted. Third parties who would be interested in a partnership with the existing licence holders under competitive bidding would be subjected to a reviewing and validation process of their credentials by the regulator and other government development entities.

4.4 Solar PV market, production and applications in Uganda

The UMEME respondent states that for the last 5 years, Uganda has been electricity-secure mainly because after Bujagali hydropower project was commissioned at 250MW on 12 July 2012, there was an excess of supply over demand. Before that, the country had a major deficit that caused significant load shedding. This made the government realize that the country could not entirely depend on hydropower as the water levels had dropped significantly due to excess water releases at the Nalubaale and Kiira dams and low rainfall and climate change thus contributing to major generation shortfall far below the intake capacity. In addition, the respondent gave examples of the generation mix which includes geothermal, solar, wind, bagasse (sugar cane refuse which is burnt to generate power) as possible alternatives in the energy mix in order to avoid dependence on one source of power.

According to ERA respondent, Uganda's peak demand is 592MW. He mentioned that most of the country's energy generation is renewable apart from the 14MW that comes from two thermal power stations. The UMEME respondent explained that solar energy is gaining traction mainly in rural areas located beyond the current grid footprint of the public utility. In the city centres, where the grid has been established for along time now, the respondent stated there has been limited adoption of solar PV generation. However, many of the commercial buildings like hotels have embraced solar energy for water heating, which has gained some traction. He mentioned that this has been largely driven by the World Bank subsidies through Private Sector Foundation Uganda (PSFU). He also stated that many of the institutions like hospitals and schools have been able to install solar water heaters. Schools within the city (especially the boarding schools) have embraced solar PV installation as an alternative source of power. This source of power is often used from 7pm to 10pm, as they cannot afford the high prices of diesel fuel for standby generators. Several of these schools use batteries for power backup. In addition, he mentioned that "solar PV does not have a big base load thus its acceptance has been limited to only a few people who need power for only 4-5 hours." ERA respondent further pointed out that those exposed to PV technology still think that solar energy is expensive despite the high annual utility electricity costs and diesel fuel costs they incur. He suggested that people need to be made aware that solar can be used for bigger applications in commercial buildings and institutions even where kilowatt-scale of loads are involved. The general perception that solar generated electricity merely serves light duty loads such as lighting systems needs to be changed.

Konserve solar company respondent highlighted that many people look at solar as a trading business while others look at solar PV as a business for the poor. However, he suggested that people need to know that PV is a technology which provides people with electricity services. He mentioned that once people get to know PV-technology as a service, the rate of adoption for solar PV systems in Uganda would increase.

ERA respondent suggested that property owners need to be made aware of the cash flow outlays and savings when using PV versus using grid-electricity from UMEME. There is significant cost savings on energy expenditure in the long run for building owners and for investors. Kampala has so many commercial office-building rooftops that are not utilized for rooftop PV DG innovations. Whereas the rooftops in the cities are an opportunity to tap for DG with rooftop PV business, the respondent of Konserve Consult Ltd highlighted that "the market is growing but it is growing downwards" in the small- scale market segment. Many people currently import solar products for sale to areas that are not connected to the grid and especially in the rural areas. However, he mentioned that there are a few people within the city (especially those who are unwilling to tolerate UMEME power blackouts and the ever increasing high electricity costs) who have decided to install close to 300W solar PV systems integrated with either automatic or manual inverter to mitigate the blackouts and UMEME electricity cost escalations.

According to the UMEME respondent, a customer's base load would influence the choice of rooftop PV systems. He elaborated that many buildings in the city would require a big roof surface to install a PV system that would meet the daily energy demands of a seven-storey building (referring to his own office building). The use of batteries would solve the energy demands of such buildings when the sun is inadequate for the demand. However, he pointed out that this would come at a high initial investment cost for battery installations, which thus slows down the solar PV uptake. He explained that office building occupants "have got to use the power when it is available and when it is not available you must have an alternative, which implies the need for a hybrid system." This respondent used his experience with the 10MW solar plant in Tororo District and expressed an example that if PV system baseload (the baseload is the ability of the system/device to power plug loads) was about 30% and a diesel generator base load at 99%, the PV systems would not be an economically viable project for the investment. He emphasized that the base load is an important component for any PV system installation. In addition, the respondent expressed another scenario of a seven-storey office building with high appliance and equipment loads and a relatively small roof surface area to accommodate the required solar panels to meet its load demand. However, he pointed out that rooftop PV systems would be viable for the lighting systems and similar light duty loads in office buildings.

4.5 Challenges of solar PV market, production and applications in Uganda

The study looked at some challenges that many respondents pointed out to explain the slow uptake of solar PV systems in Uganda. According to the UIA respondent, there are very few skilled personnel for solar PV technology in the country. He pointed out that when solar products are purchased, the operation and maintenance costs become a challenge especially when the system breaks down. In addition, he mentioned that Uganda is faced with perpetual dust and therefore installations would need frequent cleaning and maintenance. In addition, security concerns (especially over theft of solar modules once they have been installed) constitutes another reason for the slow uptake. The UMEME respondent commented that many of Uganda's private sector companies (and especially contractors) are not formally certified as solar engineering contractors/experts or as limited liability businesses. Yet, in order to get access to funding from international banks and support agents, they require world class certified contractors. The respondent highlighted that he has a similar experience with the 10MW Tororo north solar project where he was forced to collaborate with a

US-based civil company called Building Energy Ltd, which had installed many similar projects in African countries like South Africa.

Konserve Consults Limited respondent expressed the view that solar PV still remains an expensive energy technology with the cost per watt peak at about half a dollar. It is therefore a costly investment to install rooftop PV at the scale of a commercial building such as CHOB. He gave an example where their company made rooftop PV proposal for Mulago National Referral Hospital (for lighting, hotwater supply and other plug loads) but the government (Ministry of Health and MEMD) did not show much interest. In addition, he said their company tried to install solar PV systems for Kololo airstrip rooftop but "the project proved to be expensive" and was therefore abandoned.

One of the tenants in the case study building observed that Kampala straddles the equator and therefore many commercial buildings should be using solar energy, but the technology is not economically viable and hence the reason why many building owners are not showing interest. Building owners need a convincing return on investment in order to adopt such innovations.

The participant further pointed out that Kampala regularly experiences cloud cover in the afternoons, which poses a radiation reduction challenge. He demonstrated this by example where efforts to take aerial photography of the whole country have been constrained by cloud cover in the central and southern region of Uganda.

The case study building respondent also noted that the current legislation has influenced many building owners not to invest in solar PV technology. He suggested that the government should develop policies /regulations for mandatory solar PV systems for buildings and also ensure that every building owner in the city complies with the law/regulations.

The UMEME respondent added that the issue of bureaucracy where people fail to fully understand the requirements for generation under the Power Purchase Agreements (PPAs) was the other challenge facing people in Uganda. However, he stated that the regulator (herein ERA) is slowly addressing that problem. In addition, he talked about the REP 2007 Feed-in Tariff (FiTs) being too low as it was set in 2007 (almost 10 years ago). Despite these challenges, he highlighted that the fall in prices for solar PV modules has once again motivated many investors like him to invest in the technology. In addition, he pointed out that ERA increased solar PV tariffs to 11USD cents per kilowatt-hour, which he regards as an attractive price compared to countries like Zambia at 6.6USD cents and Dubai at 3USD cents. Furthermore, he mentioned that it is not feasible to invest in PV systems without the economies of scale especially for a case like Uganda where the cost of capital is about 9%. He stated that it would help to get a subsidy of some kind that would enhance viability for investors and thus make the technology more competitive.

A respondent from MEMD commented on the high initial capital cost of solar PV technology and added that the current legal frameworks do not motivate many people to take up innovations like rooftop PV. The net metering legal frameworks, which is under study by both ERA and MEMD, is likely to motivate private investors and local companies to explore innovations like mini-grid technology for rooftop applications in Kampala. However, he concurs that until the policies are in place, only own- use option is now open for consideration.

According to the Konserve respondent, most of those involved in policy matters related to solar PV technology do not adequately understand its potential. He gave an example where, for electricity generation, PV systems are exempt from tax. However, he expressed disappointment about components like charge controllers which are crucial on generation side but are currently being taxed thus reflecting a lack of understanding of how the whole technology works as a system.

ERA and MEMD representatives state that solar accessories traded within East Africa are tax exempt unlike solar products/accessories or equipment such as cables and the peripherals that are sourced outside East Africa which are subjected to taxes (import duty). The MEMD respondent also noted that any product traded that is not recognized as a solar PV product or accessory is subjected to import duty tax. UMEME respondent also argued that one reason that delayed the commissioning of the 10MW project in Tororo was due to the taxes imposed whereas he had been of the view that solar projects were zero tax based as with the case with hydropower generation projects. Consequently, he mentioned that his company in Simba Telecom Ltd, had to wait for the Ministry of Finance Planning and Economic Development (MFPED) 2016 budget to be passed in order to pave way for agreements with the regulator about tax exemptions for the solar project. Konserve respondent observed that their company had also faced similar tax challenges on the solar products that the company was dealing in. In addition, he stated they had to write a letter to MFPED seeking tax guidance on the solar accessories and products for solar PV generation.

One other challenge for PV technology that the Konserve Consults Ltd respondent highlighted was the lack of quality control. He pointed out that Uganda has failed to manage this situation, and therefore many inferior quality products have undermined the market and contributed to price distortions for compliant products. He suggested that there is need to sensitize end-users and seek government support towards non-compliant products in the market.

ERA respondent expressed the view that the existing transmission and distribution infrastructure was never planned to the capacity or standard of the imminent rapid increase in generation. The engineer gave an example of the current transmission line with 852MW-installed capacity yet by the year 2021, the country will be generating close to 2,000MW (additional 1,200MW capacity in the space of four years). The engineer estimates that the existing infrastructure to be two and half times under capacity compared to what is required to accommodate the projected generation by 2018, especially with the commissioning of Soroti 10MW solar project as well as Karuma and Isimba small hydro projects.

Reflecting on the responses of all the interviewed participants, it was observed that they were unaware of the full potential of DG with rooftop PV. Most of them were of the view that rooftop PV technology cannot power office buildings more than one storey. These respondents were aware of the solar home system applications for residential but not similar systems for commercial buildings.

4.6 Respondent opinions and recommendations for solar PV developers

According to the respondent at MEMD, for the electricity market, Uganda operates under a single-seller business model where UETCL is the only buyer and seller of bulk electricity for distribution to consumers. As a result, the law does not allow entities/ consumers to sell power to the grid or to other entities/consumers. The MEMD respondent highlighted that this is an issue which the country needs to address in order to incentivise innovations like commercial rooftop solar PV. He further highlighted that if various entities were capable of generating their own power for consumption, the demand on government resources would be significantly moderated. However, this will only occur once the right legislative frameworks and policies are adopted and implemented.

One of the challenges of the slow uptake of solar PV has been the high initial capital cost, especially where a hybrid system is required. All the respondents concurred that there is an opportunity to feed into the transmission lines in Uganda but without any payment to the generating entity. One of the respondents mentioned that they often practice illegally where a system consisting of a grid connecting inverter is designed such that solar energy generated is fed into the grid as power backup. The grid connecting investor takes over the role of the power supply using solar as opposed to UMEME. The respondent elaborated that this entails a type of flipping where the backup side is fitted thus making the grid as the backup and solar the main supply. More so, the respondent gave an example where a 15kW system was installed for a school using this type of system where the distribution network acted as the backup in order to circumvent the need for the battery storage.

The respondent at MEMD noted that developers would need to enter into an agreement with the utility in order to bank their power in the network and in the case where the building and system owner /user consumes more than what was banked, then the excess power would have to be paid for at agreed tariffs (this possibly refers to net-metering).

The UMEME respondent concluded that Uganda has a liberal policy on foreign exchange and is therefore, investor friendly. However, there are still some bureaucracy issues, which the government needs to work on urgently in order to attract foreign investments in critical sectors such as energy. More so, he highlighted that there is always going to be demand for power and a country can only grow when it has surplus power capacity rather than when it has a power shortage. The excess power can in turn force electricity prices to fall and thus attract more foreign investors to set up additional industrial projects in the country which would in-turn demand more power.

4.7 Financing mechanisms

Having abolished the end-user subsidies, the government established a finance organization called Uganda Energy Credit Capitalization Company (UECCC) to help in the financing of solar-related projects like rooftop PV innovations. ERA respondent noted that UECCC has funds from government and development partners who target PV investment. ERA engineer added that UECCC works with local banks like FINCA and other microfinance organizations towards providing solar loans for PV projects. The legal document reviewed by the researcher from UECCC office highlights the following objectives of UECCC:

- ❖ Mobilize resources from various partners for the development of renewable energy projects in Uganda
- ❖ Serve as a credit support institution and promote private sector-led renewable energy infrastructure development
- ❖ Provide financial, technical and other support to renewable energy and/or rural electrification projects in Uganda

According to the UMEME respondent, local investors and developers in Uganda need to search externally for finance because there is better availability of low-cost funding in the western world especially for full deployment of DG with solar PV technology in Uganda. The respondent pointed out that there were many investors making inquiries with him about the opportunity of collaborating or finding organizations they can collaborate with, for rooftop PV business. Yet a few years ago, he could hardly find any financing support for solar PV from abroad. The respondent gave an example of his 10MW project, whereby he acquired funding from FMO, a European Bank that managed to provide approximately USD 14.7million loan with reasonable long term of a 17-year period. Hence, he concluded that funding solar PV systems is not a problem as international finance can be sourced at a lower interest rate.

UMEME respondent recommended the emerging/innovative financing mechanisms such as the one applied by MKOPA which deals with solar home systems and a wide range of solar merchandise. He explained that under the model, the front-loaded cost of installation burden is reduced considerably. He posited that customers pay a certain amount as deposit and gradually pay up the balance within a year. In addition, the distributor has the ability to switch off the customer if he or she does not keep pace with the agreed instalments. The respondent was of the view that the business model has worked well and therefore argues that such business-model innovations are critical for the country's future energy needs as he does not expect that the public utility will ever cover supply power to more than 50% of the potential customers especially those in the rural areas. He therefore suggests that the other 50% would have to be addressed by alternative solutions such as MKOPA. Whereas the respondent was more focused on the rural areas, the study analysed that such a business model could be adopted/transformed to mitigate the high upfront cost for PV investment for CHOB.

Besides external funding and government subsidies, the study observed that building owners could equally finance rooftop PV investment. One of the key observations in this regard is that the property-building representative highlighted that Ushs2.3 million (which is approximately 660USD) was spent monthly on the standalone diesel generator operation. In addition, she stated that 8USD/m^2 is the prevailing charge for office rental. Given that the net floor area of the case study building is 4,164.16 m^2, this implies that building yields approximately 33,313.28USD/month. This is an indicator that there is potential by CHOB property manager to invest in the rooftop PV system. Alternatively, the property owner could request tenants to pay a certain amount in advance possibly with an agreement that tenant's monthly electricity costs could be reduced compared to the grid electricity tariff. This is premised on direct observation where many tenants interviewed (especially those that rented the office space for 20 years) expressed their willingness co-operate with the property manager in order to reduce their energy costs.

4.8 Conclusion

Based on the data analysis in response to the first sub-question, some of the key sub findings are captured as follows.

Renewable energy policy

Despite Uganda's grid being limited to a capacity of 89MW of RE mix, it is evident that the two existing RE policies highlighted in this chapter as well as the Electricity Act of 1999, need to be reviewed and possibly re-structured in order to facilitate scale-up adoption of grid-interactive rooftop PV for both commercial and residential buildings. However, within the existing policy and legislation, off-grid or stand-alone deployment of rooftop PV is permitted under licencing conditions. Moreover, the chapter has highlighted that a mini-grid technology could only apply if the case study building (CHOB) was located at a minimum of 1.5km away from the UMEME concession/grid.

Currently, grid-connected generation in Uganda only applies for large DG systems above 10MW. The chapter has highlighted several RE projects that are licensed and also noted the contradiction that the generation capacity is far larger than the available national grid capacity. This is an indication that there is potential for Uganda's grid infrastructure to be improved and expanded in order to incentivise grid interactive rooftop PV investments in the long run.

Challenges

- The respondents' response in this chapter clearly indicate that solar business in Uganda is still in its infancy, despite the 11 cents USD FiT tariff for solar energy generation
- Lack of supportive policies and legislation such as net metering, energy efficiency for rooftop PV technology or RE small-scale projects to facilitate the integration of solar energy use in buildings. As highlighted in the chapter some solar accessories and products traded out of East African regions are subject to tax.
- Bureaucracy challenges were also highlighted by respondents under this sub-question. However, the government is slowly addressing this challenge, especially through streamlining of regulations and related documents
- The chapter has discussed system price distortion due to inferior solar products on the market in Uganda. This is evidence of the lack of quality control system for solar products or business entity in the country
- High initial capital costs for PV systems
- Public ignorance on rooftop PV potential for existing commercial buildings such as CHOB
- Inadequate certified/skilled workforce (especially engineers and technicians)
- The city is faced with much dust hence increasing costs for operations and maintenance of the rooftop PV-technology installations

Opportunities

- The rapid fall of PV-system costs globally
- International investors interested in reducing carbon emissions with a keen interest to invest in Uganda
- The accelerating diesel fuel prices (as a competing alternative)
- Uganda's high intensity of solar radiation at an average of 5.1kWh/m^2/day
- The country is endowed with natural resources and longer sun hours (ranging from 4 to 6 hours)
- Rapid construction of commercial buildings with flat roofs in the city
- Increasing microfinance organisations in the country

Rooftop PV source of funding opportunity

The chapter has highlighted that 46% of end-user subsidies were abolished due to inequality where only 14 % had access to electricity. Later, the government decided to establish UECCC to provide solar loans at low interest-rates for rooftop solar projects. This could be an opportunity for CHOB as an alternative source of funding. Moreover, the chapter has highlighted the potential of applying for GETFiT scheme support towards small-scale projects such as rooftop PV for existing commercial buildings such as CHOB.

It has equally been highlighted that several commercial buildings, such as hotels, have embraced solar energy use, especially as a result of World Bank's subsidies to the Private Sector Foundation Uganda. It is therefore an opportunity available for rooftop PV project funding. In addition, the chapter has noted that there is potential for property owners to finance rooftop solar projects themselves for own use.

The analysis has also identified an issue that would require further research. This relates to the opportunity of using the national grid as a backup system for excess power generated from solar systems, and using both the battery storage facility and national grid as the backup mechanism. This opportunity of exporting excess power generated by rooftop PV system to the grid even where no revenue can be earned (until net metering policies are operational) could motivate diffusion of rooftop PV technology deployment in the country.

In nutshell, the current policies and legislative environment in Uganda do not permit commercial buildings such as CHOB to generate solar energy and export to the grid. However, there is an opportunity for own use only and with potential for grid export in the future. In addition, it can be expected that the prevailing market/operational gaps (such as skill shortages, unresponsive standards as well as cleaning-routines to deal with dust), are likely to be incrementally addressed once the required policy instruments come into force.

CHAPTER 5 CRUSADER HOUSE OFFICE BUILDING (CHOB) RETROFIT, ENERGY EFFICIENCY AND CONSERVATION MEASURES

5.1 Introduction

This chapter presents findings on the second sub-research question which addresses the cost-effective energy efficiency measures for retrofitting existing commercial buildings such as CHOB in Kampala. The following baseline factors are considered for energy audits of the case study building.

- Energy consumption
- Occupants satisfaction
- The conditions of the building in terms of daylighting, ventilation, building materials, orientation, office spaces, equipment (mechanical and electrical)

According to Ma *et al.* (2012), energy auditing is used to analyse building energy data, understand building energy use, identify areas with energy wastes, and guiding proposals on no-cost and low cost energy conservation measures. Under the second sub question, the objective of the study was to investigate possible interventions that would make the case study building more energy efficient either by passive design strategies or active strategies as discussed under sub-section 5.6.

5.2 Climatic conditions for CHOB

The case study building is located in Kampala- Uganda and lies at latitude 0.347596^{o}N and longitude 32.582^{o}E. Kampala straddles the equator and it experiences a tropical type of climate. The annual precipitation levels range between 1,200mm and 1,500mm wth the hottest months being January and February. The dry season starts from December to February and June to August, while the wet season starts from March to May and September to November. The monthly average temperatures for Kampala fall between 19^{o}C and 27^{o}C throughout the year (Safaris bookings, 2017).

In addition, the city is located near Lake Victoria and thus experiences cloud cover that reduces the solar hours from approximately six (the common availability levels for the region) to about four hours. Due to the high altitude around Lake Victoria, the morning hours tend to be cold and slightly rainy. The occupants in Crusader House

Office Building (CHOB) were observed wearing jackets especially in the morning hours between 8am and 11am (this was during the wet in season in September). Therefore, it is imperative to improve the solar gains into the building and maximise natural ventilation especially for the times when the sun is overhead.

5.3 The case study building location, topography and precinct

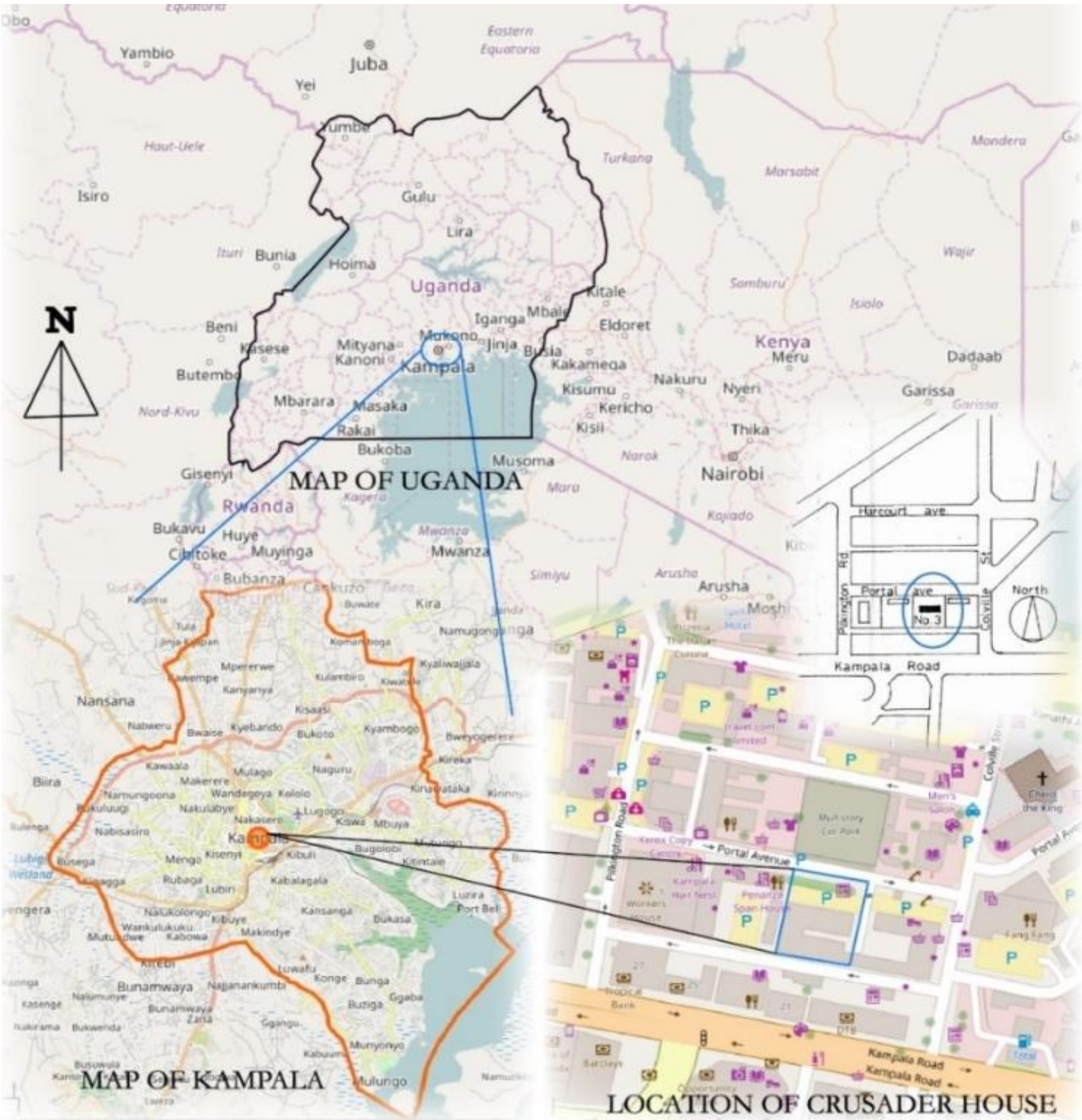

Figure 9: The case study location in Kampala, Uganda. **Source:** Open Street Maps

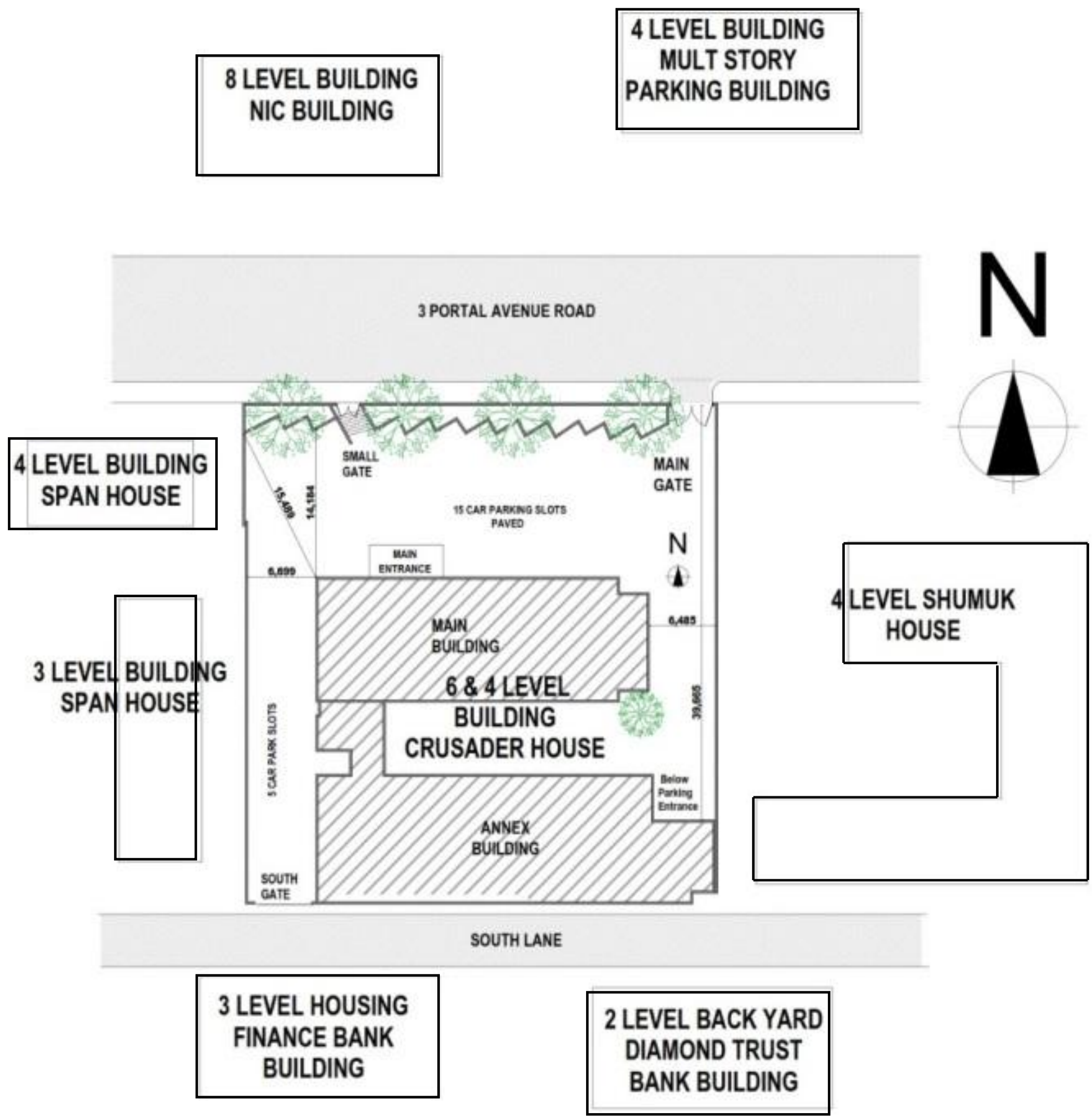

Figure 10: Crusader House site plan and immediate precinct. **Source:** Direct observation (author)

The neighbouring buildings (see Figure 10) do not overshadow the case study building (especially on the roof), and therefore they do not have an effect on the performance of rooftop PV installation in this case. Further, the case study building is shaded with trees planted in the north along 3 Portal Avenue Road. The building is oriented along the east and west axis, rectangular and has more openings on the north and south facades. The study therefore notes that the building orientation is favourable for solar rooftop PV installations. It is worth noting that buildings oriented to the north often require solar shading and maximisation of natural ventilation under equatorial climate regions.

5.4 Baseline case study building information

In reference to sub-section 1.1.4, the case study building was approved by the town council in 1987 and built in 1988 on a 2,090.8m^2 leasehold plot. The site development entails two blocks, which are the main building and the annex. The main building is older and was built in 1988 and annex was built in 1993. Even though both blocks are designed/built to a similar style (see Figure 11 and 12) but the interior partitioning pattern varies across the two blocks. However, this was deemed to be of no significance implication in the simulation and resultant energy use intensity finding.

The main building footprint is 390m^2 and the net floor area is 2,336.43m^2 while the Annex building footprint is 499m^2 and the net floor area is 1,827.73m^2. Table 5, shows a summary of the case study building baseline information which served to guide the asseement of the case study building performance.

Table 5: Crusader House building parameters

Characteristics/Building parameters	**Description**
Plot Size	2,090.8m^2 on leasehold land title
Occupancy	Office building working hours from 8:00am-5:00pm
Number of floors	10
Net floor area	4,164.16m^2
Year of Construction	1988 (main block) and 1993 (annex)
Operational/occupancy hours	10 hours for 5 days
Office occupants	240 people
Solar shade	1 metre overhangs
Openings	6mm clear single glazed steel framing and wood
Roof	Steel profile sheets on reinforced concrete
Roof area	610m^2
External walls	230mm concrete blocks
Internal walls	100mm plasterboard partition
Ceiling	Concrete
Floor	Carpet on cement screed
Parking	52 parking slots
Utility commercial electricity tariff	629UGX/kWh or 0.175USD/kWh
Utility R.E tariff	0.11USD/kWh

5.4.1 Building envelope

Open-plan

The building has a double rectangular form primarily based on open-plan design for both blocks. Different professional firms who engage in different occupations occupy the blocks. As a result, the occupants partition the office space to suit their type of work but at a risk of compromising on daylight and cross ventilation potential of the building. The shorter rectangular block to the south is five levels but with open parking on the ground floor, while the other block to the north is six levels. Therefore, the case study building has ten habitable floors, which were analysed for energy efficiency and retrofit interventions.

Figure 11: a) Primary Crusader House open plan design. b) Internal partitions

Source: a) Scanned and adapted from primary architectural drawings **b)** drafted as observed by author

Figure 11.a, above is a typical open-plan for the first floor. The plan illustrates the office space and facilities such as toilets, pantry, staircase and lifts for all levels. Figure 11.b, indicates internal partitioning of offices on the first floor. The internal-partition walls and room layouts on all the floors did not differ significantly and was therefore deemed to assume a typical configuration.

Fenestration and doors

The case study building has steel framed windows fitted with 6mm single clear glazing.

The building primarily has a glazed facade on the north and south elevations. The strip windows are 1m wide and 1.75m high and spaced at 0.3m intervals. There are a few windows on the east and west facades that provide daylight into the corridors.

External walls, shading and finishes

The external walls are 230mm thick, including 15mm plaster on both sides (internal and external) and made of solid concrete blocks. The concrete floor slabs extend 1m beyond the walls to provide shading. The soffit of the concrete slab shades is painted with dark colours. This limits daylight reflections into the internal rooms of the office spaces. Manually controlled internal blinds are used to manage direct sunlight from north façade windows. Figure 12, below shows the external wall finishes and the horizontal solar shading soffit finished with non-reflective paint/colour.

Figure 12: Crusader House northeast perspective on the left, case study horizontal shading and main entrance on the right. **Source:** Photo by the author on the 12 September at 12pm (2016).

Figure 13:a, is a view taken along 3Portal Avenue Road and 13:b, image was taken at the gate of the case study building as shown in the site plan, Figure 10 (see Sub-section 5.3). Figure 13, also shows trees on site, located in the northern portion of the site in order to shade off direct solar radiation and to trap dust from the dusty road.

Figure 13: Crusader House photographs. **Source:** Photo by the author on the 12 September 2016 at 12pm.

Roof

The roof construction is made of 200mm thick flat concrete slab with steel profile sheet fixed at a slope of approximately 6 degrees. The sheets are installed to prevent rain water logging onto the concrete slab. Currently, the roof accommodates the air conditioning plants and lift plant rooms as shown in Figure 14. The figure shows the type of the steel profile sheets, air conditioning plant and lifts plant room. The available roof area for possible rooftop PV installation is 610m^2.

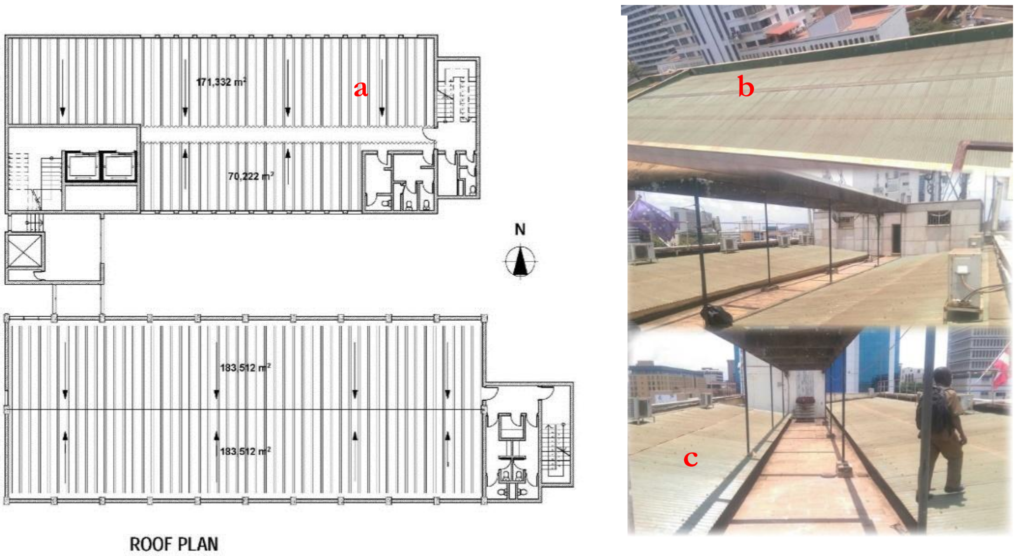

Figure 14: The case study roof plan and photograph. **Source:** drafted by author (2016); Photograph by author (2016).

5.4.2 Crusader House occupancy

The office building accommodates about 240 people in both blocks, with a majority being employees of architectural and civil engineering consulting firms. The annex building is occupied by public-sector organisations such as Project for Financial Inclusion in Rural Areas (PROFIRA) and the Judiciary Family Division (JFD). Bunyonyi Safaris, Newplan Limited, Cowi Engineering Consultants and the Austrian Embassy Development Cooperation (AEDC) are other occupants of the main building. The number of staff are as listed on Table 6 for permanent staff in the respective offices.

Table 6: Crusader House occupancy levels

TENANTS IN CRUSADER HOUSE OFFICE BUILDING				
	OFFICE BUILDING		**ANNEX BUILDING**	
LEVEL	TENANT	OCCUPANCY	TENANT	OCCUPANCY
Ground floor	Bunyonyi Safari Tours	20	Parking (open parking)	0
	Property manager	2	Property in charge	1
First floor	Newplan	69	Family Court	30
Second floor	No tenant	0	Family Court	25
Third floor	Cowi	22	Profira	11
Fourth floor	Newplan	30	Profira	11
Fifth floor	Austrian Embassy	15 (estimate)	Security	4
Total occupancy is 240 people				

5.5 Preliminary findings on energy efficiency and retrofit options for Crusader House Office Building

This part of the study involved conducting interviews with the case study building owner in order to understand the building performance, conditions and management. In order to determine the baseline energy consumption of the building, simulations were done based on EnergyPlus simulation software with Design-Builder (DB) as the user interface.

5.5.1 Crusader House baseline energy audit study

Crusader House energy audit study (walk through assessment) was facilitated by the building occupants who were interviewed based on questions aligned to the parameters outlined below:

- Office equipment and appliances
- Lighting systems
- Utility electricity bills
- Occupancy
- Facilities management operations
- Building conditions and indoor environmental quality

The building participants reponses facilitated a clearer understanding of energy consumed in the building based on the electricity bill versus the simulated energy performance outcomes.

5.5.2 Crusader House office equipment and appliances

The building has multiple loads under the category of appliances and equipment which includes printers, photocopiers, scanners, laptops, fans and desktop computers as opposed to designated centralised printing area. The researcher observed and took record of some appliance power rates and others were sourced from the supplier/manufacturer websites. Moreso, the study is delimited to equipment and appliances running 10 hours per day in CHOB. Table 7 shows the summary of all plug loads (appliances and equipment) in the building.

Table 7: Equipment and appliances running 10 hours per day

Item	Equipment and Appliances	Qty	Watts (W)	Total Load (Watts)
1	Printers (small type)	41	30	1,230
2	Printers (MFP)	6	259	1,554
3	Photocopiers	10	1,300	13,000
4	Computers (laptops)	146	75	10,950
5	Computer (desktops)	95	250	23,750
6	Server rooms	11	427	4,697
7	Server rack	1	1,100	1,100
8	Water cooler	16	300	4,800
9	Scanners	3	18	54

10	Fridge	1	400	400
11	Cordless phones	172	3	516
Grand total power without lighting loads				62,051
Power load density (62,051W/4,164.16m2)				14.9W/m2

MFP=Multi-Functional Printers

Table 7 shows equipment and appliances connected into power for full 10 hours a day. Appliances such as kettles and hand dryers, used for 10 minutes or 20mins are assumed and catered for in the over-sizing of the PV system (see chapter 6, section 6.5.1). For instance, in Chapter 6, section 6.5.1, it is presented that CHOB needed a 100W panel system to operate equipment running for 10 hours a day, thus in order to accommodate appliances not running for 10 hours (intermittent loading), the researcher selected a 250W solar module.

Menezes *et al.* (2014) cite Energy Consumption Guide 19 which highlights that benchmarks for power load density vary from 10 to 18W/m². Other sources show avariation between 10 to 20W/m² for good practice offices. The recently updated CIBSE Guide F suggests that a benchmark figure for building loads of 25W/m² is adequate for most office buildings (with 15W/m² when diversity is taken into account). The case study building has an estimated power load density of 14.9W/m².

Figure 15: Sample of the different office appliances and equipment observed in the case study building. **Source:** Photo by author (2016)

As highlighted in Table 7 and Figure 15, the equipment and appliances such as the printers, fridge and servers run for twenty four hours as opposed to the 10 office hours.

In addition, the walk-through audit revealed that most of the equipment and appliances were not energy-efficiency rated through recognised labels such as Energy Star©.

5.5.3 Crusader House lighting loads

Daylighting is not optimised in most of the cellular offices. It was observed that cellular offices located on the south of the main building and on the north of the annex building had limited amounts of daylight due to dark finishes and multiple obstructions such as the intermediate columns and the internal partitioning. Consequently, artificial lights remained switched on until closure of business at around 5:30pm. During the night lights are normally switched off and the building remains dark.

Figure 16: Type of lights at staircases and corridors. **Source:** Photographs by author (2016).

Figure 16:a, shows the type of light fitting for the main building staircase landings, while Figure 16:b shows type of light installed at staircase risers and passage connecting to annex block. Figure 16:c, shows fluorescent lights installed in the annex block corridors, plaster board interior partioning, and solid wall (as shown on plan Figure 11) situated on the northern end of the annex building. Figure 16:d, shows faulty fluorescent lights in annex block, corridor lit by diffused daylight through interior windows fixed on to the plasterboard partioning walls. It is situated in the southern end of annex building as shown in the plan Figure 11.

Figure 17-below is an open plan office space in the main building. The figure shows the typical fluorescent lights installed across all floors in the main building.

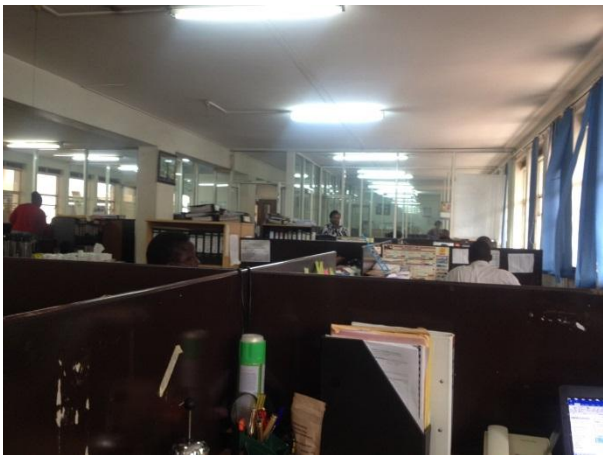

Figure 17: Office space with glazed internal partitioning, middle columns and dark colour workstations and fittings. **Source:** Photographs by author (2016)

The occupants on this floor maintained the open-plan design as per the primary architectural drawings. A larger portion of this office space had glazed partition to allow daylight diffusion. However, due to occupants/employee lifestyle and habits, the artificial lighting remained switched on for 10 hours a day.

Further, Figure 17, shows the colour of the fittings and obstructions like columns or storage facilities that reduce the amount of diffused daylight in the office space. It was observed that the windows to the north façade had manual internal window blinds as shown in Figure 17, while the windows to the south were unshaded. Likewise, in the annex block, the windows to the south had blinds, while the windows to the north were internally unshaded. The walk through audit noted that when the sun is overhead, the neighbouring building (Shumuk House) cast shadows on to these window facades with no internal window blinds (see sun path diagrams in sub-section 5.6.2.2 in comparison to site plan in sub-section 5.3).

Simulated daylight distribution of case study building

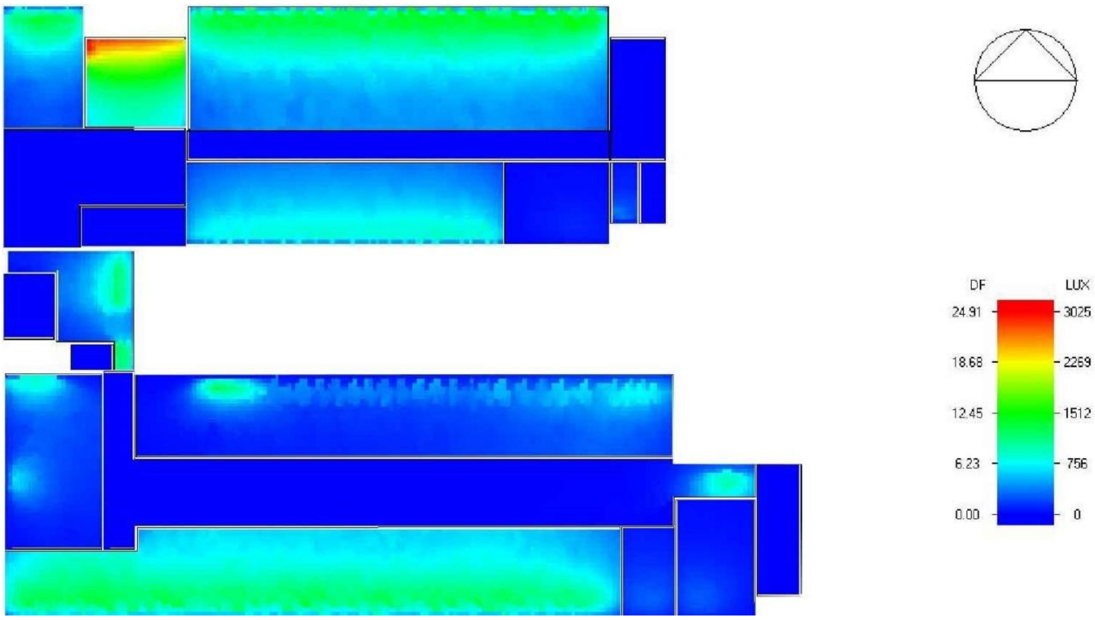

Figure 18: Building level Design-Builder simulated daylight distribution for Crusader House (dalight map taken in DB software at building level)

Figure 18, is a simulated illustration (at building level in the software-see sub Section 5.6.2.1) of the case study building. The input into Design-Builder was a clear day sky model, at 12 pm on the 12 September. Moreover, Figure 18 clearly shows that office space in the courtyard have low daylighting access (less than 756lux). However, the office spaces on the upper floors of the two blocks have abundant daylight towards the yellow and red band (between 2,269 and 2,500 lux as shown in the scale). The blue colour signifies low daylight levels (between 0 and 500lux). This illustration justifies the need to improve the amount of daylight in order to reduce demand for artificial lighting.

Based on direct observation during the visit (walk through assessment), it was noted that fluorescent tubes are mostly used in office spaces and compact fluorescent bulbs for corridors and walkways (see Figure 16 and 17). Moreover, it was observed that all the floors have similar light layouts and fittings.

According to the ASHRAE Standard 90 and the International Energy Conservation Code (as highlighted by Shapiro (2016)), the light power density (LPD) minimum standard for open-plan office should not exceed 11.95W/m². As in dicated in Table 8 the case study building has LPD of 5.76W/m² which is lower than the standard guide cited. It would therefore be assumed there is no need for lighting energy conservation retrofit, though this value can further be reduced to 4W/m² or lower thus making a cost and energy saving (assuming to be about 20%). Table 8 shows the type of light systems observed in the blocks during the visit.

Table 8: Lighting system loads in the case study per floor.

Crusader House office building: Existing lighting systems						
Building Block	**Type of Lighting**	**Qty**	**Unit Watts**	**Sub Total Watts**	**No of Floors**	**Total Watts**
Annex Block	12 of 2 Lamp F32.T8 strip fluorescent and 6 of single F32.T8	18	32	960		
	CFL bulbs	15	40	600		
				1,560	4	6,240
Main Block	12 of 2 Lamp F32.T8 strip fluorescent and 6 of singles	18	32	960		
	CFL bulbs	10	40	400		
				1,360	6	8,160
	Grand Total Watts					14,400W
	Lighting Power Density (576W/100 m²)					5.76W/m²

5.5.4 Crusader House cooling systems

Figure 19: Type of fans used in CHOB. **Source:** Photograph by author (2016)

Even though CHOB does not have centralised air conditioning system (HVAC) equipment, it has split-unit systems which are switched on during meetings only, though sometimes the staff do not switch off the air conditioning after meetings (ACs installed in boardroom and small meeting rooms only). Moreover, the cellular offices in CHOB have single-sided ventilation due to the partition walls built up to the ceiling with no opening provided on partition walls to allow for cross ventilation. This forces the staff to demand artificial cooling systems such as portable fans. Whereas the building was designed to be open-plan, several tenants have partitioned the office spaces upto the ceiling level thus impairing the cross ventilation performance benefits mainly due to increased internal heat gain. Consequently, several occupants in the annex block were observed using portable fans for cooling especially between 12 pm and 3 pm. The fans on some floor levels were connected to power for up to 4 hours.

5.5.5 Indoor environment and air quality

The images a, b, c, d in Figure 20 below, were taken to identify the use pattern of the CHOB. On several occasions over the weekdays, the cars were parked at full capacity in both blocks. Ordinarily, the building is surrounded by parking bays and dusty access roads. Despite the trees planted (to trap dust) on the north side of the site, the indoor air quality needs significant improvment. Office spaces located on the ground floor are exposed to toxic fumes as well as noise from the parking bays. One of the occupants complained that the noise levels are excessively high but other respondents commented that they have adapted to that situation.

Figure 20: The building parking bays (main and annex blocks). **Source:** Photograph by author (2016)

Figure 21: The dusty main block roof.

Figure 21 indicates the expected increase in the operations/maintenance cost of rooftop PV system investment due to the dusty environment.

5.5.6 Crusader House building occupant satisfaction/issues

The occupants commented that during power outages, they experience power surges which has increased the rate of replacing the fluorescent tubes and accessories. The occupants also mentioned that according to their tenancy agreements, they have no access to sub-metres which could allow them to determine the exact amount of energy consumed. Instead, they receive invoices for electricity consumed from the building owner and they are not aware of the basis of billing. However, they keep track of the electricity invoices and payments to the building owner. According to the property manager, tenants are billed differently for diesel generator fuel, water and grid power depending on the office space rented. The average amount paid for the total bills is Uganda Shillings 507,500 (approximately 145USD) per month.

For a retrofit application, the tenants/occupants state that they have no authority from the building owner to invest in retrofit interventions. However, they note that if the building owner decided to invest in retrofit and with the assurance of energy savings, they would support the retrofitting.

5.5.7 Main and Annex block utility electricity bills per month for the year 2015 and 2016

Utility electricity bills for the year 2015 and 2016 were received from the property manager. Table 9 and Figure 22, indicate that the monthly electricity cost fell in December and beginning of the new year. Several building occupants noted that their bills are low as majority of the employees are on holiday. Their electricity bills are high from April up to November. This signifies the high demand of energy as result of an increase in the number of staff (both full time and part time) and equipment loads.

Table 9: Main and Annex block utility electricity bills for 2015 and 2016

CRUSADER HOUSE ELECTRICTY UTILITY BILL COMPARISON FOR THE YEARS 2015 and 2016						
MONTH	**2015 Units (kWh)**	**2015 Amount (UGX)**	**2015 Approx. Amount (USD)**	**2016 Units (kWh)**	**2016 Amount (UGX)**	**2016 Approx. Amount (USD)**
January	15,279	8,885,291	2,472.09	12,927	9,338,616	2,598.22
February	17,444	10,104,553	2,811.32	13,769	9,692,000	2,696.54
March	15,671	9,328,901	2,595.51	14,302	9,969,016	2,773.61
April	16,439	9,823,941	2,733.25	16,960	11,764,035	3,273.02
May	15,205	9,226,788	2,567.10	16,068	10,955,186	3,047.98
June	15,573	9,430,265	2,623.72	17,218	11,712,605	3,258.72
July	15,060	9,149,128	2,545.50	16,518	11,293,213	3,142.03
August	15,129	9,393,732	2,613.55	16,470	11,036,952	3,070.73
September	13,162	8,278,160	2,303.17	16,146	10,774,454	2,997.70
October	15,923	9,901,801	2,754.91	15,902	10,641,451	2,960.70
November	14,171	10,205,072	2,839.29	16,952	11,502,215	3,200.10
December	13,364	9,697,568	2,698.09	15,910	9,250,561	2,573.72
TOTAL	**182,420**	**113,425,200**	**31,557.49**	**189,142**	**127,930,304**	**35,593.07**

The approximate amount in USD is determined based on Bank of Uganda interbank average exchange rate, 1 February 2017, where 1USD=3,594.24UGX.

In reference to the electricity bills of the year 2015 and 2016, the electricity escalation rate is 10% thus the variation in the values of 2015 and 2016. However, looking at the month of February electricity consumption for the year 2015 and 2016, the value is lower in 2016. The property manager pointed out that this was the period when the two building blocks were integrated to one-meter reading as opposed to separate meter readings. According to the Crusader House respondent, the merger was intended for accountability. Hence there was variation in the meter readings.

Figure 22 is a bar graph, showing energy consumption for the year 2016 and 2015. The 2015/2016 scale is at an interval of 2,000 kWh while the related cost is at a scale interval of 500 USD dollars.

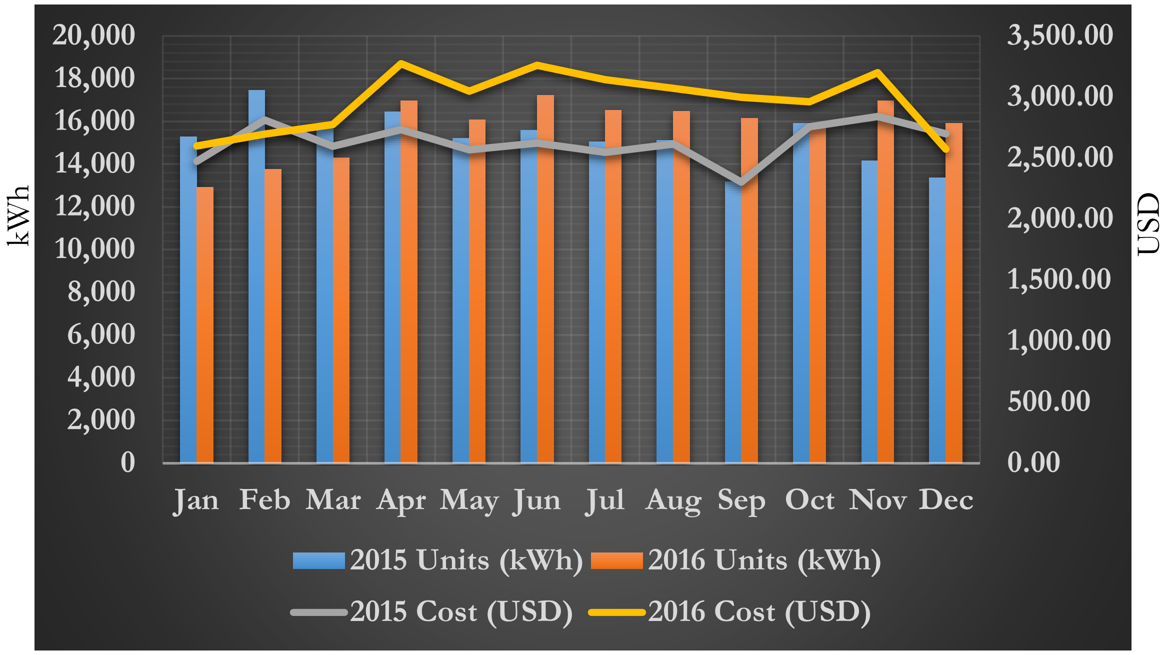

Figure 22: 2015/2016 Crusader House monthly electricity consumption and cost.

5.6 Baseline energy consumption of case study building

5.6.1 Manual calculations

To determine the baseline energy consumption manually, the following assumption was taken into account. All intermittent loads (from an electric kettle, ACs in meeting rooms, hand dryers, TVs, vacuum cleaners, and coffee machines etc.) are negligible hence only plugged loads running for 10 hours are considered (see Table 7 in Sub-section 5.5.2 for appliance and equipment and Table 8 for lighting loads.). Moreover, the negiglibale values are catered for when sizing the PV system.

Table 10: Baseline energy consumption-manual calculation

Inputs	Annual baseline energy consumption
Given; ❖ 10 working hours per day ❖ Total plug loads= 62,051 watts ❖ Total light loads= 14,400watts ❖ 250 working days per year excluding 9 public holidays ❖ Plug loads and light loads= (62,051 +14,400) = 76,451 watts per day.	76,451W X 10 hours =76,4510 Wh 76,4510Wh/1,000= 764.51 kWh per day Annually,764.51kWh X 250 days= 191,127.5 kWh.

5.6.2 Design-Builder simulations

In order to derive baseline energy consumption using the Design-Builder (DB) simulation software, weather data files for Kampala location were loaded into the DB software as one of the key inputs for simulations.

Overview of DB software and the energy model

DB software is set up to operate in a hierarchical approach where the energy model applies the following hierarchies.

- The site level
- The building level
- The block level
- The zone level

At the site level, the climate data of the building under study is inputted into the software. Most of the climate data is set at default level once an Energy Plus Weather (EPW) Sfile data of the building location is uploaded into the software as well as the building name.

The building level consists of blocks and zones. The blocks are floor levels and each block consists of zones. The zones consist of the external walls, openings, partition walls, ceiling and the floor. In addition, construction, occupant activities, lighting, HVAC and openings of a building are inputted at the zone level.

In light of this, at the building level, a DXF file of the architectural drawing was imported into the software and traced over in order to adopt for the energy model.

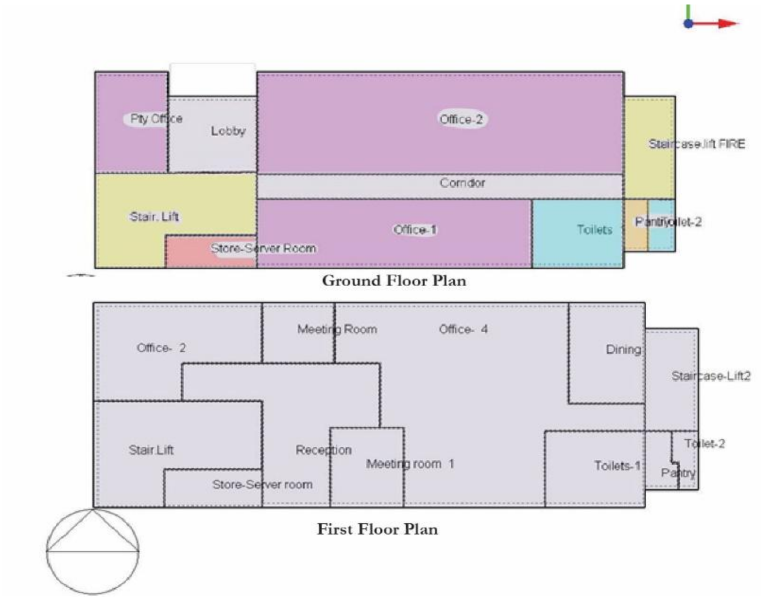

Figure 23, shows DB Energy Plus zones created for the main block ground floor and

Figure 23: Ground floor and typical first floor plans, DB simulated main block zones

first floor. The plans are drawn based on the true north arrow in the DB software

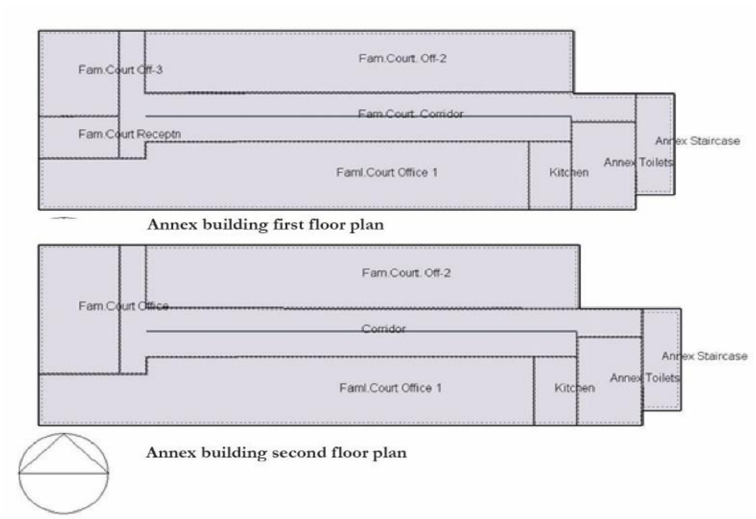

Figure 24: Typical floor plans, DB simulated annex block zones

Figure 24, shows DB Energy Plus zones created for the annex block, first and second floor. The plans are drawn based on the true north in the DB software

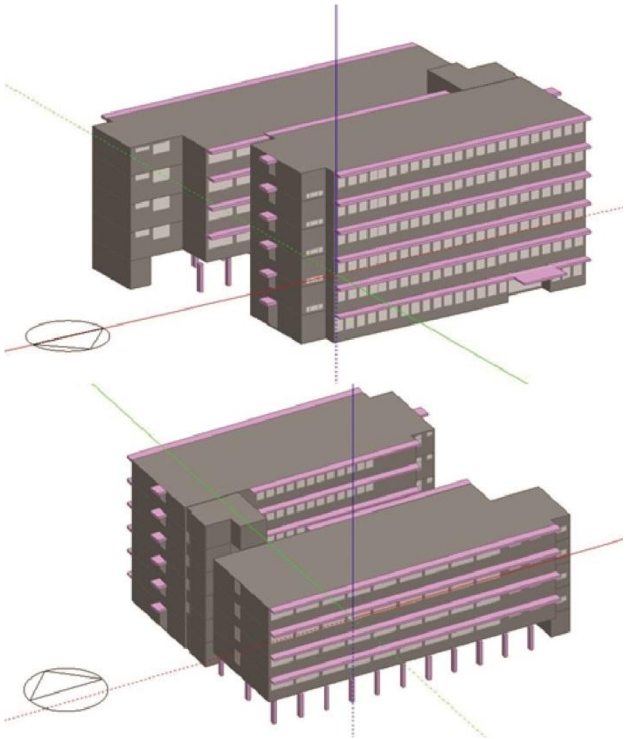

Figure 25 is the DB Energy Plus model generated for CHOB based on the inputs discussed in this chapter. The energy model views are generated from north east and south west directions in DB software. The open pillars exposed are on the ground floor open parking of the annex block.

Figure 25: Case study building DB Energy Plus model generated

5.6.2.1 The case study DB sun path outputs

The sun path diagrams were developed based on a dry season and a wet season month. The study considered the time when the sun is overhead to guide the extents for shading and derivation of the tilt angle. Further, the developed sun path diagrams were also applied to guide decission-making for a PV system suitable for the CHOB environment.

January and Feburary are the hottest months of the year in Kampala. At 12 pm, the Azimuth angle is 173 degrees and altitude angle is 69 degrees. When the sun is overhead, the solar angle is greater than 30 degrees and shadows are cast in the north-south axis. This is common for north-south oriented buildings. Thus the tilt angle for the solar panels would be in the range of 30-60 degrees (see Figure 26 and 27 sun path diagrams of CHOB)

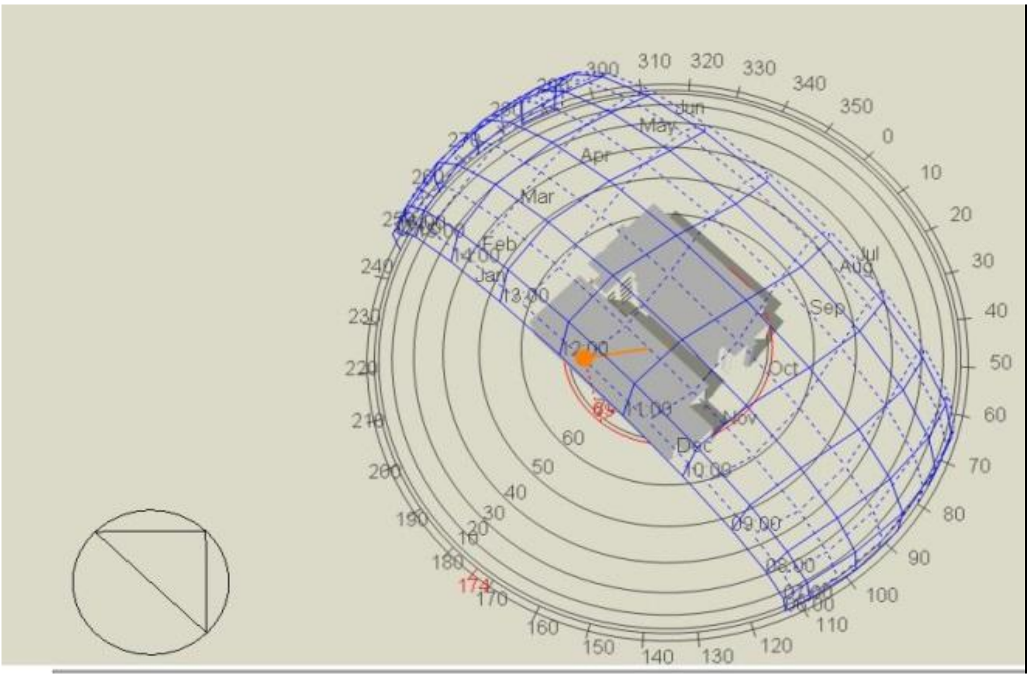

Figure 26: 16 January azimuth angles at 12 pm

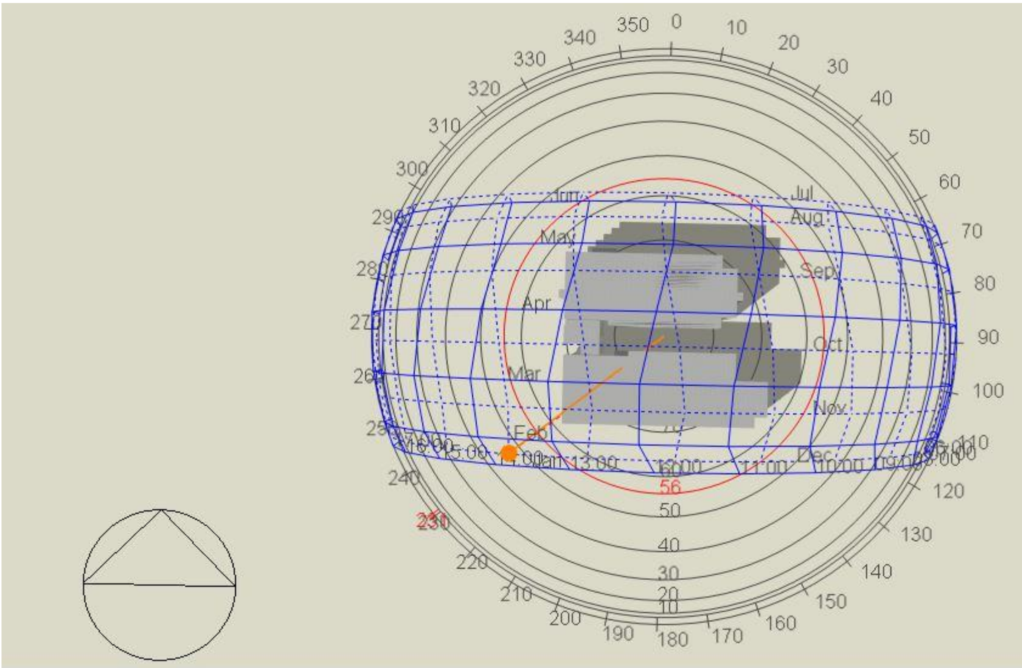

Figure 27: 16 January azimuth angles at 2 pm

Moreover, Kampala experiences heavy rainfall in April. At 12 pm, the azimuth angle is 359-zero degrees while the vertical angle is 89 degrees. At 2 pm the azimuth angle is 290 while the vertical angle is 59 degrees. The shadows are cast in the eastern direction at 2 pm while at 12 pm the shadows cast at the centre of the two blocks (see Figures 28 and 29 here below)

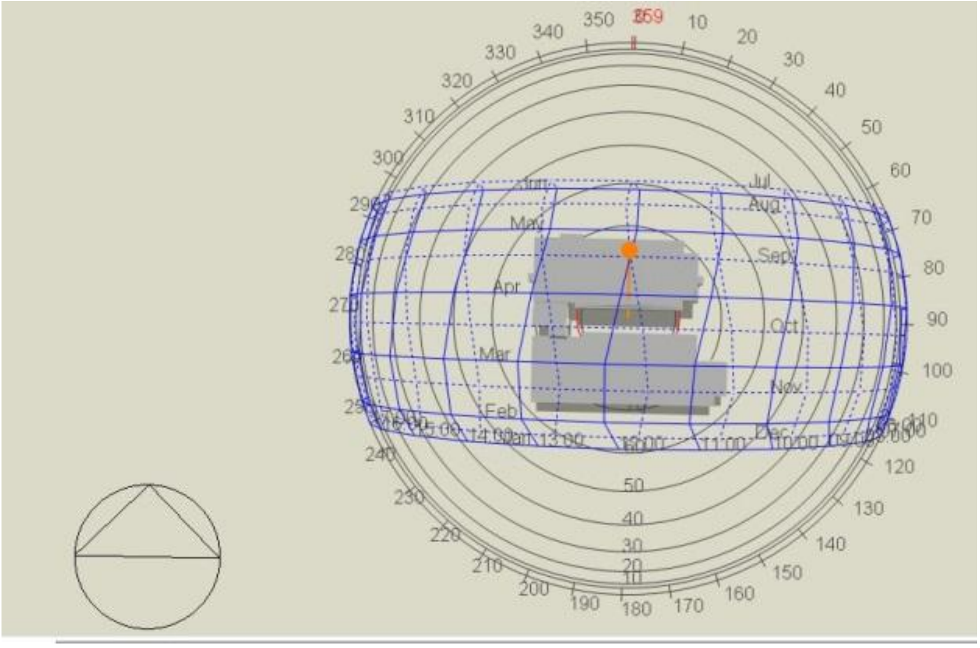

Figure 28: 16 April Azimuth angles at 12 pm

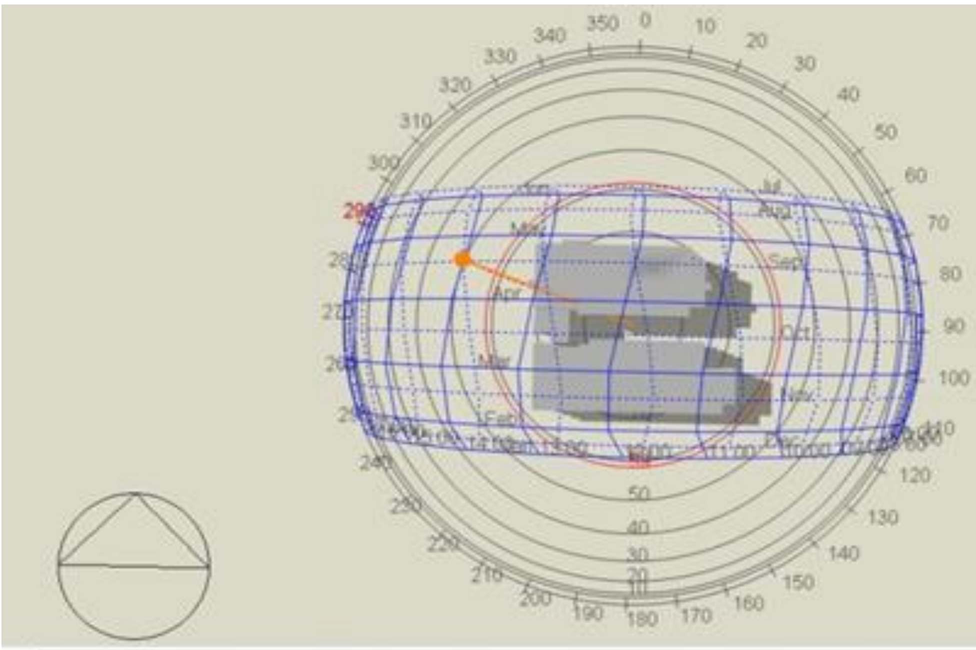

Figure 29: 16 April Azimuth angles at 2 pm

In conclusion, the charts illustrates that the tilt angle for solar panels on the case study roof ranges between 30 and 60 degrees. In addition, the study observed that the sun has a higher altitude greater than 30 degrees throughout the year hence it was a wise directive by the architects (Plan Systems Ltd) of CHOB to fix horizontal shading devices on all north-south facing openings and western facades.

5.6.2.2 Input figures/elements into Design-Builder for simulation outputs

Table 11: Inputted values into Design-Builder software for simulation outputs

	Parameters/Elements	Input values
1	Occupancy density = (people/total net floor area)	240/4,164.16= 0.0576. In reality this is translated as 17.3m^2 per person
2	Computer gains (see Table 7)= (watts/total net floor area)	34,700/4,164.16=8.333W/m^2
3	Office equipment gains (watts/total net floor area	62,051-34700=27,351/4,164.16 = 6.568W/m^2
4	Normalised power density at building scale= Light loads/ total net floor area	14,400/4,164.16= 3.458W/m^2
5	Information highlighted in Table 6, Sub-section 5.4	
6	Climate data based on Energy Plus Weather (EPW file data of Kampala)	Default longitude in DB , -0.1 as opposed to actual value which is 0.347596 Default latitude 34.75 as opposed to actual value which is 32.582

5.6.2.3 DB simulations: baseline energy consumption

The simulated baseline annual energy consumption is 192,407.31 kilowatt-hour (kWh). While the manually calculated baseline energy consumption is 191,127.5kWh The actual annual energy consumption based on electricity bills (benchmark) presented in Sub-section 5.5.7, Table 9 is 189,142kWh (for the year 2016) and 182,420 kWh (for the year 2015). The variation of the energy outputs between the simulated and manually calculated (based on walk-through audit) is 0.67% while the simulated versus the total on electricity bills is 1.73%.

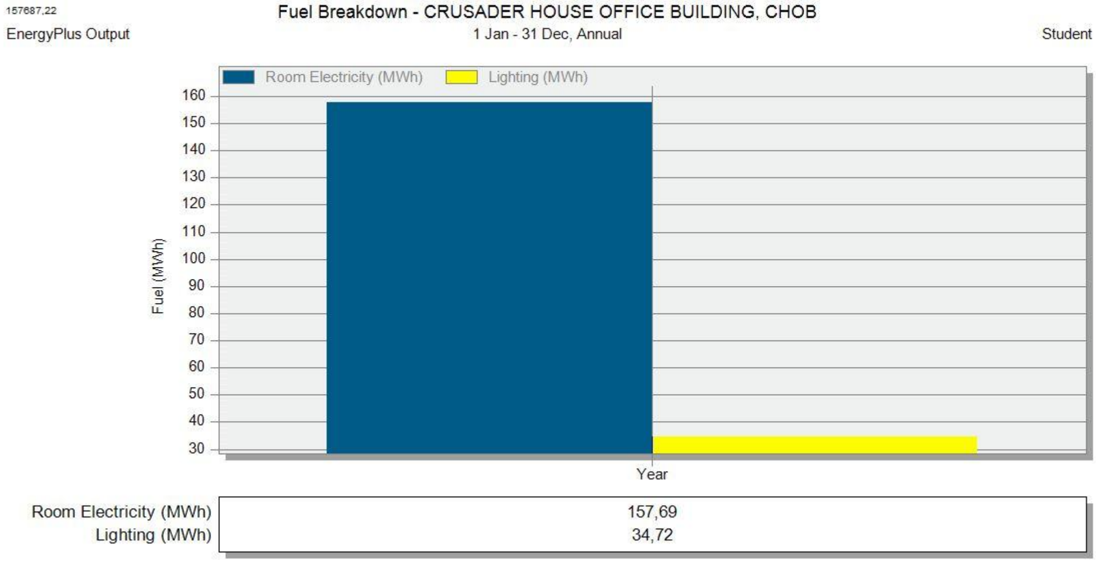

Figure 30: Annual baseline energy consumption breakdown

The input values (see Table 11) into DB software generated outputs as shown in Figure 30. The graph indicates the relationship between light loads and the plug loads (room electricity). It is evident that the plug loads (blue colour) in CHOB are high, thus for retrofitting, this study finding will be optimised in the subsequent chapters in order to derive an energy efficient building.

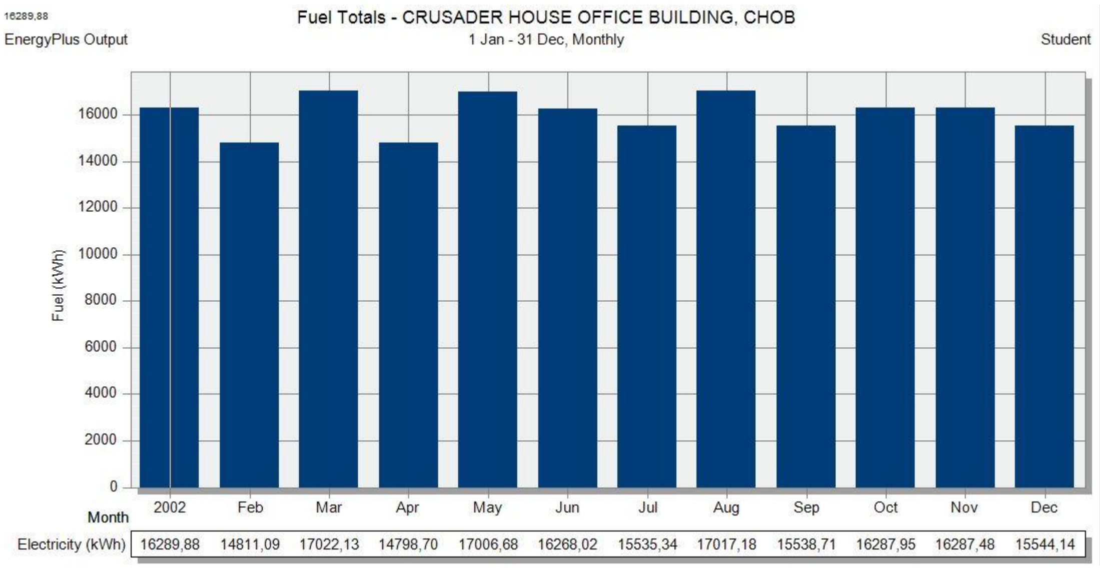

Figure 31: Montly baseline simulated CHOB energy consumption

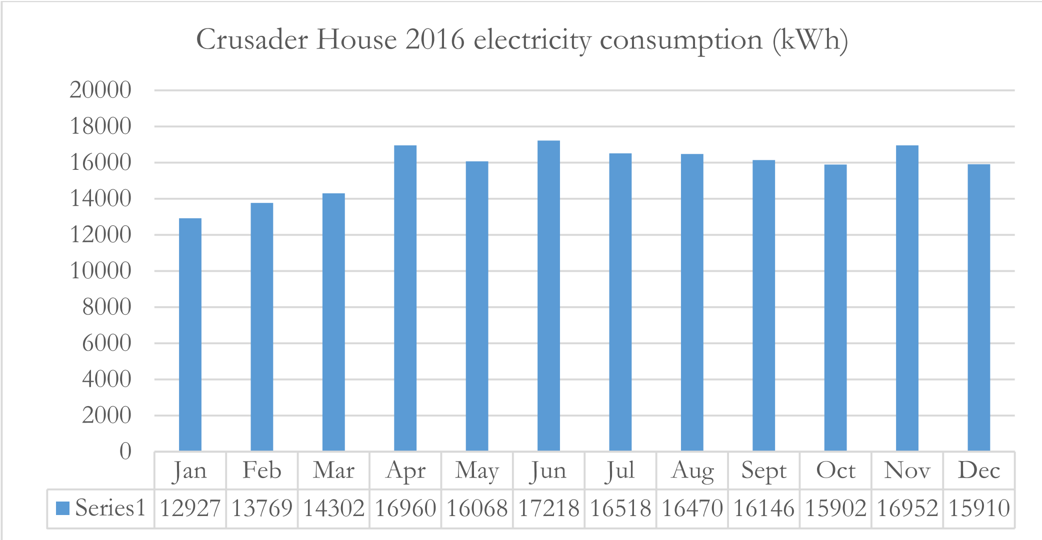

Figure 32: Monthly utility electricity consumption

Comparing the two graphs of energy consumption for both simulated (Figure 31), and utility electricity units (Figure 32), gives an insight of CHOB energy consumption pattern. The simulated values are generated based on plug loads and light loads connected into power constantly for 10 hours. The utility units are based on energy consumption by all plug loads and light systems loads at any given time. Figure 31, shows the simulated graph energy consumption levels of March, May and August to be high while for the utility units graph (Figure 32), energy consumption levels of April, June and November are the higher ones.

5.6.2.4 Annual baseline internal heat gains

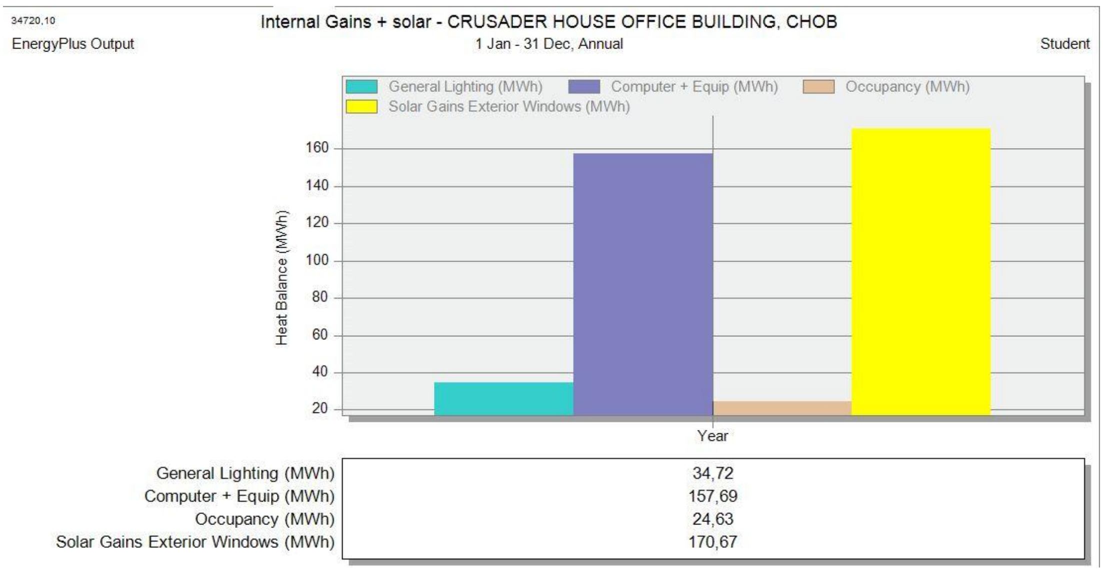

Figure 33: DB simulated annual internal heat gains

Figure 33, is an illustration of internal heat gains as result of both the plug loads and light system loads. The purple colour, the plug loads (computer and equipment) and Yellow colour (external windows) contribute a lot to the internal heat gains. Application of energy efficient measures such as Energy Star© equipment as well as passive and active energy efficiency interventions would reduce these loads and thus mitigate related carbon emissions. The heat gains generated from external windows can be reduced by introducing longer overhangs (the existing overhangs are 1metre wide. A 1.5meter overhang is expected to reduce a significant amount of the gains). In addition, introducing double glazing would be another solution while planting more trees around the building can be extremely economical.

Through sweat and respiration, human occupants also contribute, to some extent, to internal gains. The graph shows occupants contribute 24,630kWh of heat gains while general lighting (lemon blue) contributes 34,720kWh.

5.6.2.5 Monthly baseline carbon emission in the case study building

As discussed in Chapter 1, section 1.1.5 there is limited data on carbon emissions especially in existing commercial buildings such as Crusader House. Crusader House energy supply is basically hydro electricity and stand alone diesel generator, thus the baseline carbon emission in the building (simulated) is due to plug loads and lighting system loads connected into power for 10 hours. In addition, DB has default settings that convert electricity to carbon. The diesel generator emissions are presented in sub section 5.6.3 and Table 12.

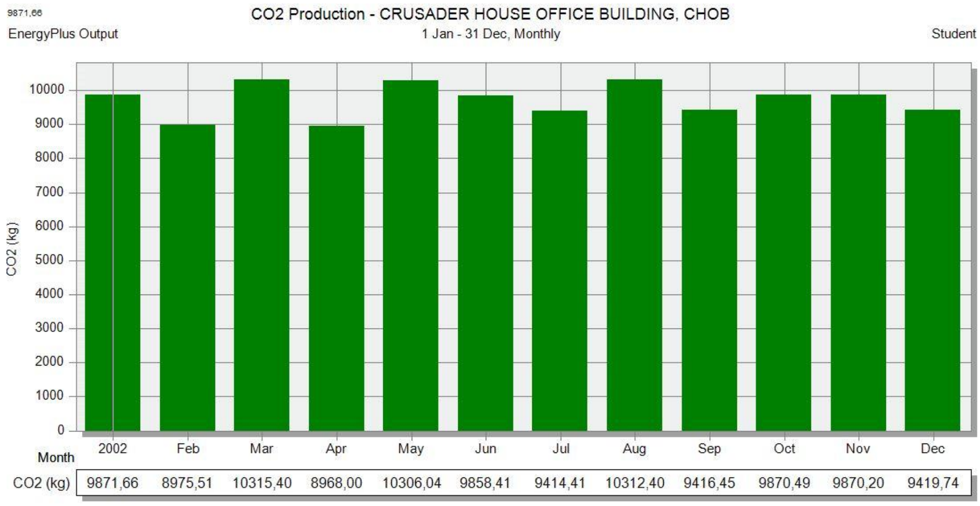

Figure 34: Monthly baseline carbon production in CHOB

Figure 34, shows the baseline monthly carbon emission in the case study building. In order to generate this graph natural gas settings were turned off in the software and others not related to electricity supply. The total simulated annual baseline carbon emission is 116,598.71kg (based on the default settings of the software). As reflected in figure 30, March, May and August indicate the highest amounts of carbons emitted by the case study building as result of electricity supplied.

5.6.3 Diesel energy consumption in CHOB

Crusader House has an installed diesel generator (Perkins-250 KVA/200 kW @ 50HZ and power factor 0.8) in the basement to mitigate the power outages. According to the property manager, the generator fuel tank capacity is 448 litres and 400 litres of diesel is used in a month. The property manager further pointed out that the stand-alone diesel generator provides electricity to power all equipment and appliances in the case study building. However, he noted that the power outages have reduced to about 2 hours in a day compared to past years (8 hours power cuts per day). This has reduced the servicing of the generator to two times in a year (after every 6 months), the total annual service cost is 2,942,000/= (Two million nine hundred and forty-two thousand Uganda Shillings). We can convert this value to USD based on 1USD= 3,594.24UGX as presented in sub-section 6.2 and this gives us about 818.53 USD=820USD). The annual diesel fuel cost is derived by multiplying 400 litres consumed per month by 12 months by diesel fuel rate. The rate of diesel fuel (3,250 UGX) is as of 12 December 2017. Therefore, the total annual diesel cost is 15,600,000/= (fifteen million six hundred thousand Uganda shillings). This is approximately 4,340.28USD. In light of this, the total annual operational and maintenance cost of the diesel generator in CHOB is 18, 542,000/= (Eighteen million five hundred and forty two thousand Uganda shillings, approximately 5,158.81USD).

In addition, the property manager pointed out that the initial cost of the generator was 24,025USD. Table 12 shows items purchased for maintaining/servicing the diesel generator and diesel fuel.

Table 12: Diesel generator operation and maintenance costs

Item	Description	Qty	Rate (UGX)	Amount (UGX)	Amount in (USD)
	FUEL COST				
1	Diesel fuel per month	400 ltrs	3,250	1,300,000	361.69
	Total annual diesel cost			**15,600,000**	**4,340.278**
	SERVICE COST				
2	Service labour cost	1	360,000	360,000	1,391.11
3	Fuel filter	1	110,000	110,000	30.605
4	Oil filter	1	160,000	160,000	44.516
	Air filter	1	340,000	340,000	94.596
5	Engine oil	30 ltrs	16,000	480,000	133.547
6	Distilled water	3 litrs	7,000	21,000	5.843
	Total annual cost	***2***	***1,471,000.***	***2,942,000***	***818.532***
Grand total (O &M)				**18,542,000**	**5,158.809**

According to Yadav, Murthy, Mishra, and Baral, (2005), the petroleum diesel fuel density is approximately 0.832kg/ltr. Therefore, the study can estimate that the total annual carbon emission in CHOB is derived by multiplying 0.832kg/ltr by 4,800litres of diesel fuel consumed in the year. This gives us 3,993.6kg (approximately 4,000kg) of carbon emission.

The stand-alone diesel generator reading is 200kW; therefore, the baseline energy consumption of diesel generator per day is derived by multiplying 200kW by 2 hours of operation per day. This gives us 400kWh per day, thus the annual baseline energy consumption is derived by multiplying 250 working days by 400 kWh, which is 100,000kWh. In the subsequent Chapter 6, the use of Diesel versus use of battery storage will be assessed and analysed.

5.7 Optimisation and interventions towards net-zero building

The watts values for manual optimisation have been accessed from the 'Energy Star©' and 'MY LED LIGHTING ©' online sources.

5.7.1 Manual calculations (optimized energy consumption)

Table 13: Equipment and appliance power optimisation

Item	Equipment and Appliances	Qty	Watts (W)	Total Load (Watts)
1	Printers (small type)	41	27	1,107
2	Printers (MFP)	6	170	1,020
3	Photocopiers	10	220	2,200
4	Computers (laptops)	146	45	6,570
5	Computer (desktops)	95	165	15,675
6	Server rooms	11	205	2,255
7	Server rack	1	750	750
8	Water cooler	16	90	1,440
10	Fridge	1	121.2	121.2
11	Cordless phones	172	1.3	223.6
Grand total power without lighting loads				31,361.8
Power load density (31,361W/4,164.16 m^2)				7.53W/m^2

Table 13, shows power load density is 7.53W/m^2. In cross-reference, Menezes *et.al.* (2014) highlight that according to the Energy Consumption Guide 19 and CIBSE Guide, good practice power load density for office buildings vary from 10 to 18W/m^2 (especially for tropical climatic buildings). This implies that the manually calculated optimised energy value can equally be justified for CHOB.

Table 14 shows 2 Lamp F32.T8 strip fluorescent lights currently installed in the building to be replaced by frosted T8 LED Tube Light, and 4" LED Downlight with high CRI replaces CFL bulbs. According to the manufacturers MY LED LIGHTING © (2017), the energy efficient bulbs and tubes have a lifespan of ranges between 2 to 5 years.

Table 14: Lighting system power optimisation. **Source;** MY LED LIGHTING © (2017) and Energy Star © (2017)

Crusader House office building existing lighting systems						
Building Block	**Type of Lighting**	**Qty**	**Unit Watts**	**Sub Total Watts**	**No of Floors**	**Total Watts**
Annex Block	Knaclean T8 LED Tube Light (LED Tube 4 Foot 15W-18W DLC)	18	18	324		
	4" LED Down light with High CRI	15	13	195		
	Sub-total			519	4	2,076
Main Block	Frosted T8 LED Tube Light (LED Tube 4 Foot 15W-18W DLC)	18	18	324		
	4" LED Down light with High CRI	10	13	130		
	Sub-total			454	6	2,724
	Grand total watts					**4,800W**
	Building light power density 4,800W/4,164.16					1.15W/m²

Table 15: Optimised energy consumption-manual calculation

Inputs	**Annual manual calculation optimised energy consumption**
Given; ❖ 10 working hours per day ❖ Total plug loads = 31,361.8 watts ❖ Total light loads= 4,800W ❖ Plug loads and light loads= (31,361.8 +4,800) = 36,161.8 watts per day.	36,161.8W X 10 hours =361,618Wh 361,618 Wh/1000= 361.62 kWh per day Annually, 361.62 kWh X 250 days= 90,404.5 kWh.

5.7.2 Design-Builder simulation (optimized energy consumption)

To determine the optimized annual energy consumption, the case study building was first simulated without light controls (tool in DB software under lighting). Energy Star© rated appliances and equipment standards were accessed from internet based sources and adopted the Autodesk sustainability energy efficiency standards for office equipment. Desktop computers labelled 250 watts were replaced with Energy Star© rated desktop computers labelled 60-165 watt and laptops labelled 75-100 watts were replaced with Energy Star© rated laptops labelled 20-45 watts. This reduced computer gains from 8.33W/m² to 5.34W/m² and office equipment gains from 6.57W/m² to 2.19W/m². These reduced density values were inputed in DB software and simulated without light controls. The simulated total optimsed annual energy consumption performance without light controls is 91,231.5kWh and with light controls, the annual optimised simulated energy consumption performance is 85,265.75kWh. This stands in comparison to the baseline values of 192,407.31kWh and 130,865.7kWh respectively.

For renewable energy application as an intervention, the simulated graph has a lower optimised energy value (85,265.75kWh) than the manually calculated (90,404.5kWh) Therefore, for sizing of the PV system, the manual calculation will be considered as presented in Chapter 6. According to solar companies consulted and in reference to Chapter 2, manually oversizing a PV system (reserve margin) is a good concept for any project. In light of this, the months of June (Figure 32) was selected to serve as a guide for the peak demand when sizing the PV system (see section 6.5.1).

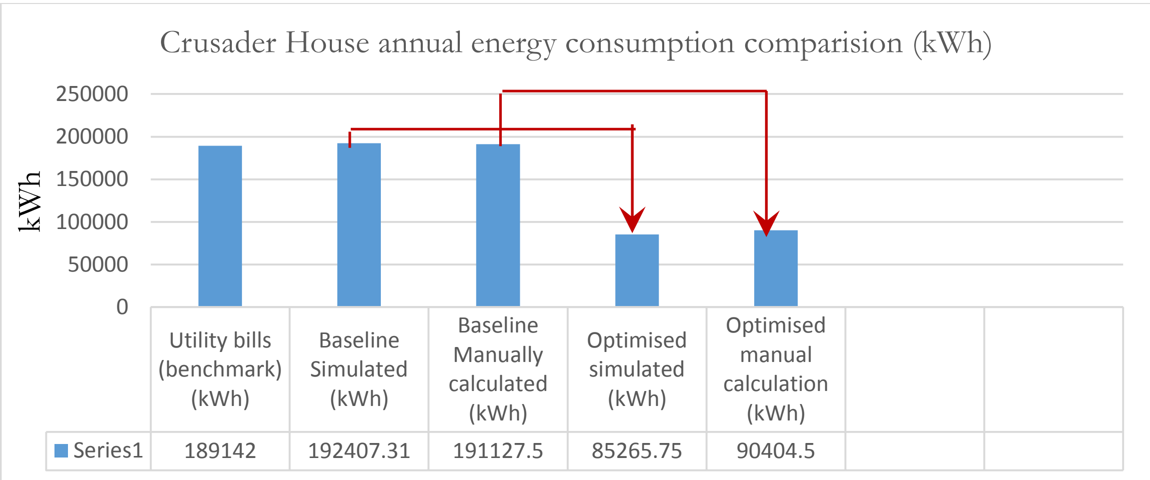

Figure 35: Energy consumption comparison for the CHOB

Figure 35, shows 2016 utility electricity consumption considered as the benchmark, as well as its relationship between the simulated and the manually calculated performance values. The baseline and manually calculated values are slightly higher because of the estimated values of equipment and appliance wattages. However, the difference is about 1% as presented in sub-section 5.6.2.3.

In order to achieve a net-zero building, the study recommends passive and active design interventions as well as management strategies (highlighted below) for net-zero commissioning of CHOB as a prototype building to pioneer for other existing office buildings in Kampala.

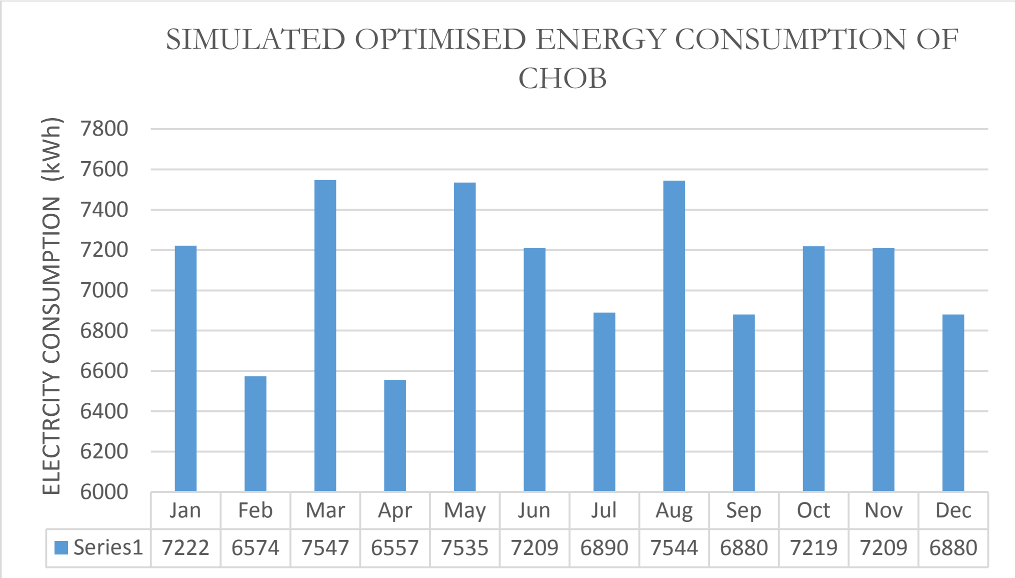

Figure 36: CHOB optimised energy consumption

Given that Design-Builder simulation software could not simulate the two blocks together, performance for each block was simulated separately and the two outputs were combined to derive overall performance. Figure 36, shows the combined optimised energy consumption of CHOB as simulated in two sections; the annex block and the main block. Figure 36 also indicates fluctuations in the month of February and April. This is attributed to the low energy consumption levels as result of reduced number of staff (less energy demand) in CHOB (see Chapter 4).

5.7.3 Passive design interventions

Window overhangs and daylighting

Crusader House is architecturally designed as an open-plan office building. It has 1m deep over hangs on all windows for solar shading, as it is oriented to the north. The over hangs are painted dark colours as shown in the Figure 12. In addition, 85% of the north façade walls were painted with dark colours which absorb more heat and also reduce the amount of daylight into the interior. The study recommends painting the north façade walls and soffit of the overhangs with reflective finishes in order to enhance diffusion of daylight into the internal spaces. Interior walls should also be painted with lighter colours and should have light colour fittings and furniture in order to optimise daylight and thus reduce the need for artificial lighting.

Natural ventilation

In the annex block, internal windows or openings should be created in the solid partitioning wall as seen in Figure 11b, Sub-section 5.4.1. Alternatively, creating a low partition (not all the way up to the ceiling) to maximise cross ventilation would be economical as opposed to buying internal window fittings. Cooling was observed as one of the major challenges experienced by occupants. Many offices were using portable fans and ceiling fans between 1pm and 3pm especially in the annex block. This could have been because of the partitioning type in the respective office spaces that limited cross ventilation performance. In light of this, the study recommends retaining the primary architectural open-plan design or use short walls (not built up to the ceiling soffit) in order to improve cross ventilation. Maximizing on operable windows would give occupants additional control over airflow in the office space.

Indoor air quality

Installing potted plants around the occupant workstations is another passive intervention to improve on the indoor air quality of the building, as it is located in an environment with lots of dust pollutants.

Figure 37: Crusader House 120 mm high wire mesh vents on top of all windows and beneath the slab/overhangs.

5.7.4 Active design interventions

In the simulations discussed in Sub-section 5.7, the light controls were considered in the simulations especially given that as lighting contributed to 11.5% reduction of energy consumption after combining Energy Star© rated equipment, appliances and LED light systems in the simulation. The assumed retrofit interventions that facilitate reduction are as follows:**Timer controls, alarms and daylight sensors**

The study recommends timer controls to turn off equipment at night hours and artificial lighting during day time automatically between mid-day and 3 pm. In addition, integration of daylight sensors and timer controls to detect daylight levels and artificial lighting usage in the office space would be essential. The use of alarms would remind the last occupant in a particular office to turn off the equipment and appliances.

Occupancy/motions sensors

Under the baseline scenarios, artificial lighting in the lifts, toilets, pantries, stores, unoccupied meeting rooms and staircases were left on over 10 hours. In light of this, the study recommends the use of motion sensors to reduce the hours of articfical light usage to about four hours. In addition, occupancy sensor installations to automatcially turn off articial lighting in rooms that are not occupied would thus contribute to energy consumption reduction.

Carbon sensors

The case study building has 120mm high wire mesh vents on each window (see Figure 37). Often the staff do not open all the windows, which thus limits cross ventilation and impairs air quality of the office space. Installing carbon dioxide sensors would improve on natural ventilation in the office space and at workstations in order to facilitate for operation of the windows and thus improved indoor air quality.

Shared office equipment

The study recommends designating a common space for sharing office equipment like printers and photocopiers in order to reduce energy consumption levels.

5.7.5 Behavioural change as other intervention for adoptation of energy efficiency

For an energy efficient culture, the study identified building owners and tenants as key role players towards an energy efficient orgnisational culture within commercial office buildings such as Crusader House. The study therefore recommends creating awareness about energy use on intervention control and behaviour change for energy efficiency and energy savings for all users (building owners and occupants). Training in energy management strategies (such as benchmarking, energy monitoring and building energy control systems) would increase occupants' knowledge about energy-use and monitoring systems in order to improve the building's energy performance.

5.8 Conclusion

This chapter has presented the case study building information, energy audits and resultant energy performance sub-findings. Three methods (manual energy consumption calculations, utility bills and Design-Builder energy plus simulations) were used to determine the baseline versus the optimised energy consumption of the building. The utility electricity consumption was considered as the benchmark from which a 1% performance gap variation between the manual and simulated values was identified. This was attributed to the equipment and appliance power wattage estimates which were generated from the internet as well as through direct observations based on the walk through audit.

The sub-findings indicate 53% energy consumtpion reduction from the baseline manual energy comsumption and 56% energy comsumption reduction from simulated baseline energy comsumption (see Figure 35). In order to allow for operational margin for the PV system, the manual optimised calculation was applied as presented in Chapter 6. The subsequent chapters provides substantiation and sub-findings on the second sub-question.

CHAPTER 6 ENERGY EFFICIENCY RETROFITS AND ROOFTOP PHOTOVOLTAIC TECHNOLOGY

6.1 Introduction

In reference to Chapter 2, sub-section 2.3.1, cost-effective energy efficiency measures were simulated as presented in Chapter 5 and then cost evaluated in order to determine the initial investment cost for energy efficiency retrofits (EEF). Sub-section 2.5.3, highlighted that only cash inflows and outflows are often considered to evaluate the economic viability of EER (depreciation and reserves will not be considered).

In order to determine the financial viability of investing in energy efficiency and rooftop PV, a 20-year life cycle is considered. The conventional unit prices were accessed from Crusader House equipment supplier (such as Mercury Ltd), online sources (as informed by building tenants) while the energy-efficient appliance unit prices were accessed from diverse online sources such as Energy Star© consumer reports, Amazon, check prices, bid or buy, Alibaba, and suppliers in South Africa such as Raydian Pty ltd. The cost estimates were further compared to quotations (based on building information sent to selected companies via E-mail with subsequent dialogue), from solar PV supplier companies such as Jinko solar, Segen pty ltd and Sunllent company based in China. As a result, a purposefuly selected range of unit prices for each product were compiled as presented in the tables on this chapter.

6.2 Economic evaluation parameters and assumptions.

To conduct cost estimates for initial investments and operations of energy efficiency retrofits, the following parameters and assumptions were applied:

- 1 USD= 13.413 ZAR (accessed on 16 October 2017 from Standard Bank-South Africa)
- I USD=3,594.24UGX (Bank of Uganda interbank average exchange rate, 1 Feb 2017)
- Analysis period is 20 years (this is based on the interview findings presented in Chapter 4 regarding ERA PPAs)
  - Discount rate is 14% (Bank of Uganda based on re-discount rate 13.5% +/- as of Jan 2018)
- Electricity escalation rate 10% (Bank of Uganda, central bank rate of October 2017), and also highlighted by ERA and the utility UMEME online source

Table 16: Energy efficient retrofits initial investments

Item	Description	Qty	Conventional rate (Cr) (USD)	Energy efficient rate (Eer) (USD)	Net rate (USD) (Eer-Cr)	Amount (USD)	Amount (UGX)
AA	**EQUIPMENT AND APPLIANCE INTERVENTIONS**						
1	Big MFP Printers and photocopiers	6	2,000	6,620.19	4,620.19	27,721.14	99,636,430
2	Small MFP printers and photocopiers	41	338	620	282.00	11,562.00	41,556,603
3	Laptops	146	550	700.00	150.00	21,900.00	78,713,856
4	Desktops (CPUs and LCD monitors)	95	1,000	1,500.00	500.00	47,500.00	170,726,400
5	Servers including a rack	12	850	2650	1,800.00	21,600.00	77,635,584
6	Fans	41	13.9	40.93	27.03	1,108.23	3,983,245
7	Water cooler	16	128	180.79	52.79	844.64	3,035,839
8	Fridge	1	250	670.90	420.90	420.90	1,512,816
9	Cordless phones	172	20	33.30	13.30	2,287.60	8,222,183
	Sub total				***7,866.21***	***134,944.51***	***485,022,956***
11	Shipment costs/ transport 20%					26,988.90	97,004,591
12	Labour cost for installation 10%					13,494.45	48,502,296
13	Any other O &M costs 20%					26,988.90	97,004,591
	Total-1					**202,416.76**	**727,534,434**
BB	**LED LIGHTING SYSTEMS INTERVENTIONS**						
14	Frosted T8 LED Tube Light (LED Tube 4 Foot 15W-18W DLC)	36	13.64	17.00	3.36	120.96	434,759
15	4" LED Down light with High CRI	25	20	27.00	7.00	175.00	628,992
	Subtotal-2					***295.96***	***1,063,751***
17	Shipment costs/ transport 20%					59.19	212,743
18	Labour cost for installation 15%					44.39	159,548
19	Any other O&M 20%					59.19	212,743
	Total-2					**458.73**	**1,648,785**
CC	**LIGHT CONTROLS**						
20	Daylight sensors	50	0	17.50	17.50	875.00	3,144,960
21	Motion sensors (TSOS5 PIR motion Sensor light switch detector)	100	0	15.00	15.00	1,500.00	5,391,360
22	Occupancy sensor	50	0	18.00	18.00	900.00	3,234,816
23	Timer controls	30	0	25.00	25.00	750.00	2,695,680

Item	Description	Qty	Conventional rate (Cr) (USD)	Energy efficient rate (Eer) (USD)	Net rate (USD) (Eer-Cr)	Amount (USD)	Amount (UGX)
24	Carbon sensors (environment type)	50	0	20.00	20.00	1,000.00	3,594,240
25	Alarms	30	0	31.00	31.00	930.00	3,342,643
28	**Subtotal-3**					***5,955.00***	***21,403,699***
29	Shipment costs/ transport 20%					1,191.00	4,280,740
30	Labour cost for installation 15%					893.25	3,210,555
31	Any other O&M costs 20%					1,191.00	4,280,740
	Total-3					**9,230.25**	**33,175,734**
DD	**PASSIVE INTERVENTIONS**						
32	Light paint: 5 litre buckets	100	0	40.00	40.00	4,000.00	14,376,960
33	Potted plants	150	0	3.00	3.00	450.00	1,617,408
	Sub total					***4,450.00***	***15,994,368***
34	Labour to demolish the middle wall on each floor of annex block to 1.5m from 3m height 20%					890.00	3,198,874
35	Operation and maintenance 10%					445.00	1,599,437
	TOTAL-4					**5,785.00**	**20,792,678**
	Grand total, VAT exclusive					**217,890.75**	**783,151,631**

Note: 1) Demolition to be done once hence no labour costs after first investment. 2). Painting and planters to be replaced after 10 years hence cost to be added to year 11. In reference to Sub-section 6.2, I USD=3,594.24 UGX.

Table 16 shows the cost estimates for investing in an energy efficient equipment. With or without, energy efficiency optimisation, Crusader House occupants would need basic office appliances. The difference between conventional (ordinary) and energy efficient equipment unit prices has therefore been considered in order to ascertain the financial viability, and towards sub-finding for the second sub-research question. The shipment, labour, operations, and maintenance values were obtained by multiplying the assumed percentage with the sub-total of the respective items as categorised in Table 16. The grand total is obtained by adding total values from the items AA, BB, CC and DD (see Table 16).

6.3 Energy efficiency retrofit financial feasibility

In order to respond to the second research sub-question, an evaluation of items (AA, BB, CC, DD as shown in Table 16) was being considered as follows:

- Evaluation of items 'AA' in Table 16 (calculated in Table 18)
- Evaluation of items 'BB', and 'CC' (see Table 20)
- Evaluation of items 'DD' (see Table 22)

The evaluation of these items was based on discounted cash flow method where both discount rate of 14% (to derive future costs/present values) and escalation rate of 10% (annual electricity inflation) (see Section 6.2) was used to derive the energy savings, net cash flow as well as the net present value.

6.3.1 Financial analysis for implementation equipment and appliance interventions

In reference to Section 6.2 and Table 16, the payback period and ROI is calculated in Table 23. The study assumes that replacement costs will only be after 5 years for equipment and appliances and the analysis period will be 10 years.

Table 17: Estimated replacement costs for interventions 'AA"

A	**5th and 15th year replacement**	**Amount (USD)**
	Not replacing the fridge	420.9
	Not replacing the Cordless phones	2,287.6
	Sub total	2,708.5
	Total replacement	**202,416.76-2708.5=199,708.26**
B	**10th year**	
	All equipment and appliances	202,416.76

Table 18: Cash flows, ROI, simple payback and NPV for equipment and appliance energy efficiency measure evaluation

A	B	C	D	E	F	G	H	I	J	K	L	M
Year	**Present value factor: PV=1/(1+d)^t**	**Electricity rate (USD)**	**Baseline energy use (kWh)**	**Baseline energy cost (USD)** **E**=(DxC)	**Optimised energy use (KWh)**	**Optimised energy cost (USD)** G=(FxC)	**Energy saving (kWh)**	**Energy saving cost (Cash Inflow) (USD)** I=(E-G)	**Project Investment Schedule (Out flow) (USD)**	**Net Cash Flow (USD)** (Inflow-outflow) K=(I - J)	**Simple Payback** (Initial Investment + 'K')	**Net Present Value (USD)** 1/(1+d)^t xK **M=**(BXK)
0								0.00	202,416.76	-202,416.76		-202,416.76
1	0.8772	0.175	191,127.50	33,447.31	90,404.50	15,820.79	100,723.00	17,626.53	0.00	17,626.52	-184,790.24	15,461.98
2	0.7695	0.193	191,127.50	36,887.61	90,404.50	17,448.07	100,723.00	19,439.54	0.00	19,439.54	-165,350.70	14,958.73
3	0.6750	0.212	191,127.50	40,519.03	90,404.50	19,165.75	100,723.00	21,353.28	0.00	21,353.28	-143,997.42	14,413.46
4	0.5921	0.234	191,127.50	44,723.84	90,404.50	21,154.65	100,723.00	23,569.18	0.00	23,569.19	-120,428.23	13,954.85
5	0.5194	0.257	191,127.50	49,119.77	90,404.50	23,233.96	100,723.00	25,885.81	199,708.26	-173 822.45	-294,250.68	-90,277.93
6	0.4556	0.283	191,127.50	54,089.08	90,404.50	25,584.47	100,723.00	28,504.61	0.00	28,504.61	-265,746.07	12,986.32
7	0.3996	0.311	191,127.50	59,440.65	90,404.50	28,115.80	100,723.00	31,324.85	0.00	31,324.85	-234,421.22	12,518.58
8	0.3506	0.342	191,127.50	65,365.61	90,404.50	30,918.34	100,723.00	34,447.27	0.00	34,447.27	-199,973.95	12,075.80
9	0.3075	0.376	191,127.50	71,863.94	90,404.50	33,992.09	100,723.00	37,871.85	0.00	37,871.85	-162,102.10	11,645.89
10	0.2697	0.414	191,127.50	79,126.79	90,404.50	37,427.46	100,723.00	41,699.32	202,416.76	-160 717.43	-322,819.53	-43,352.53
11	0.2366	0.455	191,127.50	86,963.01	90,404.50	41,134.05	100,723.00	45,828.97	0.00	45,828.97	-276,990.57	10,843.93
12	0.2076	0.501	191,127.50	95,754.88	90,404.50	45,292.65	100,723.00	50,462.22	0.00	50,462.23	-226,528.34	10,473.90
13	0.1821	0.551	191,127.50	105,311.25	90,404.50	49,812.88	100,723.00	55,498.37	0.00	55,498.37	-171,029.97	10,104.55
14	0.1597	0.606	191,127.50	115,823.27	90,404.50	54,785.13	100,723.00	61,038.14	0.00	61,038.14	-109,991.83	9,748.40
15	0.1401	0.666	191,127.50	127,290.92	90,404.50	60,209.40	100,723.00	67,081.52	199,708.26	-132 626.74	-242,618.57	-18,580.54
16	0.1229	0.733	191,127.50	140,096.46	90,404.50	66,266.50	100,723.00	73,829.96	0.00	73 829.96	-168,788.61	9,073.09
17	0.1078	0.806	191,127.50	154,048.77	90,404.50	72,866.03	100,723.00	81,182.74	0.00	81,182.74	-87,605.87	8,751.47
18	0.0946	0.887	191,127.50	169,530.09	90,404.50	80,188.79	100,723.00	89,341.30	0.00	89,341.30	1,735.43	8,448.21
19	0.0829	0.976	191,127.50	186,540.44	90,404.50	88,234.79	100,723.00	98,305.65	0.00	98,305.65		8,154.29
20	0.0728	1.073	191,127.50	205,079.81	90,404.50	97,004.03	100,723.00	108,075.78	0.00	108,075.78		7,863.78
Total								**1,012,366.87**	**804,250.04**	**208,116.83**		-163,150.52
Energy escalation		**0.100**										
Discount rate		**0.14**										
PV= Present Value		**d= Discount rate**		**t= Time**		**kWh=Kilowatt-hour**						

In reference to Chapter 2-section 2.5, a present value factor in order to derive the NPV was calculated based on the formula shown in column 'B' (see Tables 18, 20 and 22) where 'd' is 14% discount rate used across the 20 year period shown in column 'A'. Column 'C' is the utility electricity rate which is 0.175 USD (see Chapter 5, Table 5) the values in this column are cumulatively calculated based on the 10% escalation rate. For instance, in the second year, the electricity rate is determined by adding 0.175 USD (initial rate) with 10% of 0.175.

Table 18 shows spreadsheet values generated as discussed in Section 6.2. The column 'D' shows the manually calculated annual baseline energy consumption of plug loads connected into power for 10 hours (see Chapter 5, Section 5.6). Column 'E' is the baseline energy cost which is derived by multiplying the baseline energy by the electricity rate (column 'C'). Column 'F' is the annual optimised energy derived after intervening with energy efficient equipment and appliances (see Chapter 5-Section 5.7). Column 'G' is the optimised energy cost derived by multiplying the optimised energy (based on the use of energy efficient equipment and appliances) by the utility electricity rate (Column 'C'). The energy saving cost (cash inflow) is derived by subtracting the optimised energy cost from the baseline energy cost. Column 'J' shows the project investment schedule (cash outflows).

To determine the payback period, the study had previously intended to consider a 10 year analysis period but later realised that this project was not feasible in 10 years, thus in order to ascertain how long it would take to recoup the investments, a 20 year analysis period was considered as shown in Table 18. In reference to Energy Star © (2017), several equipment and appliance life cycle is about 5 years. Therefore, this was taken into account as indicated in Tables 17 and 18. Hence, the study assumed that after 5 years, that there will be no re-sale of old equipment but rather disposed as waste.

The net cash flow in Column 'K' is derived by subtracting the project investment costs from the energy saving costs, while the net present value in Column 'M' is derived by multiplying the net cash flow by the present value factor which is calculated in Column 'B'

Simple payback, ROI and NPV of equipment and appliance (items AA)

As discussed in Chapter 2-Section 2.5.3, the term simple payback refers to the number of years it would take a project to equal the capital costs or yield more than capital investment costs (San Ong and Thum, 2013). Krarti (2016) notes that the time value of money is neglected in the payback period method. Hootman (2013) further notes that the payback analysis is one of the simplest financial analyses that can be made on a project investment decision. In terms of energy efficient investment, he states that "it is a measure of the number of years' worth of energy savings it would take to pay back the initial first cost investment."(*ibid.:*333). However, this method is not good when determining the project returns because the value of money today may not be the same in the future. In addition, the life of a project is not taken into consideration hence depreciation parameters become difficult to determine. There are two methods of determining the simple packback period; the cumulative method (as cited San Ong and Thum, 2013:163) and general method (as cited by Krarti 2016:65). In light of this, the study will adopt cumulative method for all payback calculations as shown below.

Simple pay back = A+ B/C…………………………….**Equation 1** (**Source :** (San Ong and Thum, 2013:163))

Where

'A' is the year before full recovery

'B' is un covered cost at start of the year

'C' is the total cash flow during the year

General method where the simple payback is derived as the total cost of Investment (I) divided by the annual net cash flow………..**Equation 2** (**Source:** Krarti 2016:65).

Return on investment

In reference to Chapter 2-Section 2.5.3, there are several methods of calculating the return on investment (ROI). The ROI is often expressed as a percentage. The bigger the percentage the more the returns from an investment. Therefore, under this analysis, the study will consider using the formula below.

The ROI can be calculated as total net cash flow divided by total project investment schedule expressed as a percentage …………**Equation 3** (**Source:** Krarti (2016))

Net present Value (NPV)

This is determined using equation by Florio *et al.* (2008:48) and (San Ong and Thum, 2013:163)

NPV = Initial investment (I_o) +(Present value factor ($1/(1+d)^t$) multiplied by net cash flows)…………………………**Equation 4** (**Source:** Krarti (2016:66) and San Ong and Thum (2013:163).

Where

I_0 is initial investment

d. is discount rate

t is investment time period

Table 19: Financial analysis for implementation equipment and appliance energy efficiency interventions

Financial analysis	**Calculation**
Simple payback period (SP) using equation 1	17+ 87,605.87/ 89,341.30= 17.981 years
Return on investment (ROI) over 20 years using equation 3	(208,116.83/804 250.04)x100%=25.88%
Net present value (NPV) using equation 4 and as shown in Table 18	USD -163,150.52 (negative)

NPV= USD -163,150.52 (negative value), implies that the project investment cost is greater than the total net cash flow; hence equipment and appliance interventions are not economically viable to implement in the case study building.

6.3.2 Financial analysis for implementation lighting systems and light controls energy efficiency interventions

In reference to subsection 6.3.1, the payback period and ROI is calculated in Table 21. The study assumes replacement costs for light controls and lighting systems interventions (see item BB and CC in Table 16) will only be after 3 years.

Table 20: Cash flows, ROI, simple payback and NPV for Lighting systems and energy light controls energy efficiency interventions in Table 16

A	B	C	D	E	F	G	H	I	J	K	L	M
Year	**Present value factor: PV=1/(1+d)^{t}**	**Electricity rate (USD)**	**Baseline energy use (kWh)**	**Baseline energy cost (USD)** **E**=(DxC)	**Optimised energy use (KWh)**	**Optimised energy cost (USD)** G=(FxC)	**Energy saving (kWh)**	**Energy saving cost (Cash Inflow) (USD)** I=(E-G)	**Project Investment Schedule (Out flow) (USD)**	**Net Cash Flow (USD)** (Inflow-outflow) K=(I - J)	**Simple Payback** (Initial Investment + 'K')	**Net Present Value (USD)** 1/(1+d)^{t} xK M=(BXK)
0								0.00	9,688.99	**-9,688.99**		**-9,688.99**
1	0.8772	0.175	191,127.50	33,447.31	90,404.50	15,820.79	100,723.00	17,626.53	0.00	17,626.53	7,937.54	15,461.99
2	0.7695	0.193	191,127.50	36,887.61	90,404.50	17,448.07	100,723.00	19,439.54	0.00	19,439.54		14,958.73
3	0.6750	0.212	191,127.50	40,519.03	90,404.50	19,165.75	100,723.00	21,353.28	9,688.99	11,664.29		7,873.40
4	0.5921	0.234	191,127.50	44,723.84	90,404.50	21,154.65	100,723.00	23,569.18	0.00	23,569.18		13,954.85
5	0.5194	0.257	191,127.50	49,119.77	90,404.50	23,233.96	100,723.00	25,885.81	0.00	25,885.81		13,444.28
Total								**107,874.34**	**19,377.98**	**88,496.36**		**56,004.25**
Energy escalation		**0.100**										
Discount rate		**0.14**										
PV= Present Value		**d= Discount rate**		**t= Time**		**kWh=Kilowatt-hour**						

Simple payback, ROI and NPV of lighting systems and light controls (items BB and CC)

The previous Table 18 was presented and discussed. A similar approach is applied to Table 20 to derive sub-findings. Equation 1 and 2 in sub-section 6.3.1 is used to derive the financial analysis findings (simple payback period, ROI and NPV) which are tabulated in Table 21 here below.

Table 21: Financial analysis for implementation of lighting systems and light controls energy efficiency interventions

Financial analysis	**Calculation**
Simple payback period (SP) using equation 1	0+ 9,688.99/ 17,626.53= 0.55 months Approximately 5 to 6 months
Return on investment (ROI) over 5 years using equation 3	(88,496.36/19,377.98)x100%=456.7%, 91.34% per year.
Net present value (NPV) using equation 4 and as shown in Table 20	**USD 56,004.25** (positive)

Table 21 indicates that investing in lighting systems, light controls, as well as passive design items tabulated in Table 16 are economically viable. This is based on NPV (USD56,004.25 (positive)) value which is positive thus implying that the cash flows are greater than outflows and the pay back period is 5 to 6 months.

6.3.3 Financial analysis for implementation passive interventions (items DD)

As discussed in section 6.3.1, similar approach and decription of Table 18 is adopted for this scenario as analysed in Table 22. The study assumes replacement costs to be after 5 years. Therefore, as highlighted in Table 16 item DD, the study assumes that there will be no further demolitions, thus only 4,895 USD will be the investment cost on the year 5. The total capital costs for this scenario after 10 years will therefore be 10,680 USD..

Table 22: Cash flows, ROI, simple payback and NPV for passive energy efficiency interventions in Table 16

A	B	C	D	E	F	G	H	I	J	K	L	M
Year	**Present value factor: PV=1/(1+d)^{t}**	**Electricity rate (USD)**	**Baseline energy use (kWh)**	**Baseline energy cost (USD)** **E**=(DxC)	**Optimised energy use (KWh)**	**Optimised energy cost (USD)** G=(FxC)	**Energy saving (kWh)**	**Energy saving cost (Cash Inflow) (USD)** I=(E-G)	**Project Investment Schedule (Out flow) (USD)**	**Net Cash Flow (USD)** (Inflow-outflow) K=(I - J)	**Simple Payback** (Initial Investment + 'K')	**Net Present Value (USD)** 1/(1+d)^{t} xK **M=**(BXK)
0								0.00	5,785.00	-5,785.00		-5,785.00
1	0.8772	0.175	191,127.50	33,447.31	90,404.50	15,820.79	100,723.00	17,626.52	0.00	17,626.52	11,841.52	15,461.98
2	0.7695	0.193	191,127.50	36,887.61	90,404.50	17,448.07	100,723.00	19,439.54	0.00	19,439.54		14,958.73
3	0.6750	0.212	191,127.50	40,519.03	90,404.50	19,165.75	100,723.00	21,353.28	0.00	21,353.28		14,413.46
4	0.5921	0.234	191,127.50	44,723.84	90,404.50	21,154.65	100,723.00	23,569.19	0.00	23,569.19		13,955.32
5	0.5194	0.257	191,127.50	49,119.77	90,404.50	23,233.96	100,723.00	25,885.81	4,895.00	20,990.81		10,902.63
6	0.4556	0.283	191,127.50	54,089.08	90,404.50	25,584.47	100,723.00	28,504.61	0.00	28,504.61		12,986.70
7	0.3996	0.311	191,127.50	59,440.65	90,404.50	28,115.80	100,723.00	31,324.85	0.00	31,324.85		12,517.41
8	0.3506	0.342	191,127.50	65,365.61	90,404.50	30,918.34	100,723.00	34,447.27	0.00	34,447.27		12,077.21
9	0.3075	0.376	191,127.50	71,863.94	90,404.50	33,992.09	100,723.00	37,871.85	0.00	37,871.85		11,645.59
10	0.2697	0.414	191,127.50	79,126.79	90,404.50	37,427.46	100,723.00	41,699.33	0.00	41,699.33		11,246.31
Total								**281,722.25**	**10,680.00**	**271,042.25**		**124,380.34**
Energy escalation		**0.100**										
Discount rate		**0.14**										
PV= Present Value		**d= Discount rate**		**t= Time**		**kWh=Kilowatt-hour**						

Table 23: Financial analysis for implementation of passive interventions

Financial analysis	**Calculation**
Simple payback period (SP) using equation 1	0+ 5,785.00/17,626.52= 0.33 months Approximately 3 to 4 months
Return on investment (ROI) over 10 years using equation 3	(271,042.25/10,680.00)x100%=2,537.9%
Net present value (NPV) using equation 4 and as shown in Table 22	USD 124,380.34 (positive)

Table 23 shows NPV is positive thus investing in passive interventions is economically viable for CHOB.

6.4 Conclusion on energy efficiency feasibility

In response to the second research question highlighted in sub-section 1.4.1, Chapter 1 and as discussed in Chapter 2, sub-section 2.3.1, the energy efficiency interventions (lighting systems, lignting controls and passive parameters) presented in Tables 20 and 22 indicate that the interventions are cost effective for CHOB, while equipment and appliances would take approximately 18 years as indicated in Table 18 and 19 to recoup the investments thus making it not economically viable.

6.5 Financial feasibility for distributed generation with rooftop PV

In reference to Chapter 5, sub-section 5.6 and Figure 32 (monthly utility electricity consumption), the month of June shows the highest demand for electricity. Therefore, the daily peak demand (assumed to be constant) in this month will be calculated and considered for sizing the PV system. Tables 13-15, sub-section 5.7 show the optimised average daily electricity demand is 361.62kWh. Therefore, the optimised energy demand in June is equal to 361.62 kWh energy demand per day multiplied by 21 working days. This gives us 7,594.02 kWh after optimisation from a baseline of 1,7218kWh.

6.5.1 Sizing of PV system

In reference to Chapter 1, for the 10MW Soroti solar project, the solar panels were supplied by a Canadian solar company based in China. The study evaluated the three top solar manufacturers in China namely Jinko Solar., Cinco and Canadian Solar as well as a South African solar panel distributor company (Segen Solar Pty ltd) in order to compare the prices of the system for the case study building.

According to Saleh, Haruna and Onuigbo (2015), to size the PV system, it is important to know the DC voltage of the system, the average sun hours of the installation site per day and the daily average energy demand in watt-hours.

In reference to section 6.5, the next step is to determine the PV panel system to supply 361.62 kWh per day, where, energy demand per day is divided by sun hours. According to the climate-data: Kampala, the dry seasons have longer sun hours than the wet seasons. The dry seasons have an average of five hours per day while the wet seasons have four hours per day. According to Meteonorm 7.1 data, Kampala has 4.82 peak sun hours.

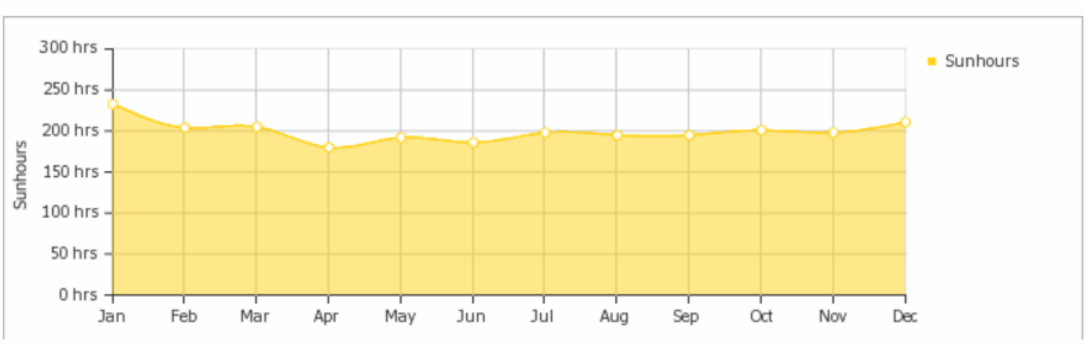

Figure 38: Kampala monthly sun hours; **Source:** Climate-data, 2016

In light of this, 361.62 kWh/4.82 hours equal to 75.02-kilowatt peak. According to Saleh, *et.al.* (2015), assume system efficiency of 90%, we divide the 75.02 kWp/0.9 to get 83.36 kWp. This is the amount of power needed to be provided by the solar modules to operate CHOB. The solar modules in the market ranging from 100W-250W would be considered and a 250W Canadian solar module was identified as suitable for further evaluation.

Electrical Data

		CS6P-220P	CS6P-225P	CS6P-230P	CS6P-235P	CS6P-240P	CS6P-245P	CS6P-250P
Nominal Maximum Power at STC (Pmax)		220W	225W	230W	235W	240W	245W	250W
Optimum Operating Voltage (Vmp)		29.2V	29.4V	29.6V	29.8V	29.9V	30.0V	30.1V
Optimum Operating Current (Imp)		7.53A	7.65A	7.78A	7.90A	8.03A	8.17A	8.30A
Open Circuit Voltage (Voc)		36.6V	36.7V	36.8V	36.9V	37.0V	37.1V	37.2V
Short Circuit Current (Isc)		8.09A	8.19A	8.34A	8.46A	8.59A	8.74A	8.87A
Operating Temperature		-40℃~+85℃						
Maximum System Voltage		1000V (IEC) /600V (UL)						
Maximum Series Fuse Rating		15A						
Power Tolerance		+5W						
Temperature Coefficient	Pmax	-0.43%/℃						
	Voc	-0.34 %/℃						
	Isc	0.065 %/℃						
	NOCT	45℃						

Under Standard Test Conditions (STC) of irradiance of 1000W/m², spectrum AM 1.5 and cell temperature of 25℃

Mechanical Data

Cell Type	Poly-crystalline
Cell Arrangement	60 (6 x 10)
Dimensions	1638 x 982 x 40mm (64.5 x 38.7 x 1.57in)
Weight	20kg (44.1 lbs)
Front Cover	Tempered glass
Frame Material	Anodized aluminium alloy
Standard Packaging (Modules per Pallet)	20pcs

Figure 39: Solar module sizes (electrical and mechanical data for 250W panel. **Source:** Canadian Solar, 2017.

To determine the number of solar panels, peak electricity demand is divided by rated output watt peak of the PV module= 83.36 kWp/0.25= 333.44 approximately 334 panels**.** This number of panels is sufficient in reference to the total available roof space, which is 610 m². The area of one solar panel as highlighted in Figure 39 as 1.6085 m². This area is multiplied by 334 panels to get 537.24 m² (approximately 570 m² to cater for any solar spacing) roof area (flat roof installation) required to install the 334 solar panels.

Alternatively, area required by 334 solar panels can be determined by the formula; Total power output is equal to total area (A) multiplied by solar irradiance and by conversion efficiency. In light of this, we assume on a clear day solar irradiance per m² =1,000W/m² and conversion efficiency of 18%

This gives us (250Wx334 panels) = (A X 1000 X 0.18) =83500W divided by 180W/m²=463.89m², which is approximately 500 m² as the estimated area required by the solar panels. The two approaches further signify that the existing roof area is sufficient for rooftop PV installations.

6.5.2 Determining the inverter capacity

Saleh, *et.al.* (2015) state that inverters are often the heart of the PV systems as they convert DC power to AC power. An inverter is rated by its output power and DC input voltage. Moreover, "the power rating of the inverter should not be less than the total power consumed in different loads, but rather have the same nominal voltage of battery bank that is charged by solar PV module" (*ibid.*:45). This implies that we need to oversize the inverter such as its power rating is larger than the plug loads of the case study building and should be equivalent to the battery capacity.

Therefore, the total optimised wattage of energy efficient plug loads and lighting system is 36,161.8W (see Chapter 5, Table 13 and 14). In order to determine the volt-Amps per day, Saleh, *et.al.* (2015) guides the study to assume the power factor of an inverter to be 80% and additional load expansion to be 20%. This gives us 36,161.8W multiplied by 10 hours and divided by 0.8 power factor, (36,161.8x10/0.8) which is equal to =452,022.5VA. We add this value with expected load expansion, (1+20%) which is 1.2 +452,022.5=452,023.7VA (approximately 500,000VA, see Table 24**)** is the required inverter size (*ibid*: 45). The total number of inverters is equal to peak energy demand divided by the rated output power of the selected inverter. Therefore, 83.36kW/50kW**=1.667=2** inverters

Table 24: Inverter specifications. Source: Canadian Solar, 2017

Canadian solar 3ph inverter 50kWCSI-50KTL-GI_H			
DC Input		**AC output**	
Max. PV Power	50kW (22.5kW/MPPT)	Rated AC output power	50 kW
Max. DC input Voltage	1,100Vdc	Max AC output power	50 kW
Operating DC input voltage range	200-1,000Vdc	Rated output voltage	480/500V
Start-up DC input voltage/power	200V	Output voltage range	384-576Vdc
Number of MPP trackers	4	Grid connection type	3Q/PE
MPPT voltage range	526-850Vdc	Rated output frequency	50/60HZ
Operating current (Imp)	114A (28.5 per MPPT)	Power factor	1 (0.8 adjustable)
Maximum. Input current (Isc)	178A (44.5A per MPPT)	Max efficiency	99%
Number of DC inputs	12A (3A per MPPT)	CEC efficiency	98.5%
Power factor	0.8	Night consumption	<1W
Maximum efficiency	98.3%	Weight	63Kg

6.5.3 Determining the battery size

Saleh, *et.al.* (2015) suggests that the deep-cycle lead-acid batteries are good for standalone PV systems because of their high performance. Saleh, *et.al.* (2015) further guides the study to determine the battery size as follows: The daily peak demand of energy is 361.62 kWh. Assuming an off-grid system, the battery usage will be 10 hours a day for 3 days

361.62kWh =361,620Wh. We multiply this value by the days of autonomy (3). This gives us 1,084,860Wh. The next step will be to multiply this value with temperature factor, where the batteries will be exposed to (assume 27^{o}C (80) factor=1). Then to determine the battery capacity, we shall consider a 48V system voltage = (1,084,860x1)/48V which is equal to 22,601.25Ah=22,602Ah (approximately 25,000Ah). This is the capacity of the battery bank required for the energy consumption assumed. This value will be divided by the chosen battery rating to derive the number of batteries.

6.6 Cost of solar PV system investment

To determine the cost of the PV system, several companies such as Jinko Solar, Sunllent, Segen (South African company) and Canadian Solar Company were contacted via E-mail to provide a quotation for purchase of the PV system items. The calculated values such as the optimised load, the building information and the sized elements of the PV system were forwarded to solar companies such as (Canadian solar and SMA) in China and suppliers/distributors in South Africa.

Table 24 shows the estimated costs of the PV system via off-grid/stand alone with battery, grid interactive with battery and grid interactive no battery. The project life will be 20 years because Uganda's PPA agreements for RE are based on 20 years (see Chapter 4 sub-section 4.3.1)

Determining the annual PV generation

In reference to Chapter 2, sub-section 2.4.1 equation ($E = A \times r \times H \times PR$) and Chapter 1, the solar radiation average for Uganda is approximately 5.1kWh/m^2/day.

In light of this,

Area of solar panel(1.638 x 0.982) **(A)=**	1.6085m^2
Calculated number of solar panels for CHOB =	334
Solar panel yield (%)=(0.25/1.6085)100 **(r)=**	15.54%
Solar radiation **(H)=**	5.1kWh/m^2
Assume system performance ratio of 80% **(PR)=**	0.8

Therefore, the annual PV generation of the selected PV system is equal to:

E=1.6085 X 334 X 0.1554 X (5.1X365 days) X 0.8 equal to 124,328.75 kWh

There are 259 working days (Monday to Friday) for CHOB in a year and 9 public official holidays thus yielding actual annual working days be 250 days. Therefore,

Annual PV generation for 250 days (E) = (1.6085 X 334 X 0.1554 X 5.1 X 250 X 0.8) equal to 85,156.68 kWh.

The surplus PV power generated by the PV system annually is equal to (Annual PV generation minus optimised energy) = (124,328.75-90,404.5) =33,924.25 kWh.

Table 25 here below, shows three technology scenario (off grid, grid interactive with battery and grid interactive no battery) initial costs that will be further be analysed to derived sub findings for technology that is economically viable for CHOB based on Uganda's current policy and legislative environment. Grid interactive with battery mitigates the frequent blackouts faced by CHOB while at the same offering opportunity for supply of surplus power to the grid in future especially when responsive policy changes come into effect.

Table 25: Cost of solar PV investment. Source: Unit prices obtained from solar technology suppliers/distributors in China and South Africa (see Appendix 3 for quotation page 181)

	Technology	**Off-grid/ stand alone**				**Grid interactive with battery**				**Grid interactive no battery**	
Item	**Description**	**Qty**	**Rate (USD)**	**Amount (USD)**	**Amount (UGX)**	**QTY**	**Rate (USD)**	**Amount (USD)**	**Amount (UGX)**	**Amount (USD)**	**Amount (UGX)**
1	Canadian solar panels poly 156x156mm, CS6P-250P, Series fuse rating, 15, short circuit (Isc) is 8.87, Max.power current (imp) is 8.3.	334	385	128,590	462,183,322	334	385	128,590	462,183,322	128,590	462,183,322
2	8G30H Deka solar Gel battery 12V 1000Ah	25	338	8,450.00	30,371 328	25	338	8,450.00	30,371 328	0	0
3	Grid-tied Canadian solar 3ph inverter 50kWCSI-50KTL-GI_H or SMA Sunny Tripower 50kW 480VAC TL Inverter STP50,000TL-US-10	2	5,549	11,098	39,888,876	2	8,500	17,000	61,102,080	17,000	61,102,080
4	Solar charge controller (220V 200A)	1	995	995	3,576,269	1	1,200	1,200	4,313,088	1,200	4,313,088
5	Shipment costs	1	6,000	6,000	21,565,440			6,000	21,565,440	6,000	21,565,440
	Sub total			**155,133**	**595,051,592**			**161,240**	**579 535 258**	**152,790**	**549,163,930**
6	Accessories such as bolts, holders 20%			31,027	111,518,484			32,248	115,907,052	30,558	109,832,786
7	Installation 20% of the PV cost			31,027	111,518,484			32,248	115,907,052	30,558	109,832,786
8	Operation and maintenance 30%			46,540	167,275,930			48,372	173,860,577	45,837	164,749,179
	Grand total			**263,727**	**985,364,490**			**274,108**	**985,209,938**	**259,743**	**933,578,680**

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6.6.1 Financial analysis for implementation of an off-grid PV system on CHOB (generation for own use)

This is the first scenario for generation of PV power via off-grid for own use after energy efficiency interventions/optimisation. In this scenario, the study assumes replacement costs in tabulated in Table 26 to be after 10 years.

Table 26: Replacement costs for an off-grid solution

Replacement cost (off grid solution)	Amount (USD)
Battery	8,450
Controller	995
Inverter	11,098
Sub total	***20,543***
Shipping 10%	2,054.3
Installation 10%	2,054.3
Total replacement cost	**24,651.6**

Table 27 shows financial analysis for an off grid solution. As discussed in Section 6.3.1, a similar approach for calculations is used in order to derive sub findings highlighted in columns 'A' to 'I'.

Payback period, return on investment and net present value calculations

In reference to equation 1 and 2 in sub-section 6.3.1, the financial viability for implementing an off grid solution with battery back up to mitigate power outages in the case study building is calculated shown in Table 27, in reference to Table 28.

Table 27: Financial analysis for an off-grid solution

Financial analysis	Calculation
Simple payback period (SP) using equation 1	10+ 35,517.2 / 41,134.05= 10.86 years
Return on investment (ROI) 20 years using equation 3	(620,277.03/288,378.60)x100%=215% or 10.75% per year
Net present value (NPV) using equation 4 and as shown in Table 28	(USD -67,916.32 (Negative)

Table 28: Off-grid PV generation after optimisation

A	B	C	D	E	F	G	H	I	J
Year	**Present value factor: PV=1/(1+d)^t**	**Electricity rate (USD)**	**Optimised energy use as result of EE (KWh)**	**Optimised energy cost (USD)** E=(DxC)	**Energy saving cost as result of EE** (Cash Inflow) **(USD)**	**Project Investment Schedule** (off-grid) (Cash Outflow) **(USD)**	**Net Cash Flow (USD)** (Inflow-outflow) H=(F-G)	**Simple Payback** (Initial Investment + 'H')	**Net Present Value (USD)** 1/(1+d)^t xH **J=**(BXH)
0					0.00	263,727	-263,727.00		-263,727.00
1	0.8772	0.175	90,404.50	15,820.79	15,820.79	0.00	15,820.79	-247,906.2	13,878.00
2	0.7695	0.193	90,404.50	17,448.07	17,448.07	0.00	17,448.07	-230,458.1	13,426.29
3	0.6750	0.212	90,404.50	19,165.75	19,165.75	0.00	19,165.75	-211,292.4	12,936.88
4	0.5921	0.234	90,404.50	21,154.65	21,154.65	0.00	21,154.65	-190,137.7	12,525.67
5	0.5194	0.257	90,404.50	23,233.96	23,233.96	0.00	23,233.96	-166,903.8	12,067.72
6	0.4556	0.283	90,404.50	25,584.47	25,584.47	0.00	25,584.47	-141,319.3	11,656.28
7	0.3996	0.311	90,404.50	28,115.80	28,115.80	0.00	28,115.80	-113,203.5	11,235.07
8	0.3506	0.342	90,404.50	30,918.34	30,918.34	0.00	30,918.34	-82,285.2	10,839.97
9	0.3075	0.376	90,404.50	33,992.09	33,992.09	0.00	33,992.09	-48,293.1	10,452.57
10	0.2697	0.414	90,404.50	37,427.46	37,427.46	24,651.60	12,775.86	-35,517.2	3,445.65
11	0.2366	0.455	90,404.50	41,134.05	41,134.05	0.00	41,134.05	5,616.8	9,733.03
12	0.2076	0.501	90,404.50	45,292.65	45,292.65	0.00	45,292.65		9,400.90
13	0.1821	0.551	90,404.50	49,812.88	49,812.88	0.00	49,812.88		9,069.40
14	0.1597	0.606	90,404.50	54,785.13	54,785.13	0.00	54,785.13		8,749.73
15	0.1401	0.666	90,404.50	60,209.40	60,209.40	0.00	60,209.40		8,435.13
16	0.1229	0.733	90,404.50	66,266.50	66,266.50	0.00	66,266.50		8,143.60
17	0.1078	0.806	90,404.50	72,866.03	72,866.03	0.00	72,866.03		7,854.94
18	0.0946	0.887	90,404.50	80,188.79	80,188.79	0.00	80,188.79		7,582.74
19	0.0829	0.976	90,404.50	88,234.79	88,234.79	0.00	88,234.79		7,318.93
20	0.0728	1.073	90,404.50	97,004.03	97,004.03	0.00	97,004.03		7,058.18
Total					**908,655.63**	**288,378.60**	**620,277.03**		-67,916.32
Energy escalation		**0.100**							
Discount rate		**0.14**							
PV= Present Value		**d= Discount rate**		**t= Time**		**kWh=Kilowatt-hour**			

Table 28 indicates the net cash flows are higher than the project investment costs, and NPV is negative. This implies that the investor will target profits today than wait for profits in future. This was as due to the discount rate 14%, which is too high (refer to section 1.7, second delimitation), thus this off grid scenario is not viable for CHOB.

6.6.2 Financial analysis for grid interactive with no battery (export on holidays and weekends)

This is the second scenario where a developer may decide to design a PV system that can generate PV electricity over the weekends and holidays only to export to the grid in order to improve the cash flows after energy efficiency intervention (This can only apply in presence of the policy changes as discussed in Chapter 4).

There are 115 days of both public holidays and weekends (9 public holidays and 106 weekends). Therefore, in reference to Chapter 2, Sub-section 2.4.1 equation, PV power generated will be (1.6085 X 334 X 0.1554 X 5.1 X 115 X 0.8) which is equal to 39,172.073 kWh. This generation over the weekends and public holidays will not need a storage facility. The 39,172.073 kWh can be sold at a feed-in tariff, which is 11 cents US dollars per kilowatt-hour. As discussed in Sub-section 6.6.1, replacement cost will only be undertaken after 10 years and these include:

Table 29: Replacement costs for grid interactive solution no battery

Replacement cost (grid interactive solution)	**Amount (USD)**
Battery	0
Controller	995.0
Inverter	11,098.0
Sub total	**12,093.0**
Shipping 10%	1,209.3
Installation 10%	1,209.3
Total replacement	**14,511.6**

As discussed in Section 6.3, Column 'H' in Table 30 is the FiT for renewable energy in Uganda which is fixed and constant value. The findings in Chapter 4 indicated that R.E business, policies such as net metering are under development and formulation. Hence, the study anticipates that there will be no escalations as DGRTPV technology innovation diffuses in the country.

Table 30: Grid interactive-no battery (weekend and public days generation export to grid)

A	B	C	D	E	F	G	H	I	J	K	L	M	N
Year	**Present value factor: PV=1/(1+d)^t**	**Electricity rate (USD)**	**Optimised energy use** as result of EE **(KWh)**	**Optimised energy cost (USD)** (E=DxC)	**Energy saving cost** as result of EE **(cash inflow) (USD)** F=E	**PV generation for 115 days no battery**	**RE Feed in Tariff rate (USD)**	**Cash Flow as result of PV generation (USD)** I=HxG	**Total Cash Flow** (optimised and PV generation) **(USD)** J= (I+F)	**Project Investment Schedule** (grid-tied NO battery) (cash outflow) **(USD)**	**Net Cash Flow (USD)** (Inflow-outflow) L=(J-K)	**Simple Payback** (Initial Investment + 'H')	**Net Present Value (USD)** 1/(1+d)^t x L **N=**(BXL)
0					0.00			0.00	0.00	259,743	-259,743.00		-259,743.00
1	0.8772	0.175	90,404.50	15,820.79	15,820.79	39,172.073	0.11	4,308.93	31,216.71	0.00	20,129.72	-239,613.3	17,657.79
2	0.7695	0.193	90,404.50	17,448.07	17,448.07	39,172.073	0.11	4,308.93	32,798.79	0.00	21,757.00	-217,856.3	16,742.01
3	0.6750	0.212	90,404.50	19,165.75	19,165.75	39,172.073	0.11	4,308.93	34,588.80	0.00	23,474.68	-194,381.6	15,845.41
4	0.5921	0.234	90,404.50	21,154.65	21,154.65	39,172.073	0.11	4,308.93	36,508.08	0.00	25,463.58	-168,918.0	15,076.98
5	0.5194	0.257	90,404.50	23,233.96	23,233.96	39,172.073	0.11	4,308.93	38,619.30	0.00	27,542.89	-141,375.1	14,305.78
6	0.4556	0.283	90,404.50	25,584.47	25,584.47	39,172.073	0.11	4,308.93	40,941.64	0.00	29,893.40	-111,481.7	13,619.43
7	0.3996	0.311	90,404.50	28,115.80	28,115.80	39,172.073	0.11	4,308.93	43,496.21	0.00	32,424.73	-79,057.0	12,956.92
8	0.3506	0.342	90,404.50	30,918.34	30,918.34	39,172.073	0.11	4,308.93	46,306.24	0.00	35,227.27	-43,829.7	12,350.68
9	0.3075	0.376	90,404.50	33,992.09	33,992.09	39,172.073	0.11	4,308.93	49,397.27	0.00	38,301.02	-5,528.7	11,777.56
10	0.2697	0.414	90,404.50	37,427.46	37,427.46	39,172.073	0.11	4,308.93	52,797.40	14,511.60	27,224.79	21,696.1	7,342.53
11	0.2366	0.455	90,404.50	41,134.05	41,134.05	39,172.073	0.11	4,308.93	56,537.55	0.00	45,442.98		10,752.60
12	0.2076	0.501	90,404.50	45,292.65	45,292.65	39,172.073	0.11	4,308.93	60,651.72	0.00	49,601.58		10,295.26
13	0.1821	0.551	90,404.50	49,812.88	49,812.88	39,172.073	0.11	4,308.93	65,177.30	0.00	54,121.81		9,853.92
14	0.1597	0.606	90,404.50	54,785.13	54,785.13	39,172.073	0.11	4,308.93	70,155.43	0.00	59,094.06		9,437.91
15	0.1401	0.666	90,404.50	60,209.40	60,209.40	39,172.073	0.11	4,308.93	75,631.38	0.00	64,518.33		9,038.79
16	0.1229	0.733	90,404.50	66,266.50	66,266.50	39,172.073	0.11	4,308.93	81,654.93	0.00	70,575.43		8,673.13
17	0.1078	0.806	90,404.50	72,866.03	72,866.03	39,172.073	0.11	4,308.93	88,280.83	0.00	77,174.96		8,319.44
18	0.0946	0.887	90,404.50	80,188.79	80,188.79	39,172.073	0.11	4,308.93	95,569.32	0.00	84,497.72		7,990.20
19	0.0829	0.976	90,404.50	88,234.79	88,234.79	39,172.073	0.11	4,308.93	103,586.66	0.00	92,543.72		7,676.35
20	0.0728	1.073	90,404.50	97,004.03	97,004.03	39,172.073	0.11	4,308.93	112,405.74	0.00	101,312.96		7,371.70
Total					**908,655.63**				**994,834.19**	**274,254.60**	**720,579.59**		**-32,658.61**
Energy escalation		**0.100**											
Discount rate		**0.14**											
PV= Present Value		**d= Discount rate**		**t= Time**		**kWh**=Kilowatt-hour							

Note: replacement of battery, inverters and solar controller after 10 years. re-shipping costs 10% , re-installation 10%

Payback period, return on investment and net present value calculations for weekend and holiday export

In reference to equation 1 and 2 in Sub-section 6.3.1, the financial viability for implementing a grid interactive option with no battery back up to is calculated as in shown in Table 31 in reference to Table 30.

Table 31: Financial analysis for grid interactive solution no battery

Financial analysis	**Calculation**
Simple payback period (SP) using equation 1	9+ 5,528.7 / 27,224.79= 9.20 years
Return on investment (ROI) 20 years using equation 3	(720,579.59/274,254.60)x100%=262.7
Net present value (NPV) using equation 4 and as shown in Table 30	(USD -32,658.61 (Negative)

The negative NPV value at the end of twenty years signifies that the project is not worth investing despite the project inflow illustrated in Table 30 being more than the investment project cost. This implies that cash at hand is more valuable than cash in future via grid interactive application no battery for weekend and holiday.

6.6.3 Financial analysis for grid interactive with battery (full year, 365 days PV generation targeting the future net metering policy)

In the absence of the net-metering policy in Uganda, this third business scenario is intended for own use surplus power exported to the grid at no feed-in tariff given that the building will be expected to produce more power than it consumes. When the net metering policy is established, the business case will be attractive to several investors or developers. The storage facility in this set up is therefore intended to cater for power outage periods. In light of this, the NPV financial analysis presented in Table 32 will motivate on the decision making for investment in this business case scenario.

Moreover, it is projected that replacement of batteries, the inverter and solar charge controllers will be in the tenth (10) year. Refer to the replacement cost values in Sub Section 6.6.1.

Table 32: Grid interactive with battery (full 365 days rooftop generation with target of net metering policy)

A	B	C	D	E	F	G	H	I	J	K	L	M	N
Year	**Present value factor: PV=1/(1+d)^t**	**Electricity rate (USD)**	**Optimised energy use (KWh)**	**Optimised energy cost (USD)** (E=DxC)	**Energy saving cost as result of EE (cash inflow) (USD)** F=E	**PV generation for 365 days with battery**	**RE Feed in Tariff rate (USD)**	**Cash Flow as result of PV generation (USD)** I=HxG	**Total Cash f Flow (optimised and PV generation) (USD)** J= (I+F)	**Project Investment Schedule** (grid-tied with battery) **(cash outflow) (USD)**	**Net Cash Flow (USD)** L=(J-K)	**Simple Payback** (Initial Investment + 'H')	**Net Present Value (USD)** 1/(1+d)^t x L **N=**(BXL)
0					0.00			0.00	0.00	274,108.00	-274,108.00		-274,108.00
1	0.8772	0.175	90,404.50	15,820.79	15,820.79	124,328.75	0.11	13,676.16	29,496.95	0.00	29,496.95	-244,611.05	25,874.73
2	0.7695	0.193	90,404.50	17,448.07	17,448.07	124,328.75	0.11	13,676.16	31,124.23	0.00	31,124.23	-213,486.82	23,950.10
3	0.6750	0.212	90,404.50	19,165.75	19,165.75	124,328.75	0.11	13,676.16	32,841.91	0.00	32,841.91	-180,644.90	22,168.29
4	0.5921	0.234	90,404.50	21,154.65	21,154.65	124,328.75	0.11	13,676.16	34,830.81	0.00	34,830.81	-145,814.09	20,623.32
5	0.5194	0.257	90,404.50	23,233.96	23,233.96	124,328.75	0.11	13,676.16	36,910.12	0.00	36,910.12	-108,903.97	19,171.12
6	0.4556	0.283	90,404.50	25,584.47	25,584.47	124,328.75	0.11	13,676.16	39,260.63	0.00	39,260.63	-69,643.34	17,887.14
7	0.3996	0.311	90,404.50	28,115.80	28,115.80	124,328.75	0.11	13,676.16	41,791.96	0.00	41,791.96	-27,851.37	16,700.07
8	0.3506	0.342	90,404.50	30,918.34	30,918.34	124,328.75	0.11	13,676.16	44,594.50	0.00	44,594.50	16,743.13	15,634.83
9	0.3075	0.376	90,404.50	33,992.09	33,992.09	124,328.75	0.11	13,676.16	47,668.25	0.00	47,668.25		14,657.99
10	0.2697	0.414	90,404.50	37,427.46	37,427.46	124,328.75	0.11	13,676.16	51,103.62	24,651.6	26,452.02		7,134.11
11	0.2366	0.455	90,404.50	41,134.05	41,134.05	124,328.75	0.11	13,676.16	54,810.21	0.00	54,810.21		12,968.10
12	0.2076	0.501	90,404.50	45,292.65	45,292.65	124,328.75	0.11	13,676.16	58,968.81	0.00	58,968.81		12,241.93
13	0.1821	0.551	90,404.50	49,812.88	49,812.88	124,328.75	0.11	13,676.16	63,489.04	0.00	63,489.04		11,561.35
14	0.1597	0.606	90,404.50	54,785.13	54,785.13	124,328.75	0.11	13,676.16	68,461.29	0.00	68,461.29		10,933.27
15	0.1401	0.666	90,404.50	60,209.40	60,209.40	124,328.75	0.11	13,676.16	73,885.56	0.00	73,885.56		10,351.37
16	0.1229	0.733	90,404.50	66,266.50	66,266.50	124,328.75	0.11	13,676.16	79,942.66	0.00	79,942.66		9,824.95
17	0.1078	0.806	90,404.50	72,866.03	72,866.03	124,328.75	0.11	13,676.16	86,542.19	0.00	86,542.19		9,329.25
18	0.0946	0.887	90,404.50	80,188.79	80,188.79	124,328.75	0.11	13,676.16	93,864.95	0.00	93,864.95		8,879.62
19	0.0829	0.976	90,404.50	88,234.79	88,234.79	124,328.75	0.11	13,676.16	101,910.95	0.00	101,910.95		8,448.42
20	0.0728	1.073	90,404.50	97,004.03	97,004.03	124,328.75	0.11	13,676.16	110,680.19	0.00	110,680.19		8,057.52
Total					**908,655.63**				**1,182,178.88**	**298,759.60**	**883,419.28**		**12,289.47**
Energy escalation		**0.100**											
Discount rate		**0.14**											
PV= Present Value		**d= Discount rate**		**t= Time**		**kWh**=Kilowatt-hour							

Note: replacement of battery, inverters and solar controller after 10 years. re-shipping costs 10% , re-installation 10%

Payback period, return on investment and net present value calculations for full 365 days rooftop generation with target of net metering policy

In reference to equation 1 and 2 in sub-section 6.3.1, the financial viability for implementing a grid interactive option with battery back up to is calculated as shown in Table 30 below in reference to Table 29.

Table 33: Financial analysis for grid interactive solution with battery

Financial analysis	**Calculation**
Simple payback period (SP) using equation 1	7+ 27 851.37/ 44 594.50= 7.62 years
Return on investment (ROI) 20 years using equation 3	(883,419.28/298,759.60)x100%=295.696%
Net present value (NPV) using equation 4 and as shown in Table 32	USD 12,289.47 (positive)

The positive NPV value at the end of twenty years signifies that the project is worth investing as the project inflows are greater than the outflows grid interactive application no battery for weekend and holiday.

6.6.4 Financial analysis for a hybrid of optimised energy and PV generation (off-grid-battery)

In reference to Table 29 (for PV cost) and Table 12 (for diesel annual cost), Table 31 shows cost analysis for a hybrid of the optimised energy and PV generation. It is evident from Table 31 that it is economically viable to invest in energy efficiency and the PV systems thus no need for stand alone diesel generator. The costs incurred on operating and maintaining the diesel generator in turn become savings.

Table 34: Cost analysis (savings as result of optimised energy, PV generation and diesel)

A	B	C	D	E	F	G	H	I	J
Year	**Present value factor: PV=1/(1+d)^t**	**Optimised energy cost savings as result of EE (USD)** (See Table 32)	**Energy saving cost as result of PV (USD)** (See Table 32)	**Annual Diesel cost savings as a result of PV and EE (escalation at 10%)** (See Table 12, Chapter 5)	**Total Cash Flows (USD)** (C+D+E)	**Project Investment Cost** as result of (EE and PV-battery) (USD)	**Net Cash Flow (USD)** L=(J-K)	**Simple Payback** (Initial Investment + 'H')	**Net Present Value (USD)** 1/(1+d)^t x H **J=**(BXH)
0			0.00		0.00	279,200.98	-279,200.98		-279,200.98
1	0.8772	15,820.79	13,676.16	5,158.810	34,655.76	0.00	34,655.76	-244,545.22	30,400.03
2	0.7695	17,448.07	13,676.16	5,674.691	36,798.92	0.00	36,798.92	-207,746.30	28,316.77
3	0.6750	19,165.75	13,676.16	6,242.160	39,084.07	0.00	39,084.07	-168,662.23	26,381.75
4	0.5921	21,154.65	13,676.16	6,866.376	41,697.19	0.00	41,697.19	-126,965.04	24,688.91
5	0.5194	23,233.96	13,676.16	7,553.014	44,463.13	0.00	44,463.13	-82,501.91	23,094.15
6	0.4556	25,584.47	13,676.16	8,308.315	47,568.95	0.00	47,568.95	-34,932.96	21,672.41
7	0.3996	28,115.80	13,676.16	9,139.147	50,931.11	0.00	50,931.11	15,998.14	20,352.07
8	0.3506	30,918.34	13,676.16	10,053.061	54,647.56	0.00	54,647.56		19,159.43
9	0.3075	33,992.09	13,676.16	11,058.367	58,726.62	0.00	58,726.62		18,058.44
10	0.2697	37,427.46	13,676.16	12,164.204	63,267.82	0.00	63,267.82		17,063.33
11	0.2366	41,134.05	13,676.16	13,380.625	68,190.84	0.00	68,190.83		16,133.95
12	0.2076	45,292.65	13,676.16	14,718.687	73,687.50	0.00	73,687.50		15,297.53
13	0.1821	49,812.88	13,676.16	16,190.556	79,679.60	0.00	79,679.60		14,509.66
14	0.1597	54,785.13	13,676.16	17,809.611	86,270.90	0.00	86,270.90		13,777.46
15	0.1401	60,209.40	13,676.16	19,590.572	93,476.13	0.00	93,476.13		13,096.01
16	0.1229	66,266.50	13,676.16	21,549.630	101,492.29	0.00	101,492.29		12,473.40
17	0.1078	72,866.03	13,676.16	23,704.593	110,246.78	0.00	110,246.78		11,884.60
18	0.0946	80,188.79	13,676.16	26,075.052	119,940.00	0.00	119,940.00		11,346.32
19	0.0829	88,234.79	13,676.16	28,682.557	130,593.51	0.00	130,593.51		10,826.20
20	0.0728	97,004.03	13,676.16	31,550.813	142,231.00	0.00	142,231.00		10,354.42
Total		**908,655.63**	**273,523.20**	**295,470.84**	**1,477,649.67**	**279,200.98**	**1,198,448.69**		**79,685.86**
Energy escalation		**0.100**							
Discount rate		**0.14**							
PV= Present Value		**t=** Time, **kWh**=Kilowatt-hour							

Payback period, return on investment and net present value calculations for hybrid of optimised energy and PV generation (battery) investment

Table 35: Financial analysis for a hybrid of optimised energy and PV generation

Financial analysis	**Calculation**
Simple payback period (SP) using equation 1	6+ 34,932.96/ 50,931.11= 6.69 years
Return on investment (ROI) 20 years using equation 3	(1,198,448.69/279,200.98)x100%=429.24%
Net present value (NPV) using equation 4 and as shown in Table 29	USD 79,685.86 (positive)

The positive NPV implies this fourth scenario is worth investing, as the total net cash flows are greater than the investment costs.

6.6.5 Comaparison of off grid system with battery against the diese generator

Table 36: Crusader House annual diesel generator costs

Year	Annual baseline Diesel energy (kWh)	Diesel fuel rate (USD) (escalation at 10%)	Diesel fuel cost as a result of runing the generator
1	100,000.00	0.904	90,400.00
2	100,000.00	0.994	99,440.00
3	100,000.00	1.094	10,384.00
4	100,000.00	1.203	12,322.40
5	100,000.00	1.324	13,354.64
6	100,000.00	1.456	14,590.10
7	100,000.00	1.601	16,149.11
8	100,000.00	1.762	176,164.03
9	100,000.00	1.938	193,780.43
10	100,000.00	2.132	213,158.47
11	100,000.00	2.345	234,474.32
12	100,000.00	2.579	257,921.75
13	100,000.00	2.837	283,713.93
14	100,000.00	3.121	312,085.32
15	100,000.00	3.433	343,293.85
16	100,000.00	3.776	377,623.23
17	100,000.00	4.154	415,385.56

Year	Annual baseline Diesel energy (kWh)	Diesel fuel rate (USD) (escalation at 10%)	Diesel fuel cost as a result of runing the generator
18	100,000.00	4.569	456,924.11
19	100,000.00	5.026	502,616.53
20	100,000.00	5.529	552,878.18
			5,177,659.95

The study findings indicate that it is economically viable to invest in PV system solution with battery storage as compared to running a standalone diesel generator to provide electricity for CHOB. Whereas the diesel generator runs for 2 hours a day, the running costs are higher than what the PV system would offer. For instance, Table 28 shows that the capital costs of investing in an off-grid solution with battery after 20 years USD 288,378.6 while the capital costs to run a diesel generator after 20 years for fuel alone is while USD 5,177,659.95.

6.7 Conclusion on DGRTPV financial viability

In response to the research sub-question 3, the financial viability (discussed in Chapter 6) have indicated all scenarios (Table 28, off grid solution with battery), scenario 2 (Table 29, grid interaction with battery back-up solution) and scenario 3 (Table 31, a hybrid of optimised energy, PV and Diesel) are viable to meet the building energy security/supply. However, given that Uganda does not have net metering policy which currently under formulation, the study recommends an off grid solution with battery to meet the energy demands of CHOB. During power outages, CHOB will draw electricity from the batteries.

Lastly, the sub-section 6.5, has indicated that the roof is not a constraining factor for DGRTPV for CHOB. The PV system sizing yielded 334 solar panels (requiring about 500 m^2) and yet the roof is 610 square metres. The study can conclude that this is a good opportunity for rooftop PV investment especially via grid interactive with battery technology (see Table 32 and also Table 147) The following Chapter 7, will present a business model that can be adopted for CHOB.

CHAPTER 7 THE RESPONSIVE BUSINESS MODEL SCENARIOS FOR DISTRIBUTED GENERATION WITH ROOFTOP SOLAR PHOTOVOLTAIC FOR CRUSADER HOUSE

7.1 Introduction

The previous Chapters 1-6 have discussed financial and technical appraisals, the political and legislative environment for Renewable Energy Technology (RET) solutions for Crusader House Office Building (CHOB). The chapters have created a clearer understanding on RE political, environmental and design in Uganda. This understanding will assist to identify a responsive business model amongst the several models described in Chapter 2. Based on the findings from Chapter 2, 5 and 6, the roof rental and solar service (third party) business models were presented as feasible for CHOB via off-grid and grid interactive with a battery solution. However, based on policy and legislative environment presented in Chapter 4, the solar service (third party) could be the responsive business model that can operate via both off-grid and grid interaction with battery solution. When the net metering policy is established/formulated in Uganda, the developers will yield more revenues via providing turnkey solutions such as engineering, financing of PV installations, the sale of electricity to the grid as well as consultancy. In comparison, the roof rental business model operates perfectly via grid interactive solution with FiT policy and net metering only. In light of this, this chapter is divided into four sub-sections. The first describes the selected business model. The second sub-section presents the model conceptualisation and a brief on the selected business model source of funding. The business model will be analysed using the SWOT (strength, weakness, opportunity and threat) strategic analysis system, and lastly, the conclusion of the chapter.

7.2 The solar service (third party) business model analysis

In reference to Slavik and Bednár (2014:21) definition of the term 'business model' ("a system of resources and activities, which create a value that is useful to the customer and the sale of this value makes money for the company") (see Sub-section 2.7).

Solar service or third party business model conceptualization

Depending on the policy changes for grid interactive and off-grid technology, and as highlighted in Section 7.1, the study can adopt/ assume a company to provide engineering, procurement and construction (EPC) services. This company will adopt Osterwalder, Pigneur, & Clark (2010) nine component business model canvas tool (see Table 34) to describe the third party business model application which will be analysed using the SWOT strategic analysis tool (see Table 35).

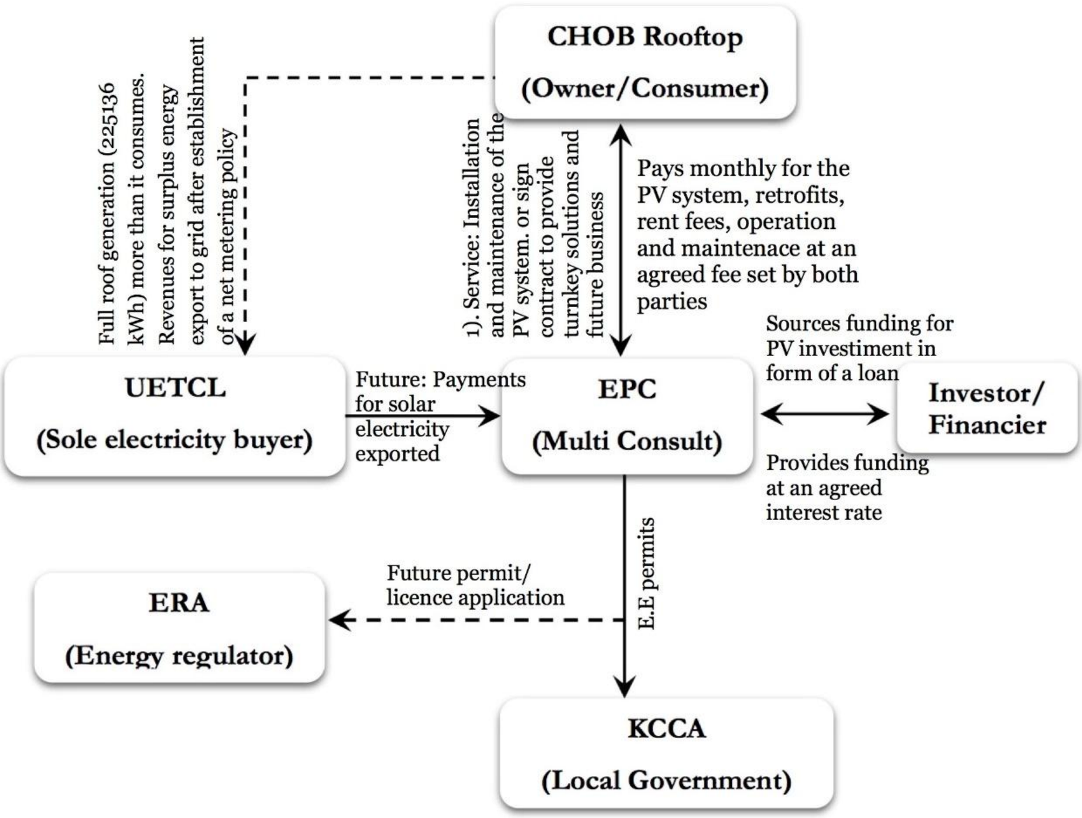

Figure 40: Solar service/ third party business model conceptualisation

Source: by author (2017)

Figure 40 shows the EPC (multi consult firm) as the the main player. The EPC sources funding from investors or financiers through crowdfunding platforms or foreign partnerships. In addition, the EPC searches for potential building owners who will be able to pay monthly installments for the PV system and also for retrofit applications as well as for maintenance and operation costs for up to 10 years when they can own the whole PV system set up. Under this process, the building owners would consume PV electricity generated at no additional cost and be assured of energy cost saving while also Later be guaranteed for quality service and maintenance of the PV system. The two parties (roof owner and developer (EPC)), sign a contract on the cost of renting the roof and the PV system. If the owner fails to pay for the PV electricity or breach the contract, they would be penalised or face electricity cut off and also miss out on the roof rental payments.

Moreover, when the net metering policy is formulated, the building owner and EPC sign another agreement for sale of surplus electricity to the grid. UETCL pays EPC for surplus energy exported to grid and the revenue generated is shared amongst either the EPC and building owner or EPC hands over a certain percentage to the client and remains with the other portion for maintenance and operations of the PV system. However, this is dependent on the type of agreement between the two parties. In addition, the EPC will have to apply for a licence from ERA (electricity regulator) to be able to export power to the grid. Otherwise, UETCL would not allow paying EPC without any proof of licence from ERA (the regulator). Moreover, for retrofit application, refurbishment of the building, the EPC will apply to Kampala Capital City Authority for plan approvals.

Figure 41: Solar service (third party) full in house services. **Source:** adopted from Hou (2014:18)

Figure 41 shows solar service business model core activities for CHOB developer. The core capabilities would be those highlighted in Figure 41 based on the existing RE policies. Figure 42 (here below) shows the business model framework adopted to describe solar service business model for CHOB developer or investor.

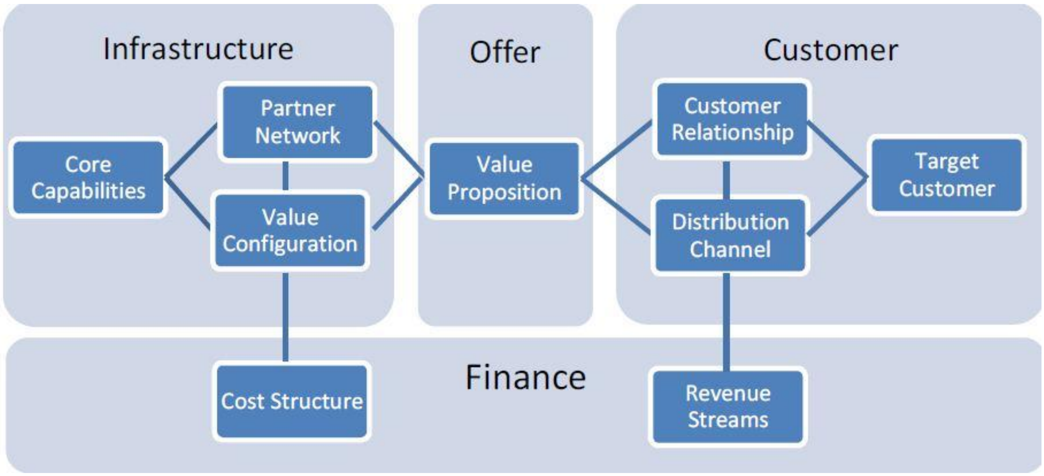

Figure 42: Business model description framework. **Source:** adopted from IEA-RETD (2013)

Table 37: Solar service (third party) business model description for CHOB developer

Item	Business model component	Description
1	Key partners	In reference to secion 7.2, key partners kick start DGRTPV technology on CHOB, the study suggests identifying a Know-how group/ individuals (such as the Utility operator, agent consultants, IT companies, financiers, and insurance companies), Manpower (installers, product manufacturers and service partners), Customer referrals and Telecommunication company. Due- diligence of these key partners is essential. In summary, key partners include (third parties, competitors-utility, and joint ventures)
2	Key activities	In this model, the main activities will be energy efficiency and retrofit consultancy: Building energy audits, simulations and optimisation: Solar PV engineering and design services: Energy production: solar PV electricity, solar equipment and building energy efficient equipment. In summary, (problem-solving, production and platform/network)
3	Key resources	These will be commercial office building rooftops with limited solar shadow casts. Equipment, human resources (staff) and access to financiers. In summary (physical resource-office buildings, intellectual resource-in house, human resource-staff and financial)

Item	Business model component	Description
4	Value propositions	This will mainly be, sale of electricity and products (building energy efficient equipment and solar products), Consultancy (design and installation and maintenance)
5	Customer relationships	This will be based on a contract basis depending on the type of service and products purchased. Personal assistance (Free call consultations to energy expert for first one minute, face to face conservations and email) An online platform for customers to raise comments about the services and products, purchases/orders (experiences)
6	Distribution channels	Option to order online and in person delivery, designated store and office and call centre and virtual sales offices (customers may not need to come to company office).
7	Customer segments	❖ Commercial office buildings as core: Engineering solutions and design of the system services ❖ Platform for access to external funding (foreign investors /financiers), ❖ Monitoring, installation, operation and maintenance. ❖ Supplier of solar PV products ❖ Ownership and operation
8	Revenue streams	Electricity sale (only when the net metering policy is established despite the presence of FiT, Solar and energy efficiency equipment sales, Consultancy services (installation, operation and maintenance) rental/leasing of uncertain company assets. Brokers are expected to earn for each deal transacted.
9	Cost structure	To accelerate DGRTPV technology via solar service business model, costs to be incurred will mainly be facility costs, transmission (electricity costs) insurance and consultancy. In light of this, all services such as IT costs, installations, engineering and design will be mitigated by having a full-service in-house company). In summary, (labour costs and component/equipment costs)

7.3 Source of funding

The potential sources of funding of this business model are outlined in Chapter 2 , Table.3. Whereas in Chapter 4, the property manager expressed his willingness to rent out the roof to any investors or developer, the study can conclude that the developer interested in applying this model would first interact with the CHOB property manager to ascertain his willingness to fund the project. However, as discussed in Chapter 4, there is already an existing government credit fund organization called Uganda Energy Credit Capitalization Company for PV development projects. Therefore, for a starter-developer, this is an opportunity to tap for DGRTPV for CHOB.

7.4 Solar service (third party) business model analysis using SWOT strategic analysis tool

Harrison and Gretzky (2010:92) states that SWOT (Strengths, Weaknesses, Opportunities and Threats) is defined as "an examination of an organization's internal strengths and weaknesses, its opportunities for growth and improvement, and the threats the external environment presents to its survival." In addition, SWOT is a preliminary decision-making tool that sets the stage for business investment. It involves the collection and evaluation of key data such as how many potential commercial existing buildings can be rented for rooftop PV business under solar service business model. SWOT-analysis also evaluates the internal potential and limitations and the probable/likely opportunities and threats from the external environment. All the positive and negative factors inside and outside the firm business model that affect the success are appraised. Table 36 shows the solar service business model analysis for CHOB.

Figure 43: The SWOT analysis tool **source:** Soma (2010)

Table 38: SWOT Analysis of solar service or third party business model

INTERNAL STRENTH AND WEAKNESS		EXTERNAL OPPORTUNITIES AND THREATS	
Strength	**Weakness**	**Opportunity**	**Threat**
❖ Ability to fund bigger PV system ❖ Building owner has the opportunity to own the PV system ❖ Significant size and scale of the business yields more revenue (products such as electricity sale and services) ❖ Possible quick return of investments ❖ Energy security will be achieved ❖ Conducive working environment for staff ❖ Increased revenue for developer ❖ Owner benefits cheap energy ❖ Revenue generation for both parties depending on the PPA ❖ Opportunity for Joint Venture and partnerships ❖ Multiple sales channels.	❖ Misunderstanding may occur with regard to who benefits more. ❖ May require periodic contract reviews ❖ Insecure repayment ❖ Costly training of new staff when old leave the company. ❖ Building owner may not find interest with the perception the tenant benefits from energy savings.	❖ Policy changes ❖ High demand of energy consumption reduction ❖ Financial support potential by experts interested in reducing emission of greenhouse gases in cities (could be FiT). ❖ Solar module global price fall and increasing diesel fuel cost.	❖ Policy changes ❖ Slow policy permits and political interference ❖ Lack of awareness knowledge of a some financiers (local and international) ❖ Increasing number of equipment may reduce surplus export quantity. ❖ Lack of standard contract forms for rooftop solar PV systems ❖ Cumbersome permit processes because of political interference ❖ New tenant with different activity and function ❖ Utility may interfere with the procurement process of the PV system ❖ Climate change may affect the number of sun hours hence increase investment costs. ❖ Increase in battery costs

7.5 Conclusion

In reference to Chapter 6, and Chapter 7, solar service business model will yield profits for DGRTPV developer. However, the study notices that the developer investment costs will be high therefore prioritising on electricity generation, operations, installation maintenance, and engineering and design solutions as opposed to the provision of equipment through retail will be essential to avoid issues such as equipment price distortion and quality.

Moreover, this chapter has responded to the main research question based on the findings in Chapter 6 and Chapter 4. The study concludes that grid interaction technology solution is currently not an option because of the existing policies and legislative environment in Uganda. However, the chapter also presented that an off grid solution with battery back-up is a good opportunity for CHOB. If the policy changes, this can move towards a grid interactive solution with a battery system to mitigate the power outages thus enhancing energy security and climate change mitigation.

CHAPTER 8 CONSOLIDATION OF FINDINGS AND THE OVERALL CONCLUSION

8.1 Introduction

The rapid growth of the building industry in Uganda, particularly the existing unutilised rooftops of commercial buildings in Kampala and the natural resources such as long sun hours bring a great opportunity to explore for DG applications with rooftop PV. In light of this, the study appraised several literature (aligned to policy and legislative environment, energy efficiency and retrofit application, DGRTPV financial viability and business model) as illustrated in the conceptual framework Figure 2 in Chapter 1. Furthermore, several scenarios such as investing in off-grid and grid interactive with battery solutions were explored to meet the objective of enhancing energy security and climate change mitigation intervention for CHOB. This chapter consolidates the study findings in cross-reference to the research questions outlined in section 1.4 as presented here below.

8.2 Consolidation based on the research questions

8.2.1 Sub-question 1

What are the policy/legislative opportunities and challenges for distributed generation with rooftop PV for CHOB?

In response to this question, Chapter 2 highlighted the demand side policy instruments and supply-side policy instruments as critical opportunities for DGRTPV application for CHOB. The demand-side policy instrument (see section 2.2) include:

- Net metering, Taxi credits (consumer subsidies),
- FiTs, Interconnection standards
- Demonstration projects (public investment)
- Green tags and RE portfolios
- Energy efficiency policy

The supply-side policy instrument opportunities include:

- Research and development grant
- Tax concession/ exemptions
- Support for manufacturing through low-cost loans and

- Investor subsidy

Currently, Uganda has the FiT policy and investor subsidies through Uganda Energy Credit Capitalisation Company Ltd. This policy application is still in its infancy (only nine (9) companies generating RE power via off-grid solutions upcountry have benefited from the policy). Hootman (2013) argues that such should not be the case because there are many commercial buildings in urban areas/cities. The built environment in urban areas is second only to the manufacturing sector in terms of emission of greenhouse gases into the atmosphere. Hootman (2013) further states that buildings contribute 45% of carbon emission among other greenhouse gases. Therefore, Uganda's current FiT policy of integrated with the net metering, tax exemptions and demonstration project policies, would facilitate the enhancement of energy security and climate change mitigation for CHOB as a prototype project.

In Chapter 2 and 4, ERA respondent highlighted that ERA has a plan to establish the net metering policy for small-scale generations. This idea was primarily driven because of the two 20MW solar projects in the country which were commissioned in 2016 and 2017. Therefore, this is a good opportunity for CHOB to operate under the grid interactive solution, policy changes and related costs as discussed in Chapter 6 and 7. Net metering policy innovation for projects such as DGRTPV for CHOB would facilitate the government to evolve effective interventions for climate change mitigation as well as methodologies for enhancing energy security.

Challenges

The study findings highlight the challenge of synchronising the utility (UMEME) and small-scale generation via commercial building DGRTPV technology. It was presented in Chapter 2 that grid operator demands such as protection, control, and energy quality, need to be streamlined in order to facilitate effective business for the solar PV developers.

Twaha *et al*., (2016) in Chapter 1 and finding in Chapter 4 pointed out that funding has been a major obstacle for the establishment of the net metering policy. Moreover, aborting of the end-user subsidies as discussed in Chapter 4 was due to the channels and ways/methods of subsidisation used by the authorities. Authorities needed to streamline on who qualified to have access to the subsidy and there was a need to establish monitoring schemes.

In Chapter 4, the study highlights the issue of bureaucracy where people fail to fully understand the requirements for acquiring the power purchase agreements (PPAs) and technology application has hindered support for DGRTPV. In addition, the study finds that several organisation/authority representatives involved in policy matters related to solar PV technology do not adequately understand its potential; hence, regulations formulated are bound to hinder the rate of technology diffusion and adoption.

8.2.2 Sub-question 2

What are the cost-effective energy efficiency interventions for retrofitting into CHOB?

Patterson (1996 and 2006:377) defined *energy efficiency* as being a generic term because there is no quantitative measure of energy efficiency apart from relying on a series of indicators to quantify energy efficiency changes. The study contradicts Patterson (2006) as several measures such as energy audits, power consumption manual calculations, simulations, and financial assessment was conducted in order to conclude if the building was energy efficient or not. Therefore, such approach is not related to a 'series of indicators' as put forward by the author. Buildings such as CHOB offer mitigation strategies where carbon dioxide emissions reduction can be pursued at relatively low costs through retrofit interventions. There are many procedures that are conducted to a ascertain the levels of energy efficiency and potential of enhancing energy security.

In Chapter 2 and Chapter 5, the study made use of a case study approach to test the theoretical knowledge of DG with rooftop PV and energy efficiency. Manual calculations and use of Design-Builder simulation software were used to investigate the cost-effective energy efficiency interventions for CHOB. Several energy efficiency initiatives were tested to determine the effectiveness of each initiative. The use of financial feasibility tools such as NPV, ROI, and simple payback guided the study to ascertain the cost-effective measures for the CHOB. It was discovered that replacing equipment and appliances with more efficient ones is not cost effective (see Table 18, Chapter 6). Lighting systems, intelligent controls, and passive measures proved to be the most cost-effective energy efficiency measures for the case study building as outlined below (see also Table16, Chapter 6).

- ❖ Adding effective sun shading systems such blinds (to control internal heat gains and losses)
- ❖ Taking full advantage of natural ventilation and daylighting (to minimize the need for artificial lighting during daytime and to avoid the use of fans for cooling).
- ❖ Use of light colour fittings, painting the interiors with light colours to reflect daylight into the spaces thus reducing the need for artificial lighting.
- ❖ Installation intelligent control systems such as daylight sensors, motion sensors, ventilation controllers (carbon sensors) to optimize fresh air levels based on occupancy and the interior conditions
- ❖ Installing energy saving lamps such as the light-emitting diode (LEDs)
- ❖ Tenant energy management web-based systems to enable monitoring and adjustment of energy consumption levels.
- ❖ Application of renewable of energy such as solar energy. Substitutions of traditional energy by installing photovoltaic panels and solar water heaters constitute additional opportunities for retrofit.

The NPV of these outlined measures above were positive (section 6.3.2)

8.2.3 Sub-question 3

To what extent can distributed generation with rooftop PV guarantee energy supply for CHOB?

Based on findings in Chapter 5 and Chapter 6, it was evident that the size of the roof is a critical component to guarantee energy security for CHOB. Crusader House office building rooftop is 610m^2. To guarantee energy supply for the building, the building energy audits and building performance assessment were carried out using Design-Builder simulation software and manual calculation of the equipment and appliance load to ascertain the baseline load and the optimised load of the CHOB. In Chapter 5, the baseline simulated annual power consumption of the building is 192,407.31kWh and manually calculated baseline energy was 191,127.5kWh. The annual optimsed load of the building was based on simulation is 85,265.75kWh while the annual optimised manual calculation was 90,404.5kWh. The outputs (both simulated and calculated) variation with the utility bills (189,142kWh) is approximately 1%.

The optimised energy manual calculation was used to size the PV system based on the month with a high demand for energy. The findings yielded 334 solar panels of a 250W. Sunllet solar company in China calculated 300 solar panels of the 260W while Jinko solar company calculated 230 solar panels of the 330W. The number of solar panels quoted by solar companies were equivalent to the study finding (334 solar panels) because the the bigger the size of the panel wattage the fewer number of panels. The study choice of a 250W solar panel was considered on the assumption that the 250W panels are more readily available on market in Uganda.

In light of this, the 334 panels can generate 124,328.75 kWh. This value is bigger than the optimised 90,404.5 kWh that the building consumes. Therefore, the surplus power is 39,172.073 kWh (approximately 31.51%). Based on working hypothesis presented in section 1.5 and the rationale of the study in section 1.3, 100% CHOB energy demands need to be met before surplus export to the grid. Therefore, the study can conclude that DGRTPV investment in CHOB can guarantee 68.49% energy supply and potentially export surplus of 31.51% to the grid at FiT (68.49% of total energy generation is what CHOB demands to consume). Alternatively, we can reduce the size of the system such that only 68.49% is supplied since the country currently has no net metering policy.

Despite this opportunity, the following challenges need to be taken into consideration.

- Power quality. PV modules are exposed to harsh weather conditions such as temperature fluctuations, humidity corrosives and dust that affects the efficiency and lifespan of the infrastructure.
- Utility inexperience with DG operators with arguments based on voltage levels, power factor, higher wear and tear of equipment as well as safety.
- Lack of technical standards necessary for connecting the equipment, as issues such as low voltage within the distribution grid

- ❖ UMEME Uganda's main electricity distributor would pose a threat to the innovations; as such, innovations would result in their revenue losses and other transactional costs.
- ❖ Excessive bureaucratisation of the necessary authorisation processes for the installation, commissioning of generation and the promoting of a new facility needs to be addressed and streamlined.
- ❖ Political interference and lack of national procedures for standard interconnections of DG systems
- ❖ Lack of adequate information on financing options available for individual investment in EE
- ❖ The lack of awareness among consumers on viability and performance of PV technologies
- ❖ Inadequate skilled workforce.

8.2.4 Sub-question 4

What is the financial viability of distributed generation with rooftop PV for CHOB?

To find the financial viability of DGRTPV for CHOB, Chapter 6 finding was based on three scenarios:

1. Application of an off-grid system with back up solution using optimised energy generation (based on 90,404.5 kWh optimised energy)
2. Application of grid interactive system with no battery (weekend and public holidays) based on 39,172.073 kWh PV generation for 115 days and FiT at 11 USD cents.
3. Application of grid-interactive with battery (full roof) generation based on 124,328.75 kWh PV generation at FiT of 11 USD cents. Revenues generated from 90,404.5 kWh optimised energy also added up to total cost based on PV generation at utility tariff 0.175 USD
4. Application of a hybrid of optimised energy and PV generation (off-grid-battery)

Scenario 1 and 2 findings indicate that it is not worth investing (The NPV values are negative as shown in Tables 28 and 30) whereas scenario 3 and 4 findings are feasible for DGRTPV investment (The NPV values are positive as shown in Tables 32 and 34). The calculations shown in Tables 28, 29, and 31 were discounted at 14% and escalated based on 10% interest rate as reflected on the Bank of Uganda and utility online sources. The financial appraisals motivated the study to conclude that scenario 3 and 4 were financially viable for DGRTPV investment for CHOB via grid interactive technology and can be financed by GETFIT program, UECCC, bank loan, crowdfunding and individuals (self-financing).

8.2.5 Main research question

What would be the responsive business model scenarios for distributed generation based on rooftop PV technology as an opportunity towards energy security and climate change mitigation intervention for Crusader House Office Building (CHOB) in Kampala, Uganda?

Several authors have defined the term business model. The study adopted Slavik and Bednár (2014) definition, which refers to a system comprising of resources and activities, that create value to customers hence yielding revenue to the company or investors. Based on this definition, the study presented several types of commercial building business models for DGRTPV for CHOB. Due to the political and legislative environment discussed in Chapter 4, two business models (roof rental and solar service /third party) were identified to be ideal for CHOB. The study prioritised the solar service/ third-party business model because of existing policy and business environment/context in Uganda. Secondly, this model was chosen with the expectation that government would be informed about the necessity of the net metering policy and other demand side policy instruments as discussed in Chapter 2. This model is flexible with grid interactive and off-grid technology application; hence, the target towards enhancing energy security and climate change mitigation could be achieved. In addition, the model synchronises with already existing policy in Uganda where generation for own consumption and no option of selling to the grid is permitted as stated by ERA respondent, Chapter 4. However, barriers such as technological, socio-economic and regulatory are highlighted as possible obstacles for DGRTPV technology for CHOB.

8.3 Recommendations

8.3.1 Energy efficiency

Energy Efficiency (EE) is a new concept that has gained ground in developed countries and slowly gaining traction in developing countries. It is only through studies such as this one that countries like Uganda are able to identify and mitigate energy consumption of commercial buildings in the city and their carbons emissions into the atmosphere. The study found it necessary that for EE full deployment in Uganda, the following recommendations (especially arising from international practice and interview data from this study-Chapter 2, 5 and 6) are critical for full-scale rollout of retrofitting interventions at a building scale as presented also in Chapter 2, section 2.3.

- ❖ Creating awareness amongst all building designers, environmentalists, engineers, contractors, manufacturers, developers, building owners, building occupants and policymakers in the built environment will motivate for energy efficient applications
- ❖ Increasing customer/public awareness through demonstration projects
- ❖ Establish a Green Building Council that collaborates with researchers to build local expertise through training and exposure to experiences in other countries
- ❖ The government needs to support schools and other educational facilities to champion the concept among the young generation in schools and tertiary institutions through energy efficiency awareness and promotion interventions
- ❖ The government needs to put in place policy restructuring and reforms such as mandatory minimum energy performance requirements (MEP), energy labelling and certification schemes to provide information to owners, buyers, and renters (the study finding indicate appliances and equipment loads as a critical challenge that needs an intervention of EE policies and regulations) (see Chapter 6, section 6.3, page 126-130).

8.3.2 DGRTPV energy policy and legislation

In Chapter 2, it was recommended that FiT Policy should be well managed and activities should be closely monitored in order to attract potential investment companies. In addition, well-trained personnel in the government or private audit organizations should be assigned the responsibility of handling this process in order to facilitate the smooth operation of the policy.

Further, the permitting process for DGRTPV should be streamlined. For full deployment of DGRTPV, the government needs to support the innovation through waiving commercial building generation business licenses, taxes, and other installation fees requirements. This finding suggests that the government can formulate policies that support building-to-building interconnections with the support of the utility without having to export power to the grid.

Setting up an online platform for DGRTPV projects could enhance efficient evaluation and monitoring of PV projects as well as PV funding thus mitigating challenges such as the one highlighted by Twaha *et al* (2016) where end-user subsidies were aborted because of the inadequate evaluation and monitoring process methods in the provision of the subsidies by government authorities. Moreover, government support towards revamping outdated regulations of the 1930s and 1950s, policies and plans to support innovations such as grid interactive DG with rooftop PV applications in the country as well as ensuring full public awareness through setting up demonstration projects is essential for full deployment and adoption of DGRTPV technology.

8.4 Conclusion

In comparison to developed countries and middle income countries such as South Africa, China, USA and Thailand, and especially given their less advantageous climatic conditions, Uganda has a great opportunity for DGRTPV. However, findings on Uganda's policies and regulations (such as FiTs, subsidy policy, financial support and net metering) signify that Uganda has gaps in critical areas such as resource management and customer support in the provision of engineering solution services that need to be streamlined because the demand side policy instruments applied in the front-runner countries are feasible for Uganda to adopt immediately.

The business model scenarios presented in this study demonstrate an opportunity for Uganda to be energy secure as commercial buildings would be self-generating power for own use. In addition, rooftop PV solar energy generation on these commercial buildings would reduce the need for stand-alone diesel generators during power outages thus reducing emissions of greenhouse gases into the atmosphere.

8.5 Further research

Based on the study findings discussed in Chapter 5 up to Chapter 7, further research is needed on how to measure and certify energy efficiency minimum standard and the requirement for application or adoption in Uganda. For DGRTPV full deployment, political interference versus the existing policies and regulation is a major threat to the innovation. Therefore, there is need a to investigate a common consented understanding of all political parties and opinions about the commercial building rooftop PV deployment in Uganda. Lastly, the study calls for further research on the Uganda's financial market and financiers in order to asesss the potential of financing DGRTPV projects locally as opposed to over dependence on international donor funding or private-sector investors. This is particulary critical for a country like Uganda where political risk still remains as a major concern among foreign and local potential funders/investors as well as project developers.

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APPENDICES.

Appendix 1: Question structures/semi structured interview questions.

Crusader House Mercantile Properties Limited.

1. How many square metres does Crusader House plot cover?
2. When did you develop the property?
3. Who funded the development? Could you please avail me with the drawings and bills of quantities that were used for Crusader House development?
4. Who manages the maintenance and operations of the building?
5. I see a diesel generator room; how do you manage this standalone diesel generator?
6. How often do you run it and the related energy costs?
7. Tell me about the revenue generation trend of Crusader House?
8. Have you ever considered using solar PV either as standby or main electricity supply for electricity?
9. Would you be open to charge someone else to rent crusader house roof for PV electricity generation?
10. What are crusader house regulations and to what extent do tenants practice energy efficiency measures?

A) Crusader House Tenants (CEO/ Respondents)

1. When and why did you decide to locate in Crusader House?
2. What is your core business and how long have you been operating?
3. What is your monthly/ weekly expenditure on electricity?
4. How many electrical appliances does your firm operate in the building?
5. How many staff members in your firm occupy the building regularly?
6. What is your opinion on energy consumption trend or pattern in your office?
7. How often do you experience power outages, and how do you manage the situation?
8. Have you ever considered the alternative of using solar PV?

B) Minister or Expert: Ministry of Energy and Mineral Development

1. Tell me about solar PV energy production in Uganda?
2. What is your opinion about commercial rooftop solar PV in Uganda?
3. Tell me about Renewable Energy Policies and taxes for solar PV investors.
4. To what extent can government partner with private sector rooftop solar PV developers?
5. Who takes record of daily solar radiations in Uganda and where can this information be accessed?

6. Who are the major players of solar PV power in Uganda?
7. Why is there a slow uptake for solar PV in commercial and institutional buildings?
8. What are your recommendations for commercial/institutional building rooftop PV solar initiative?

C) Other experts and developers of rooftop PV distributed generation and retrofit.

1. Tell me about your solar PV experience, market, and applications.
2. What are the regulations for distributed generation with rooftop solar PV investment in Uganda?
3. What is your opinion about mini/micro grid or grid interactive operations for rooftop solar PV in Uganda?
4. Tell me about standardization and interconnection of regulations for grid interactive rooftop solar PV?
5. What is your opinion about rooftop PV distributed generation in Uganda?
6. What are the building regulations for retrofitting commercial buildings in Kampala?
7. What is your opinion about energy efficiency and building performance for office buildings in Kampala?
8. What major challenges you experienced in this sector?
9. Tell me about the current Renewable Energy generation as of RE policy 2007.
10. Tell me about the current status of these tariffs and their possibility for commercial building applications.

    1) Feed-in Tariffs
    2) Global Energy Feed-in Tariff (GET-FIT)
    3) Renewable Energy Policies

11. What is your opinion about feeding back to the grid?
12. Tell me about the solar business models in Uganda
13. Tell me about your revenue models that underpin your business?
14. What are the financing mechanism opportunities for upfront capital investment, operations and maintenance of solar applications in Uganda?
15. Tell me about your experience with solar business in Uganda, policies and regulations that control your operation in the country?
16. Tell me about the energy security of Uganda?

Appendix 2: Ethics clearance certificate

SCHOOL OF ARCHITECTURE AND PLANNING
HUMAN RESERCH ETHICS COMMITTEE

CLEARANCE CERTIFICATE
PROTOCOL NUMBER: SOAP110/12/07/2016

PROJECT TITLE:	Opportunities and Challenges for Distributed Generation with Rooftop Photovoltaic (PV) for Uganda: A case study of Crusader House, Kampala
INVESTIGATOR/S:	Ceasar Migisha (Student No. 1231324)
SCHOOL:	Architecture and Planning
DEGREE PROGRAMME:	MArch in Sustainable and Energy Efficient Cities (March SEEC)
DATE CONSIDERED:	19 September 2016
DECISION OF THE COMMITTEE:	APPROVED
EXPIRY DATE:	19 September 2017

CHAIRPERSON ____________________
(Professor Daniel Irurah)

DATE: 16 · 09 · 2016

cc: Supervisor/s: Prof. Daniel Irurah

DECLARATION OF INVESTIGATORS

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to endure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee.

Signature **Date** 27/10/2016

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