**UNIVERSITY OF NAIROBI**

**SCHOOL OF ENGINEERING**

**DEPARTMENT OF MECHANICALAND MANUFACTURING ENGINEERING**

**Master of Science Project Report**

# System Design and Levelized Cost of Electricity Assessment for Solar PV Electrification: Case Study of Kalisasi Village, Mwingi Sub-County, Kitui County

By

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*Report submitted in partial fulfillment for the Degree of Master of Science in Energy Management in the Department of Mechanical and Manufacturing Engineering in the University of Nairobi*

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## DECLARATION

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This research report is submitted with our approval as University Supervisors:

**Prof. Wekesa Cyrus** Signature: Date: 17/11/2022

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## DEDICATION

The undertaking of my research is an offering to the Almighty God, who has been at my side from the very start to the present day. Throughout this whole situation, my wife, my siblings, and my parents have been nothing but kind and encouraging to me, and they deserve my sincere gratitude for their support.

In addition, I would want to take this opportunity to thank each one of my instructors for the valuable contributions they made to my academic experience.

To God is the glory.

## ACKNOWLEDGEMENTS

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May the Almighty God bless you ALL.

**ABSTRACT**

There is significant evolution underway in the electric power sector, with increased harnessing of renewable energy sources (RES) and efforts to decarbonize the energy system. Not only has technological innovation driven dramatic capital cost declines in renewable energy systems, favorable policies too have accelerated the deployment of these systems. Further, consumers want to manage energy costs and assure reliability of their electricity supplies. But because consumers producing their own energy independent of energy utility companies is a relatively new and growing trend, there still exist opportunities for research to better understand the trend and generate better insight to aid decision-making .From the consumers' perspective, limited understanding due to little information available means that their decision-making relies on estimation and projections. Most of the done studies are hardly academic in nature and the results of projects' analyses are not generally available to the public. Further, the application of solar PV electrification is site-specific, with a need to understand the site load and its characteristics as well as the prevailing solar energy resource in order to arrive at objective conclusions. This study performed a techno-economic evaluation of solar PV electrification at Kalisasi Village, Mwingi Sub-County, Kitui County, with specific focus on determination and characterization of the electrical load at the site, assessment of the solar energy resource, sizing of the solar PV system and determination of the levelized cost of energy (LCoE). Characterization of the electrical load entailed establishment of average load, peak demand, load factor from the generated daily load curve. Direct normal radiation data obtained from the Global Solar Atlas online application prepared by Solargis under contract from the World Bank helped estimate the solar energy resource. Based on the load profile and supply resource, the system was sized using PV*SOL analysis tool. The LCoE was determined based on annual capital and operations and maintenance costs, system lifetime, discount rate and annual energy delivered by the solar PV system. Results showed that daily load factor for the load in question was 40.7%, with average and peak daily demand being respectively 10.75 kW and 26.42 kW. Further, the solar energy resource at the site can be utilized practically throughout the year, with an annual average DNI of 1658 kWh/m$^2$/year. The total annual cost (capital plus O&M) of USD 14,681.76 spread over 115,246 kWhr/yr gives an LCoE of USD 0.127/kWhr, equivalent to approximately Ksh. 14/kWhr. This compares favorably with the power from Kenya Power, even cheaper.

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# LIST OF ABBREVIATIONS

| Abbreviation | Definition |
|---|---|
| **AC** | Alternating Current |
| **BES** | Battery Energy Storage |
| **CAGR** | Combined Annual Growth Rate |
| **DC** | Direct Current |
| **DNI** | Direct Normal Irradiation |
| **EPRA** | Energy and Petroleum Regulatory Authority |
| **ERC** | Energy Regulatory Commission |
| **IEA** | International Energy Agency |
| **IRENA** | International Renewable Energy |
| **kWh** | Agency Kilowatt hour |
| **KCIC** | Kenya Climate Innovation Centre |
| **KOSAP** | Kenya Off-grid Solar Access Project |
| **Li-ion** | Lithium-ion |
| **LCOE** | Levelized Cost of Energy |
| **NPC** | Net Present Cost |
| **NPV** | Net Present Value |
| **NREL** | National Renewable Energy Laboratory |
| **O&M** | Operation and Maintenance |
| **PV** | Photovoltaic |
| **RALPT** | Rural Africa Load Profile Tool |
| **REREC** | Rural Electrification and Renewable Energy Corporation |
| **RE** | Renewable Energy |
| **REA** | Renewable Energy Agency |
| **RES** | Renewable Energy Sources |
| **ROI** | Return on Investment |
| **SHS** | Solar Home System |
| **Solar PV** | Solar Photovoltaic |

# CHAPTER 1: INTRODUCTION

## 1.1. Background

The electric power industry is currently undergoing significant transformation, which is leading to the emergence of new choices for the supply and consumption of electricity services. A greater reliance on renewable energy sources (RES), efforts to reduce the carbon footprint of our power grids (and other critical infrastructure), and an ever-increasing network of interconnected power grids and other critical infrastructure are some of the diverse forces that are at work to transform the energy system (Rapier, 2020).

Commercial electricity consumers, like their industrial counterparts, are increasingly adopting solar energy for heating, cooling, lighting, and even production during the day while relying on the grid power during off-peak and night hours – a trend that has accelerated over the past decade mainly due to maturity of renewable energy technologies (Obonyo, 2021). The supporting factor for this new paradigm is the need by the consumers to have cheap and reliable energy (IEA, 2021). Some entities on this trend include Garden City Mall, with an ongoing 858 kW solar PV project meant to generate and supply electric power within the facility, and Total Kenya (Ltd), which recently announced plans to installed solar PV in its 107 petrol service stations for pumping, lighting, refrigeration, and air conditioning (Nyabira and Nduati, 2021).

Traditionally, energy has been sourced from fossil fuels and biomass (wood, crop waste, and charcoal), with a considerable impact on the environment and human health (Longa, and van der Zwaan, 2017; Eitan, 2021). Fundamental to mitigation of climate change is a need to shift away from fossil fuels to an energy mix largely driven by renewables and nuclear energy (Owusu, and Asumadu-Sarkodie, 2016). In line with this, the cumulative RE installed capacity has increased gradually over the years and in 2019, low carbon sources that include RE and nuclear contributed 15.7% of global primary energy (Ritchie and Roser, 2020). The world RE consumption has seen drastic risen since year 2001, with the uptake of renewable having gradually increased over the years resulting in approximately 260 GW of installed capacity in 2020 (IRENA, 2021). Notably, more than 80% of new electricity sources added in 2020 were from renewable sources, with the bulk of this addition coming from distributed generation systems and consumers doing their own generation.

## 1.2 Problem Statement

The major factors driving the current energy transition include demand for reliability, diversity, abatement of greenhouse emission, and cheaper energy sources. The result is that electricity consumers in diverse sectors – manufacturing, processing, commercial, agriculture, hospitality, and learning institutions – have increasingly installed own electricity generating plants. The aim is to completely move away from the grid or use grid power as a backup, a move projected to challenge the established structures in the electricity market.

The idea of domestic, commercial and even industrial consumers producing their own energy independent of energy utility companies is relatively new but ongoing. For this reason, there still exist opportunities for research undertakings to better understand this ongoing trend, thus generating broader insight and information to aid decision-making. From the consumers' perspective, limited understanding due to little information available means that their decision-making relies on estimation and projections. While many companies in Kenya and the world undertake these self-generation energy projects (mostly based on solar PV installations), the work is hardly academic in nature and the results of projects' analyses are not generally available to the public.

Like most renewable energy technologies, the application of solar PV electrification is site-specific, with a need to understand the site load and its characteristics as well as the prevailing solar energy resource in order to arrive at objective conclusions. For this reason, this study seeks to determine and characterize the electrical load data at Kalisasi Village – Kanzanzu Location, Mwingi Sub-County, Kitui County – followed by analysis of the solar energy resource data at the site, concluding with a techno-economic analysis of the viability of providing power to the locality via solar PV technology with associated accessories.

## 1.3 Justification

There is currently ongoing significant migration of electricity consumers from the grid, either in whole or in part. This self-generation is aided is aided mainly by falling prices of RE and storage devices. In Kenya, for example, the main off-taker, Kenya Power, has expressed worries concerning this trend. Therefore, this study intends to shed further light on self-generation and will be of benefit to policy makers, the consumers intending to shift, and traditional companies in the electrical energy sub-sector. Using the knowledge generated from this study, the consumers would make informed decisions based on the LCoE trends for both self-generation and grid power. Moreover, the off-taker, in this case Kenya Power, will have a clear projection of what the future holds.

## 1.4 Research Objectives

### 1.4.1 Main Objective

The main objective of the study is to perform a techno-economic evaluation of solar PV electrification: Case Study of Kalisasi Village, Mwingi Sub-County, Kitui County**.**

### 1.4.2 Specific Objectives

The specific objectives of the study are the following:

i. Determine and characterize the electrical load at the case study site.
ii. Assess the prevailing solar energy resource
iii. Size the solar PV system, with focus on solar panel, battery and inverter capacities
iv. Perform a levelized cost of energy determination and evaluation

## 1.5 Scope of the Study

While the study has as its focus the techno-economic analysis of electrifying a Village based on solar PV technology, the economic aspect of the analysis will principally cover the LCoE, because this is the baseline parameter that determines the cost of the electrical energy supplied to consumers and hence how much profit margin is possible by comparing with alternatives. For this primary reason, net present value, internal rate of return and even payback period are not covered, important as they are. The other focus of the study will only be on the electrical plant (solar panels, batteries and inverters), and excluded will be the distribution network assessment and design.

## 1.6. Organization of the Report

This Report is organized as follows. Chapter 1 is the introduction, providing a context to the study area (background), research problem and objectives. Chapter 2 documents the literature related to the study area, concluding with a research gap. Chapter 3 describes the methods applied to realize the objectives. Chapter 4 documents results of the study and associated discussions of the same and Chapter 5 gives the conclusions and recommendations.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Introduction

Solar photovoltaic (PV) systems have taken the lion's share of new investment in renewable energies in recent years due to the modular construction of these systems, falling prices, and aid from governments all over the world through appropriate energy policies. Solar photovoltaics (PV) has become one of the most rapidly expanding sectors in the world thanks to a compound annual growth rate (CAGR) of more than 40 percent over the course of the last 20 years (Jager-Waldau, 2017). The same factors account for the attractiveness of the sector to investors and customers (Gathimu, 2018). What follows is a review of the global solar PV industry (applications, capacity and price evolution) and an examination of the solar PV market development in Kenya, including the state of solar PV mini-grid development. Following that is a documentation of related research works and concludes with a research gap.

## 2.2 Global Solar PV Applications, Capacity and Price Evolution

According to a report published by the International Energy Agency Photovoltaic Power Systems Programme (IEA PVPS, 2017), solar photovoltaic technology has made the transition from its initial and price niche market improvements in the 1990s to the current massive global rollout and elevated levels of competition. Indeed, solar PV electricity now competes very favorably with electricity from conventional sources, and therefore finds applications in residential (5 – 10 kW), commercial (10 kW – 2 MW) and utility-scale (beyond 2 MW) sectors (Fu et al, 2017; Fraunhofer Institute for Solar Energy ISE, 2018). As Figure 3.1 shows, the total cost per watt in 2017 is USD 2.80 for a 5.7 kW residential plant, USD 1.85 for a 200-kW commercial plant, USD 1.03 for a 200 MW (fixed tilt) utility scale plant and USD 1.11 for a 200 MW (one-axis tracker) utility scale plant. The cost progressively decreases due to economies of scale in production.

Figure 2.2 shows the levelized cost of energy for various renewable energy technologies compared with conventional power plants at different locations in Germany, again showing favorable solar PV cost economics (Fraunhofer Institute for Solar Energy ISE, 2018). Because of the increasing competitiveness of solar PV electricity, annual growth in power installations is in the double-digit range. In fact, at the end of 2017, the cumulative installed PV capacity (globally) exceeded 400 GW, with the annual installations in 2017 amounting to 100 GW, an estimated 30% growth compared to 2016 (Solar Power Europe, 2018).

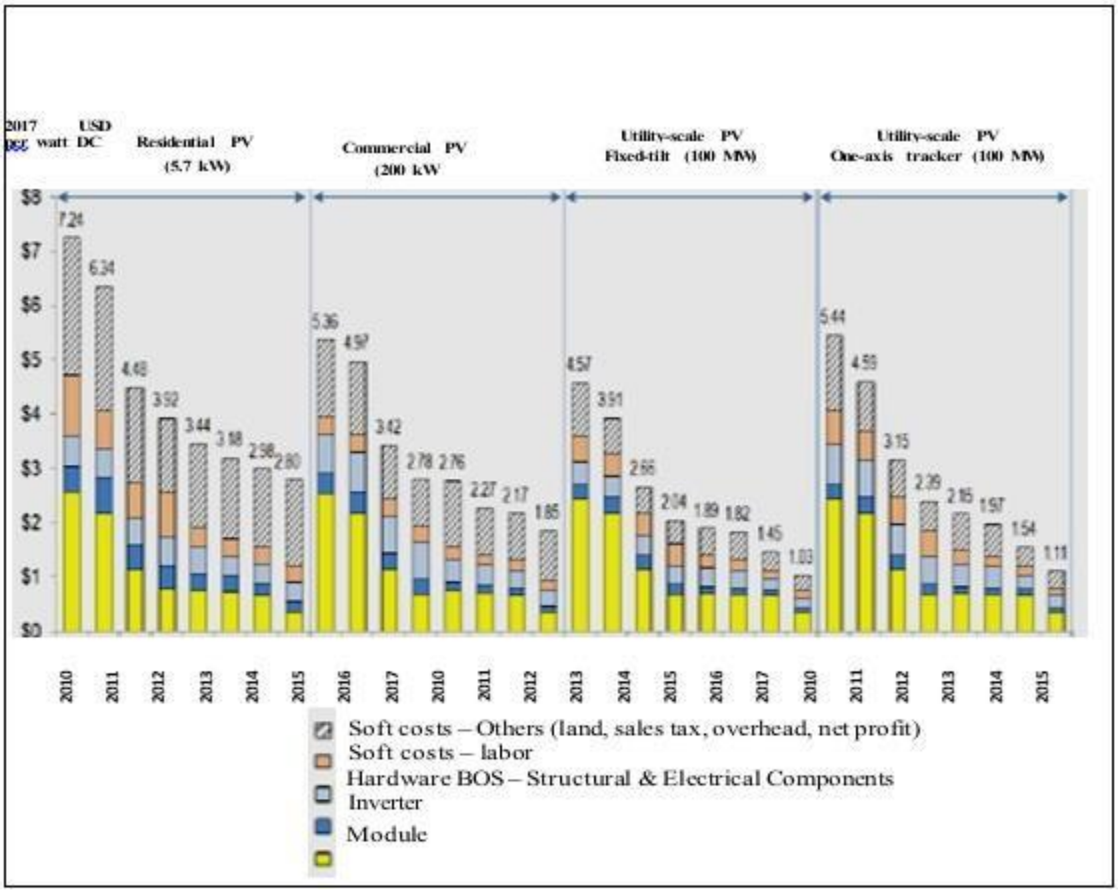


Figure 2. 1: Solar PV system cost benchmark summary, 2010 – 2017 (Fu et al, 2017)

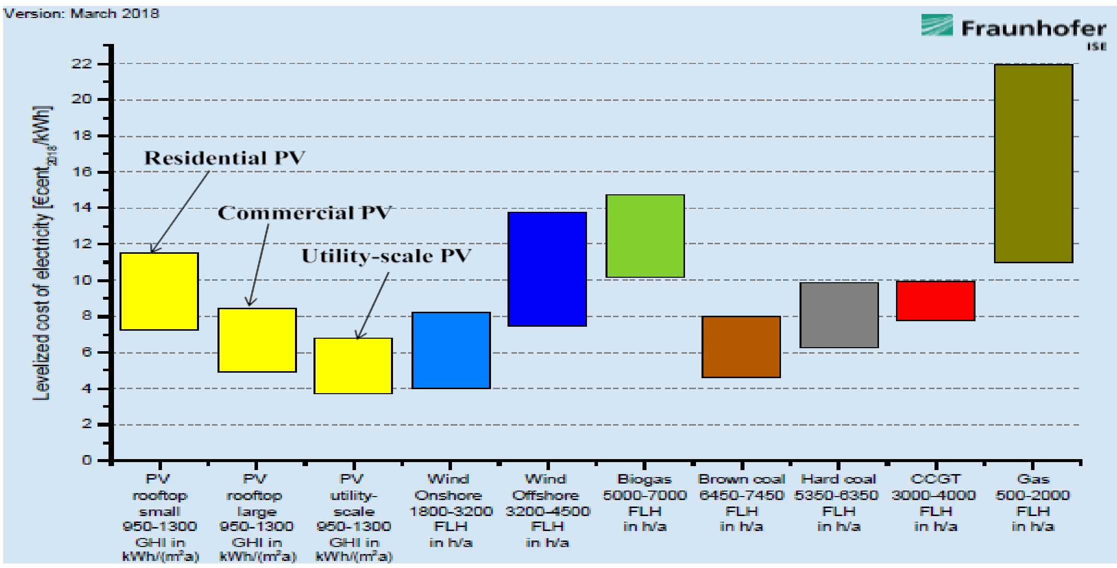


Figure 2. 2: LCOE of RE technologies and conventional power plants at different locations in Germany in 2018 (Fraunhofer Institute for Solar Energy ISE, 2018)

Renewable energy technologies continue to receive attention around the world because of the requirement to address climate change, enabling policies, significant technological innovation and innovating financing schemes. Still there exists other issues arising as the market has grown.

For example, there has been significantly increased investment in solar cell and solar module manufacturing capacity, leading to oversupply in capacity (Figure 2.3). The oversupply has in turn depressed prices of solar cells and solar modules, with an overall effect being insolvency of many companies (CGTI, 2011; Jäger-Waldau, 2017). Related to this is that there has been consolidation in the industry, leading to the takeover of a significant number of companies.

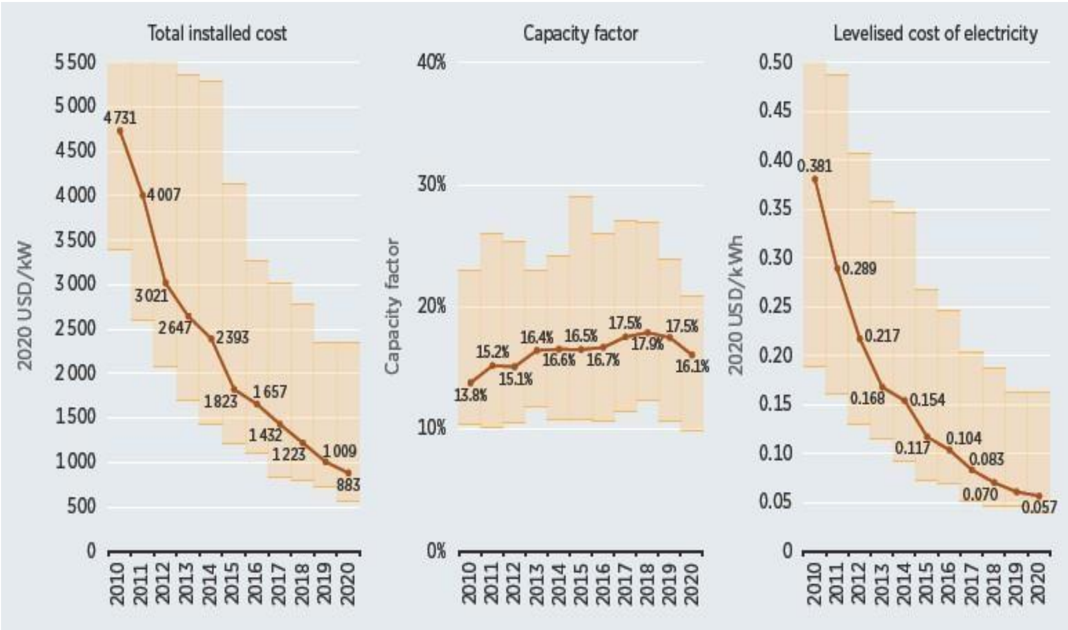


Figure 2. 3: Global weighted average total installed costs, capacity factor and LCOE for Solar PV, 2010 – 2020 (IRENA, 2021)

### 2.3 Kenya Solar PV Market Development

In the 1970s, the government of Kenya started employing solar photovoltaic systems to power remote broadcast facilities, which marked the beginning of the country's utilization of solar energy resources. A nationwide solar PV supply chain was not developed until the early 1980s (Ondraczek, 2013). This was the consequence of the government, international donors, and development agencies performing off-grid solar PV projects for school lighting, water pumping, and vaccine refrigeration. Both demonstration projects and training sessions for solar professionals were simultaneously funded thanks to the generosity of donors. As a consequence of this rise in demand, there has been a rise in the utilization of solar power systems in rural Kenya, which has led to the entry of private investors into this sector. Consequently, during the 1980s, a private market segment began to expand concurrently with the donor market section.

While the donor market segment still exists, since the 1990s private investors have mainly driven the solar PV sector. Notably, the market dynamics began to shift from institution-based systems as of 2009 to private sector dominated systems, such as soar home systems (SHS) as of 2014, reaching levels of 400,000 units (Da Silva, 2014). The evolution of the solar PV industry in Kenya has seen the country emerge as the most advanced and mature nation in the East African region in regards to solar PV technology.

Further evidence of the growth of the solar photovoltaic business in Kenya may be seen in Figure 2.4, which was provided by the Kenyan Energy and Petroleum Regulatory Authority (EPRA). It is important to note that import numbers are subject to some degree of uncertainty. Statistics on shipments can even include stock from the previous year if necessary. Wafers, cells, and modules can all be grouped together and referred to as "solar products" in the reports that certain businesses submit regarding their solar product shipments.

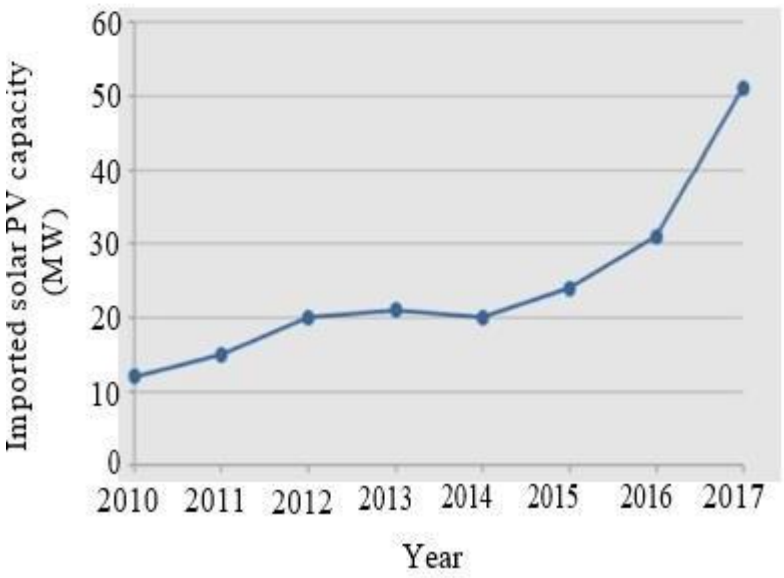


Figure 2. 4: Annual capacities of imported solar PV panels, 2010-2017 (ERC, 2018)

In their study of the solar PV industry in Kenya, ERC determined the current status of installed solar PV systems in the country as given in Table 2.1

Table 2. 1: Current Status of installed solar PV systems in Kenya

| System Category | Main Customer(s) | Estimated Aggregate Capacity (MW) |
|---|---|---|
| Solar Lanterns | Individuals/NGOs, etc. | 9 |
| Solar Home Systems | Individuals/NGOs, etc. | 20 |
| Stand-alone PV Systems | Individuals, National Gov’t, NGOs | 20 |
| | County Governments, Supermarkets | 0.603 |
| Solar Pumps | Individuals, Institutions, NGOs, etc. | 20 |
| Solar PV Mini-grids | KPLC, REA, MoEP, Private Investors, NGOs | 1.32 |
| Grid-connected Systems | Manufacturing farms, flower farms, etc. (Strathmore University, UNEP, Garden City, Garissa Solar PV Planet, etc.) | 60.83 |
| **Total** | | **131.753** |

Source: Authors’ analysis from the ERC solar PV baseline study, 2018.

The solar PV industry has the role of delivering solar electrical power solutions to customers and there are several business entities in the sector – solar PV mini-grid operators, off-grid solar PV systems suppliers, etc. That is to say, in the Kenyan solar PV industry, there are commercial entities that facilitate delivery of solar PV equipment and their integration into final systems. These entities include one manufacturer of solar PV panels such as Solinc EA Ltd, Naivasha, and one manufacturer of solar batteries (ABM Athi River) (KCIC, 2016). There are also importers, dealers/suppliers, retailers/vendors, and installers (technicians) that serve local and regional customers. The industry is essentially composed of many small and medium enterprises, a fact that was corroborated by a recent solar PV market assessment that revealed that almost 52% of the commercial entities operate as sole proprietor businesses (KCIC, 2016). Figure 2.5 shows the institutional landscape of the electrical energy sector in Kenya.

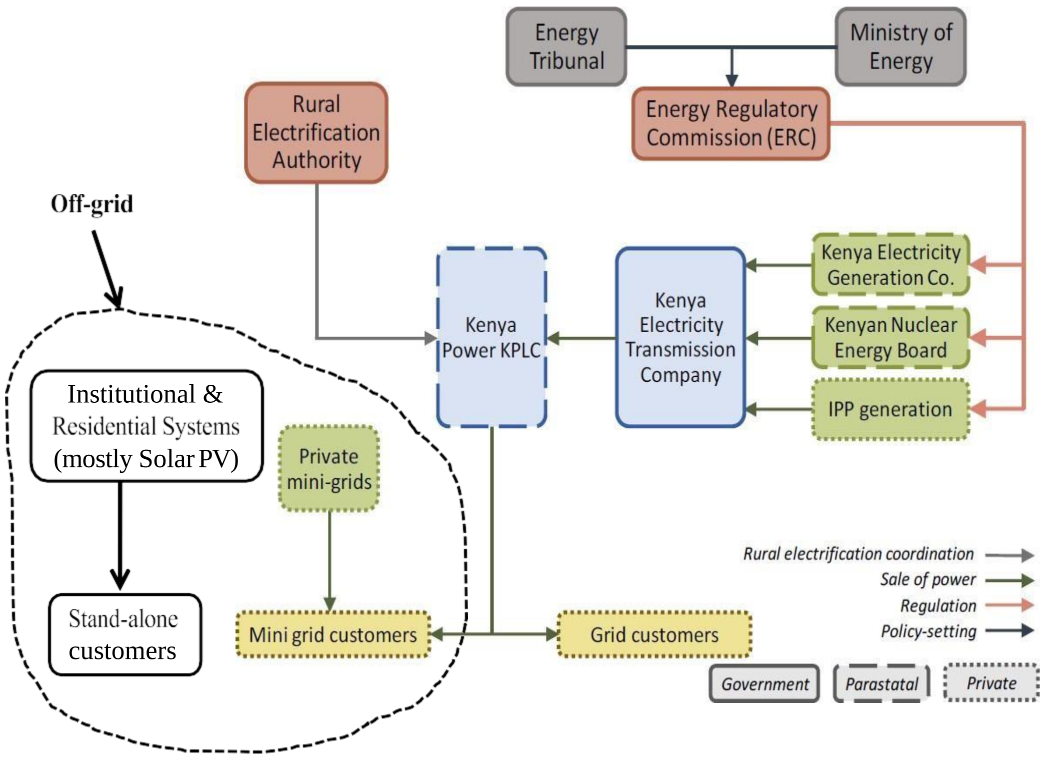


Figure 2. 5: Institutional landscape of the electrical energy sector in Kenya (Modified from World Bank (Castalia et. al, 2017) & (GIZ, 2016))

The government of Kenya places a high priority on the development of off-grid areas. In point of fact, the World Bank collaborated with the government of Kenya to initiate the Kenya Off-Grid Solar Access Project (K-OSAP), which has the goal of increasing access to electricity in 14 counties spread across the nation (Kenya Power and REA, 2017).

## 2.4 Solar PV System Types

Solar PV systems are mainly classified into two main types, that is: Grid-connected and Stand-alone PV systems. This is elaborated in Figure 2.6.

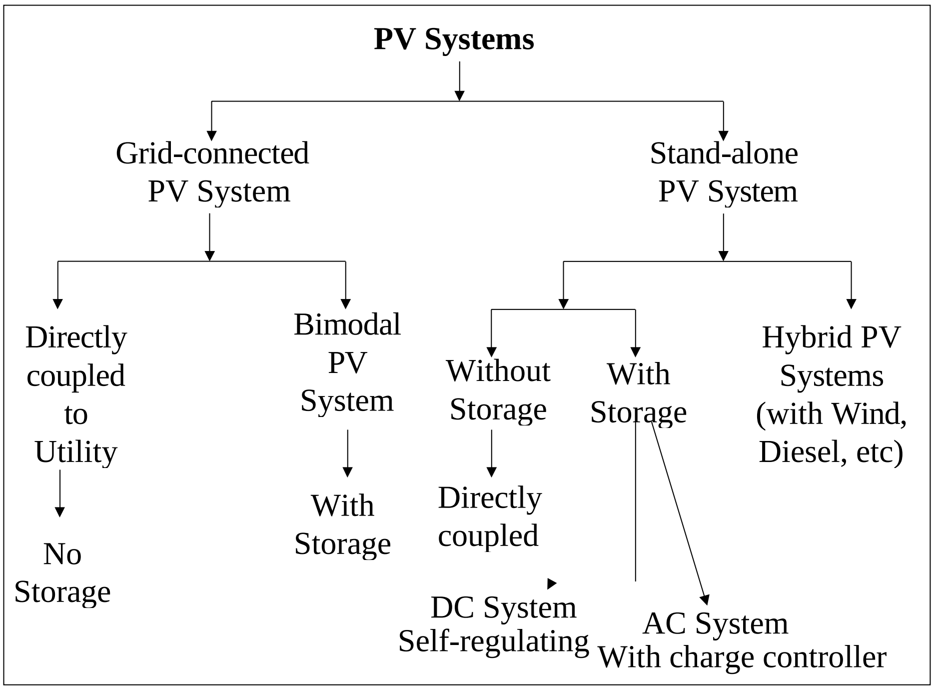


Figure 2. 6: Solar PV System Types (Source: Generated by Author)

Stand-alone PV systems work independent of the grid (off-grid) and mainly consist of PV generator, an energy storage system, AC and DC loads and power conditioning elements (Figure 2.7).

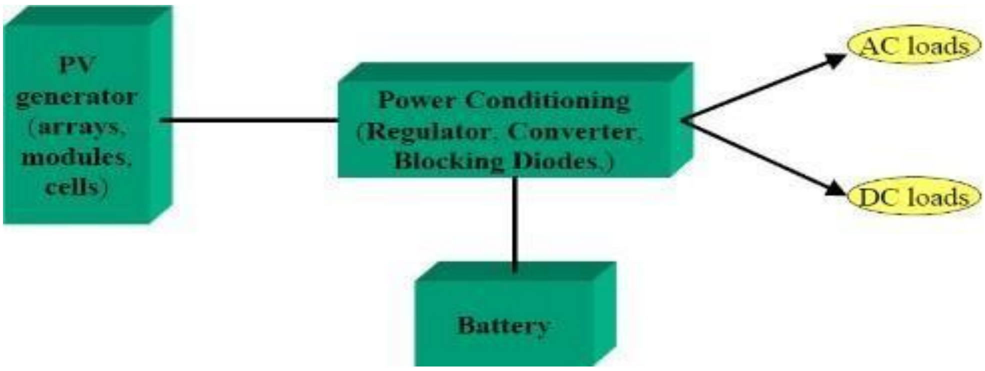


Figure 2. 7: The components of a stand-alone solar PV system (Source: Author)

The storage system mainly comprises of batteries while the power conditioning elements act as an interface between all the elements of the PV system giving protection and control. A stand-alone PV system without battery storage has to have a perfect match between the supply and demand; that is, the PV system has to match the load requirement forming a directly coupled system. A Hybrid PV system employs other energy sources to supplement the PV system in meeting the load requirements. These energy sources could include; wind turbines, hydro, diesel generators and fuel cells.

In the grid-connected mode, we have a configuration show in Figure 2.8. A PV array directly coupled to the utility without storage is known as "Utility-Interactive PV System or Grid-Tied PV System". A Bimodal PV system stores excess energy into the battery banks for utilization when the PV production is insufficient.

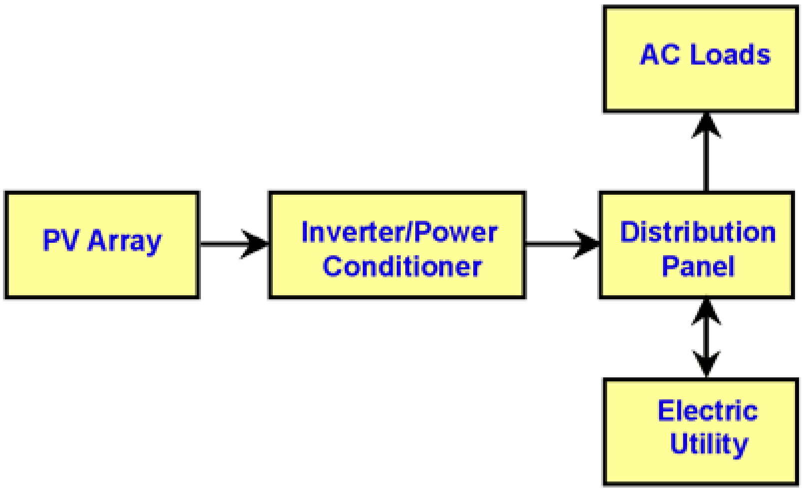


Figure 2. 8: Grid Connected PV System Schematic (Source: Author)

## 2.5 Related Research Works

Arising from social considerations, governments all over the world help meet rural energy requirements through promotion of renewable energy technologies. Solar PV technology is among the options most preferred by governments to provide energy to people in remote communities owing to its ability to sustain itself from sunlight. In some cases due to the geographical remoteness of a region, governments may prefer to initiate micro-grids as opposed to connecting the area to the national power grid, which may prove to be economically unviable. Thus, decentralized energy generation systems have been in existence for a while.

Table 2.2 highlights some of the public mini-grids in Kenya with a solar PV component incorporated. These are mini-grids part of the public sector operated supply infrastructure, with Kenya Power and REREC being active players. For this reason, the price of electricity is the same as for those consumers connected to the grid. We see that these mini-grids have only recently been enabled with solar PV generation, having relied mostly on diesel generating sets. In addition, we have private sector mini-grids that are small in size and whose electricity price is many times that of what public mini-grids charge.

From Table 2.2, we see that most of the solar PV capacity was incorporated in the mini- grids fairly recently (from year 2011 onwards), and that the installed solar PV capacities are mostly limited below 100 kW. The number of connections is also very varied, from the low of 160 to an estimated 10,000 connections. These connections serve diverse entities (households, public facilities, and even businesses).

Several studies assess the potential of mini-grids for electricity supply in Kenya. Carbon Africa Ltd, et. al (2015) analyzed viability, commercially, of mini-grids without external support, in the form of government subsidies. Findings show that in relatively higher-income rural communities, commercial viability is more likely. The viability could be enhanced through government intervention to reduce capital costs.

Opiyo (2016) shows that for Kendu Bay Area, Kisumu, Kenya, 36% of the remaining non-electrified rural households can be cost-effectively served by community-based solar PV mini-grids. Zeyringer et al (2015) analyzed grid-extension compared to stand-alone solar PV mini-grids and found that off-grid solar PV systems are the most cost-effective option, distance from the grid considered.

Table 2. 2: Public mini-grids in Kenya with Solar PV (New Climate Institute, 2018)

| **County/Locality** | **Commission Date** | **Number of Connections (June 2016)** | **talled Capacity, kW (October 2018)** |
|---|---|---|---|
| Homa Bay (Mfangamano) | 2009 | 3000 | 650 (diesel); 10 (solar, 2013) |
| Isiolo (Merti) | 2007 | 1485 | 250 (diesel); 10 (solar, 2011) |
| Mandera (Elwak) | 2009 | 1700 | 740 (diesel); 50 (solar, 2012) |
| Mandera (Mandera) | 1979 | 8000 | 3,130 (diesel); 330 (solar, 2013) |
| Mandera (Rhamu) | 2013 | 400 | 520 (diesel); 50 (solar) |
| Mandera (Takaba) | 2013 | 500 | 320 (diesel); 50 (solar) |
| Mandera (Laisamis) | 2016 | 160 | 264 (diesel); 80 (solar) |
| Tana River (Hola) | 2007 | 1300 | 800 (diesel); 60 (solar, 2012) |
| Turkana (Lodwar) | 1976 | 9598 | 3425 (diesel); 60 (solar, 2012) |
| Wajir (Eldas) | 2013 | 342 | 184 (diesel); 30 (solar) |
| Wajir (Habaswein) | 2007 | 1180 | 1160 (diesel); 50 (wind, 2012); 30 (solar, 2012) |

### 2.6 Summary and Research Gap

Solar PV technology competes very favourably with grid-connection for rural electrification applications; in some specific situations, it is even more cost-competitive. But like all other renewable energy technologies, the application of solar PV electrification is site-specific. There needs to be an understanding of the load size and its characteristics as well as an assessment of the solar resource at the site in question. For this reason, this study seeks to determine and characterize the electrical load data at Kalisasi Village, the case study location, followed by analysis of the solar resource data at the site, and conclude with a technical and economic analysis of the viability of providing power to the locality via solar PV technology with associated accessories.

# CHAPTER 3: METHODOLOGY

## 3.1 Introduction

This chapter describes the methods and tools used to realize the objectives of the study. Firstly, we document how the electrical load data at Kalisasi Village, the case study location, was obtained and analyzed. This is followed by solar resource data at the site. Next is the technical design computations and finally the economic analysis tools.

## 3.2 Determination of the Electrical Load and its Characterization

To electrify an area, or to expand the existing power facility, it is first necessary to understand and quantify the electrical load at the site. For this purpose, the Rural Africa Load Profile Tool (RALPT) from the National Renewable Energy Laboratory (NREL) was applied. The tool provides hourly electrical load profiles for loads commonly found in Sub-Saharan Africa (different household types and commercial entities such as water pumping for irrigation, grain milling, small shops, schools, clinics, and street lighting). It is assumed that there is no variation in the load profiles from weekday/weekend and from season to season. From the generated load profile, the average load, peak load and load factor can be determined. The load factor refers to the energy consumed over a 24-hour period divided by the energy that would have been consumed assuming the maximum load exists on the system for 24-hours (see Figure 3.1).

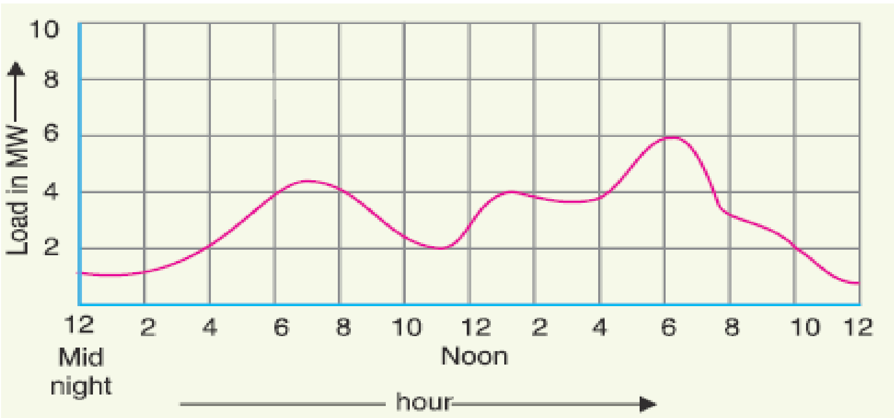


Figure 3. 1: A typical load curve

The peak of the daily load curve indicates the highest demand placed on the power plant, while the area under the daily load curve provides an indication of the total number of kilowatt-hours (kWh) produced throughout the day. The daily load curves are helpful because they show the progression of the load that is being placed on the plant throughout the day. Simply dividing the area of the daily load curve by the total number of hours is all that is required to arrive at an accurate estimate of the station's typical daily load. In the final step of the calculation, the load factor is determined by taking the ratio of the area under the curve to the total area of the rectangle. The different kinds of loads each have their own unique load factors. Different loads have different load factors.

### 3.3 Assessment of the Solar Energy Resource

Direct normal irradiance (DNI), which is a measurement of the amount of solar radiation absorbed by an area that is perpendicular to the sun's current position, was used to determine the amount of solar radiation that is emitted per unit of area. Solargis worked on the project for the World Bank and created the Global Solar Atlas (https://globalsolaratlas.info/), which was then utilized to generate the DNI radiation data. The database that was used to compile the information is owned by Solargis, and it is maintained by the company. You can use it to estimate the amount of solar power that can be generated from a photovoltaic power system based on the location and input parameters that you choose for the system. This can be done by entering information such as the location and the parameters. The data obtained in the above manner needs no further analysis for use in this research, as it essentially gives the energy per unit area at the site. Knowing the surface area on which this energy falls – and the solar panel conversion efficiency from solar radiation to electrical energy – one can easily compute the resultant electrical energy output.

### 3.4 Technical Design of the Solar PV System and Accessories

Properly designed and sized solar PV systems are a reliable power option for many remote applications around the world. They are also increasingly being adopted by large corporate organizations, commercial and industrial. For these systems to deliver acceptable performance, it is necessary to design them with appropriate knowledge of solar PV system performance as well as application of good engineering practices when installing equipment. It is also necessary to develop and follow the appropriate operation and maintenance plan.

The key components in the solar PV system design are: determination of solar panel sizes, determining the battery capacity (where storage is needed) and sizing the inverter. Equation

(3.1) provides the required solar panels capacity, in which the factor 1.25 accounts for losses. Equation (3.2) gives the battery size, while Equation (3.3) gives the inverter, where typically the safety factor is in the 1.25 to 1.30 range. Typically, the battery loss is 0.85, while the depth of discharge is 0.6.

$$\text{Panel Size} = \frac{\text{(daily consumption)(1.25)}}{\text{Peak sunlight hours}} \quad (3.1)$$

$$\text{Battery Size} = \frac{\text{(Total watthours) (days of autonomy) (Battery loss)}}{\text{(depth of discharge)(battery voltage}} \quad (3.2)$$

$$\text{Inverter Size} = \frac{\text{(daily consumption) (safety factor)}}{\text{Operation period}} \quad (3.3)$$

Thus, by knowing the daily energy consumption (Section 3.2) and the radiation resource (Section 3.3), the solar panel, battery and inverter sizes can be established, either by manual calculation or through appropriate software. Indeed, several software tools exist to automate aspects of the design. For this particular study, the PV*SOL Expert was used. It is a solar project analysis and planning tool that provides capabilities such as analysis of effects of shading. With the help of this software suite, users are able to design, simulate, and conduct a financial analysis on photovoltaic systems of varying sizes, ranging from small off-grid systems to large grid-connected systems and utility scale.

### 3.5 Levelized Cost of Electricity from the Solar PV System

Performing economic analysis of an energy project provides answers to important questions. It helps determine the payback period, net present value, internal rate of return, and – particularly important – levelized cost of electricity (LCoE). This is given in Equation (3.4).

$$LCoE = \frac{\text{Lifecyle Cost}}{\text{Lifetime Electricity Production (kWh)}} = \frac{\frac{\sum_{t=0}^{n}(I_t+O_t+M_t+F_t)}{(1+r)^t}}{\left(\frac{\sum_{t=0}^{n}E_t}{(1+r)^t}\right)} \quad (3.4)$$

where $t$ refers to the time (in years) of consideration, $n$ is the life time of the project, $I$ is annual capital cost (amortized), $O$ is operational cost, $M$ is maintenance cost, $F$ is fuel cost $E$ is energy generated in year $t$, $r$ is discount rate per unit. For renewable energy projects, $F$ is typically zero.

### 3.6 The Conceptual Framework

This is shown in Figure 3.2. The key independent variables are the daily energy consumption, peak load, solar insolation levels, available solar PV Technologies and Technology costs. On the other hand, the dependent variables are the solar PV system design specifications and the LCoE.

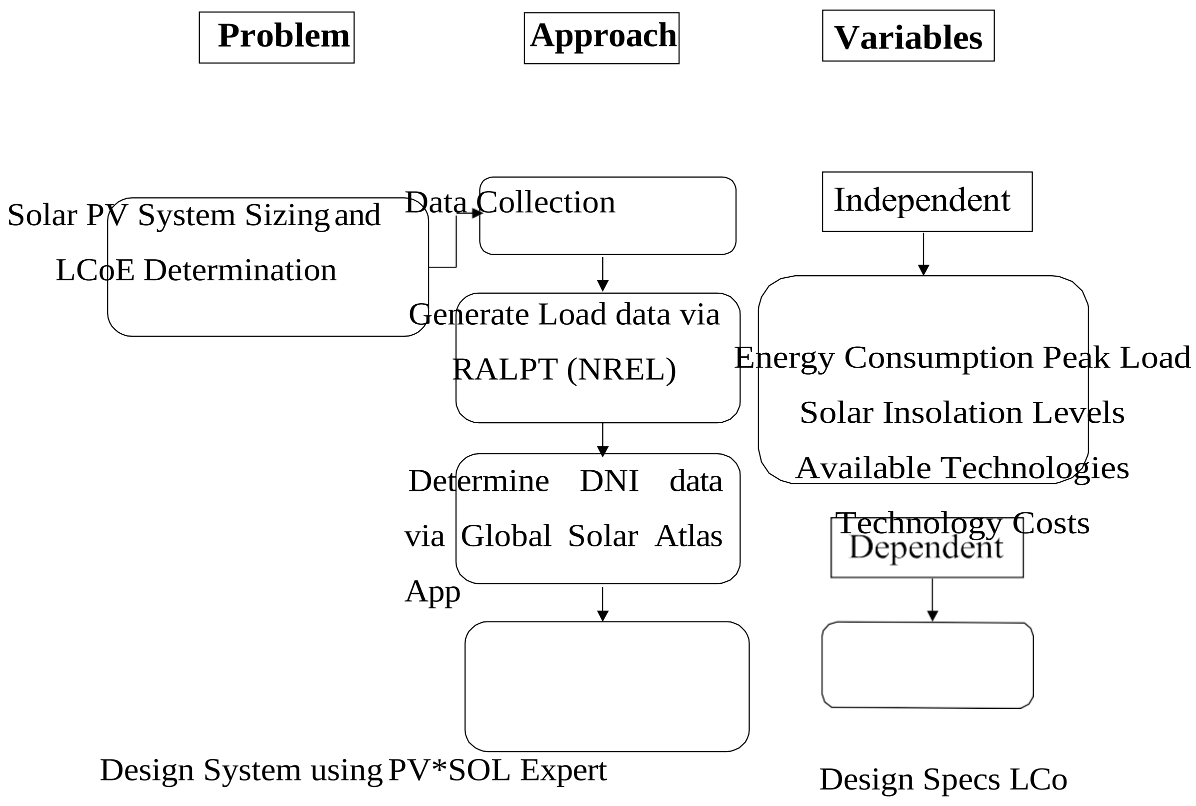


Figure 3. 2: Research Conceptual Framework

# CHAPTER 4: RESULTS AND DISCUSSIONS

## 4.1 Introduction

The overall objective of this research was to perform technical and economic evaluation of solar PV electrification, focusing on Kalisasi Village, Kanzanzu Location, Mwingi Sub-County, Kitui County. This Chapter documents the findings of the study, in addition to relevant discussions. The organization of the results and discussions is in order of the specific objectives of the research.

## 4.2 Determination of the Load and its Characteristics

The first objective of the study was to quantify and characterize the electrical load at Kalisasi Village. Table 4.1 gives the hourly variation of the load, over a period of 24 hours from 12.00 am to 12.00 am.

Table 4. 1: Hourly load for Kalisasi Village

| Time of the day | Total household load (Kw) | Total commercial load(Kw) | Total load(Kw) |
|---|---|---|---|
| 0:00 | 3.25 | 3.36 | 6.61 |
| 1:00 | 2.22 | 3.36 | 5.58 |
| 2:00 | 1.66 | 3.36 | 5.02 |
| 3:00 | 1.39 | 3.46 | 4.85 |
| 4:00 | 1.39 | 3.56 | 4.94 |
| 5:00 | 1.51 | 3.05 | 4.56 |
| 6:00 | 1.85 | 3.18 | 5.03 |
| 7:00 | 2.37 | 4.51 | 6.89 |
| 8:00 | 3.93 | 5.48 | 9.41 |
| 9:00 | 4.38 | 6.22 | 10.60 |
| 10:00 | 4.50 | 6.22 | 10.72 |
| 11:00 | 4.47 | 6.12 | 10.60 |
| 12:00 | 3.43 | 6.03 | 9.45 |
| 13:00 | 3.15 | 6.03 | 9.18 |
| 14:00 | 3.07 | 6.12 | 9.20 |
| 15:00 | 2.88 | 6.12 | 9.00 |
| 16:00 | 3.81 | 6.20 | 10.01 |
| 17:00 | 6.90 | 5.10 | 12.00 |
| 18:00 | 10.56 | 4.59 | 15.14 |
| 19:00 | 16.04 | 5.38 | 21.42 |
| 20:00 | 20.64 | 5.79 | 26.42 |
| 21:00 | 19.34 | 5.69 | 25.02 |
| 22:00 | 12.40 | 4.52 | 16.92 |
| 23:00 | 6.02 | 3.36 | 9.37 |

The data in Table 4.1 represents aggregated consumption from 495 households, 60 streetlights, 15 small shops, 3 schools, 1 water-pumping facility and 1 clinic. From the data, daily energy consumption can be estimated to be 141 kWhrs, 117 kWhrs and 258 kWhrs respectively for the household category, commercial category and the total. Further, from Table 1, we observe that peak demands for the three categories are, respectively, 20.64 kW, 6.22 kW and 26.42 kW. Finally, the minimum demands the three categories are, respectively, 1.39 kW, 3.05 kW and 4.56 kW. For better clarity, Figure 4.1 is generated from the same data, representing daily load profile for the Village.

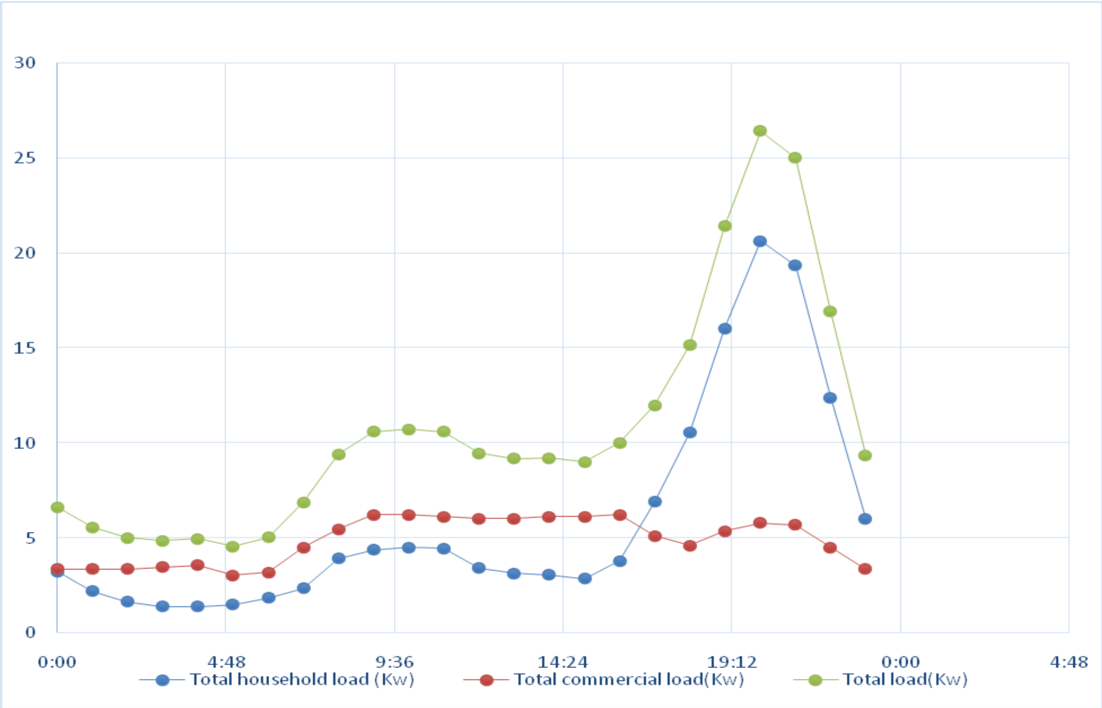


Figure 4. 1: Hourly load for Kalisasi Village (24 hours)

From both Table 4.1 and Figure 4.1, we observe that the household low is quite low from mid night to around 6.00 am, rises from then to a low peak at around 9.30 am. After that, the load drops until 16.00 pm, then starts rising to hit a daily high peak load of about 21 kW at around 20.00 pm. Thereafter, the load drops fairly dramatically as time approaches mid night. This load characteristic is typical of household: low consumption most of the day, but high peak during evening hours. Such aload profile, as described above, results in very low load factors.

In fact, the load factors for the different consumers at Kalisasi Village (from Table 4.1) are calculated and documented in Table 4.2, with the aggregated household load presenting the lowest load factor.

Table 4. 2: Characterization of Electrical Load: Kalisasi Village

| Load Category | Peak Demand (kW) | Daily kWhrs Consumed | Annual kWhrs Consumed | Estimated Load Factor | Average Load (kW) |
|---|---|---|---|---|---|
| Household | 20.64 | 141 | 51465 | 28.5% | 10.75 |
| Commercial | 6.22 | 117 | 42705 | 78.4% | |
| Total | 26.42 | 258 | 94170 | 40.7% | |

Low load factor, such as for household load, implies that the installed capacity of key infrastructure components (distribution lines and transformers mostly) is grossly under-utilized except during some 4 hours of high peak period. Low load factor is also typical for rural electrification schemes, where mostly the household loads are catered for. The commercial load, on the other hand, has a more gentle variation throughout the day. As can be observed from Figure 4.1 and Table 4.2, this kind of load has a significantly high load factor (78.4% for Kalisasi Village). Power supply companies prefer this kind of load because of better utilization of installed infrastructure. Looking at the total load, Figure 4.1 shows that the household load influences the overall shape of the load profile significantly, more so during high peak hours, bringing the total load factor to 40.7%.

From an electrical energy supply perspective, a low load factor means that the annual capital and operations and maintenance costs must be spread over fewer energy units. This means the cost per unit of energy must be higher for these types of consumers.

### 4.3 Assessment of the Solar Energy Resource

In order to correctly size a power system, it is necessary to quantify the load that the system has to support, as documented in Section 4.2 for Kalisasi Village. Just as important, it is also necessary to assess the primary energy sources at the location of interest, from which electricity can be generated. For this reason, an assessment of the solar energy resource at Kalisasi Village, Kanzanzu Location, Mwingi Sub-County, Kitui County, is essential. These findings are summarized in the form of direct normal irradiation (DNI), which measures the amount of solar energy that a given surface area receives when it is perpendicular to the sun's beams as they travel straight down from the sky. In other words, DNI measures the amount of solar energy that a surface area receives when it is facing the sun in a direction that is normal to its beams.

Data on diffuse non-ionizing radiation (DNI) was compiled for the Global Solar Atlas online app (https://globalsolaratlas.info/) using information from a database of solar resources that is owned and maintained by Solargis. Solargis was hired by The World Bank to construct this database as part of a contractual agreement. It computes an estimated sun resource, air temperature, and potential solar power output for a given location and set of input parameters for a photovoltaic (PV) power system's potential solar power output. Table 4.3 shows the average hourly profiles of DNI in Wh/m$^2$, for Kalisasi Village, from January to December. The data is displayed also in Figure 4.2. Further, the daily total in Table 4.3 are captured in Figure 4.3.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 - 1 | | | | | | | | | | | | |
| 1 - 2 | | | | | | | | | | | | |
| 2 - 3 | | | | | | | | | | | | |
| 3 - 4 | | | | | | | | | | | | |
| 4 - 5 | | | | | | | | | | | | |
| 5 - 6 | | | | | | | | | | | | |
| 6 - 7 | | | | 11 | 14 | 3 | | | 4 | 31 | 25 | 12 |
| 7 - 8 | 160 | 167 | 163 | 198 | 220 | 117 | 84 | 111 | 184 | 236 | 163 | 174 |
| 8 - 9 | 282 | 323 | 309 | 328 | 363 | 232 | 182 | 220 | 360 | 379 | 251 | 281 |
| 9 - 10 | 363 | 430 | 448 | 422 | 450 | 323 | 267 | 321 | 501 | 510 | 350 | 383 |
| 10 - 11 | 476 | 536 | 515 | 492 | 486 | 371 | 332 | 397 | 547 | 575 | 445 | 492 |
| 11 - 12 | 594 | 636 | 577 | 544 | 504 | 375 | 352 | 413 | 566 | 606 | 509 | 569 |
| 12 - 13 | 655 | 693 | 607 | 551 | 511 | 356 | 335 | 382 | 546 | 591 | 515 | 581 |
| 13 - 14 | 654 | 692 | 610 | 556 | 509 | 325 | 296 | 345 | 544 | 576 | 505 | 543 |
| 14 - 15 | 651 | 673 | 594 | 552 | 516 | 339 | 288 | 333 | 531 | 549 | 490 | 523 |
| 15 - 16 | 609 | 618 | 552 | 515 | 496 | 328 | 272 | 312 | 498 | 499 | 447 | 484 |
| 16 - 17 | 521 | 526 | 450 | 433 | 432 | 299 | 245 | 286 | 440 | 417 | 370 | 415 |
| 17 - 18 | 360 | 400 | 303 | 263 | 264 | 192 | 159 | 199 | 285 | 232 | 195 | 269 |
| 18 - 19 | 44 | 67 | 34 | 12 | 10 | 11 | 11 | 16 | 16 | | | 18 |
| 19 - 20 | | | | | | | | | | | | |
| 20 - 21 | | | | | | | | | | | | |
| 21 - 22 | | | | | | | | | | | | |
| 22 - 23 | | | | | | | | | | | | |
| 23 - 24 | | | | | | | | | | | | |
| Sum | 5368 | 5764 | 5161 | 4877 | 4774 | 3272 | 2821 | 3335 | 5020 | 5201 | 4264 | 4744 |

Table 4. 3: Average hourly profiles: DNI (Wh/m$^2$), Kalisasi Village

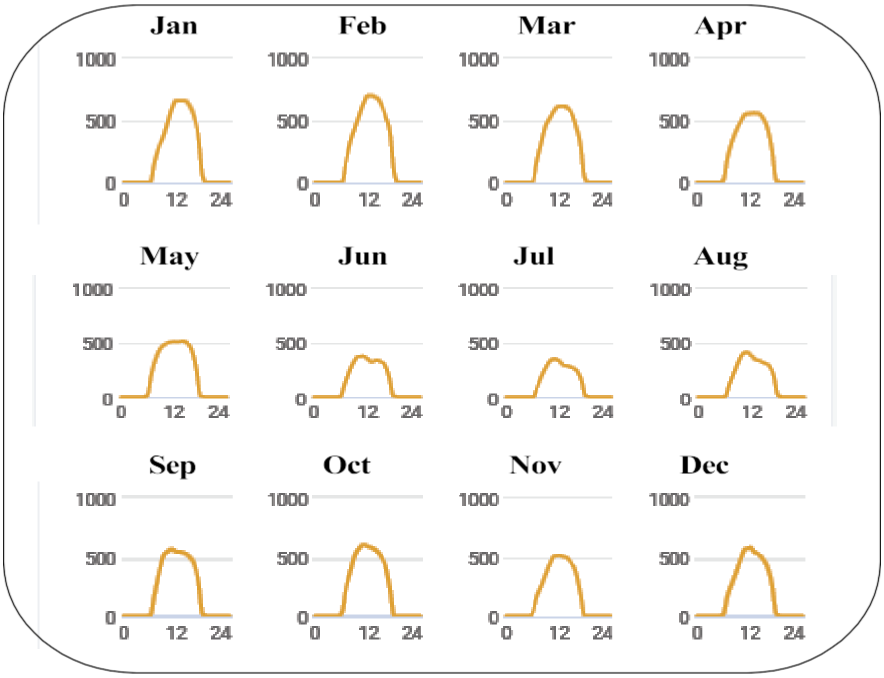


Figure 4. 2: Average daily profiles: DNI (Wh/m2), Kalisasi Village

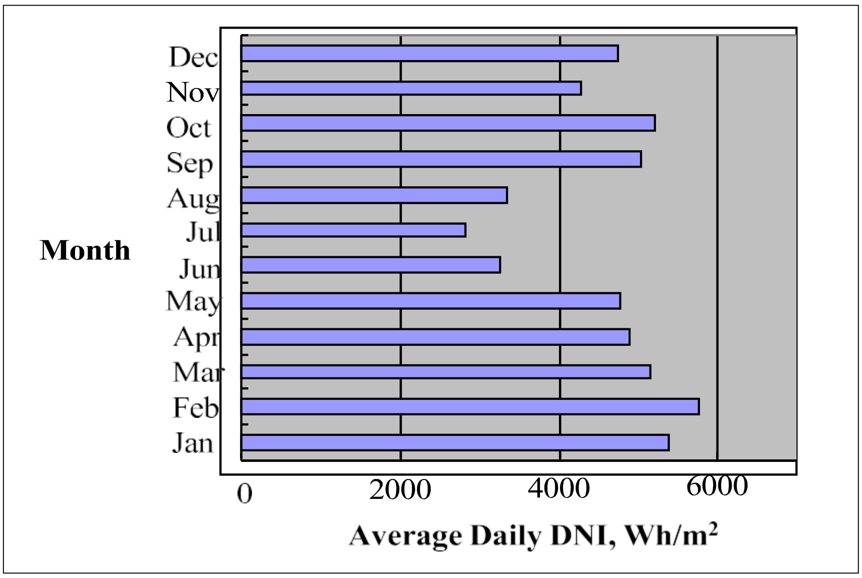


Figure 4. 3: Average daily profiles: DNI (Wh/m2), Kalisasi Village Table 4. 4: EPRA licensed solar power plants with DNI values

| Plant Name | Location | Plant Capacity (MW) | DNi Values (kWh/m$^2$ per day) |
|---|---|---|---|
| Alten Solar Power Station by Alten Energy,Kenya | Eldoret | 40 | 5.908 |
| Radiant Solar Power Station by Radiant Energy,Kenya | Plateau Area, close to Eldoret Town | 40 | 5.836 |
| Eldosol Solar PV project by Eldosol Energy, Kenya | Plateau Area, close to Eldoret Town | 40 | 5.836 |
| Strathmore University solar power plant | Nairobi City | 0.6 | 3.937 |
| Malindi solar plant by Global Eleq. | Malindi, Kilifi County | 40 | 4.757 |
| Imenti Tea factory solar plant | Imenti Tea Factory | 0.92 | 4.214 |
| Powerhive Kenya Ltd solar power plants | Kisii and Nyamira Counties | 3.0 | 4.751 |
| Talek solar power plant by Talek Power Company Ltd | Talek, Narok County | 0.05 | 5.436 |
| Two Rivers solar power plant by Two Rivers Power Company Ltd | Nairobi County | 2 | 4.273 |

Finally, Figure 4.4 shows the monthly average profiles at the site of interest, giving an annual average DNI of 1658 kWh/m$^2$/year.

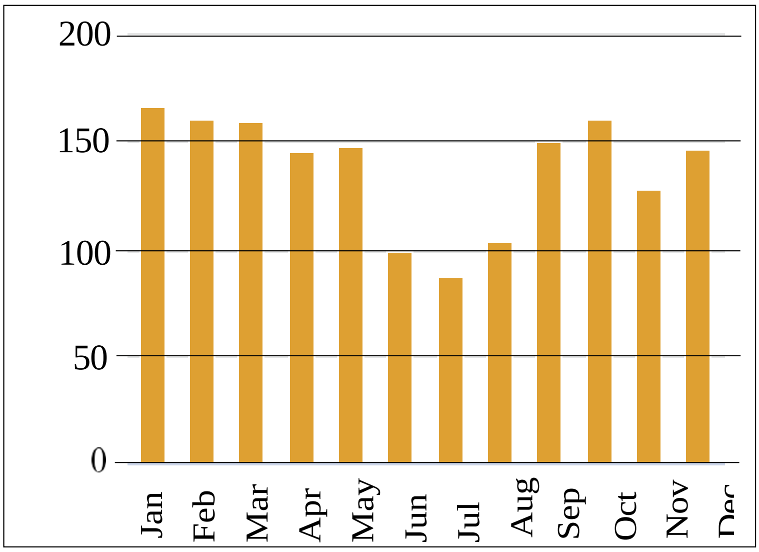


Figure 4. 4: Monthly average profiles: direct normal irradiation (kWh/m$^2$)\

**4.4 Sizing of the Solar PV System**

The sizing of the solar PV system is made based on several considerations captured and elaborated below:

- **Energy demand.** Collect data per household of appliances & usage patterns. This is used to generate a daily load profile.

- **Climate Data.** Uses both historical and future predictions on climate to estimate the expected energy yield for a specified location. Climate data also reduces the risk for investors, as they can be able to ascertain the amount of energy they can generate and sell to the users over the project lifetime

- **Site Location.** The coordinates of the site to assist with understanding the appropriateness of the site considering factors such as the topography, accessibility to site, closeness to the users, demographic patterns associated with the area, etc

- **Equipment Data.** Includes the technical datasheets, warranty & guarantees of the different equipment from the manufactures so as to properly select the products that work best for the project & depending on the intended lifetime.

As seen from Figure 4.1 and Table 4.2, the daily peak demand is 26.42 kW (and daily energy consumption is 258 kWhrs) occurring at around 20.00 pm – time when there is no sunshine. Therefore, consideration has to be given for energy storage through appropriately sized batteries. Also, the solar PV system capacity must be significantly greater than 26.42 kWp to account for the variability and uncertainty in the energy resource and to provide for an appropriate safety margin.

On the basis of the above considerations as inputs (as well as climate data for Kalisasi Village) and employing Valentin Software GmbH (PV*SOL algorithms), the system specifications in Table 4.5 were established. It is observed that the total system capacity is 70.68 kWp, capable of generating enough electrical energy for customer consumption (52,856 kWhr/yr), charging the battery (23,150 kWhr/yr) and feeding to the grid (39,240 kWhr/yr). Basically, the customer consumption is met through direct solar PV generated electricity as well as from the battery during evenings when there is no sunshine. The system in question is comprised of 228 solar panels, each 310Wp. For this number of solar panels, the total PV generation surface is 444.2 $m^2$, roughly equal to a space of 21 m by 21 m. The installation would be mounted, open space and covering the specified area of space.

The design provides for two batteries of total rating 5360 Ah, with a total annually battery energy storage of 23,150 kWhr. This energy storage is able to provide for 40 hours of autonomy per week (no sunshine period), worst-case scenario. Further, three inverters each rated 25 kW, 400 V, 50 Hz are needed, delivering a total of 75 kW rating.

Table 4. 5: Technical System Details for the Kalisasi Solar PV Project

| S/No | **Component** | **No. of Units** | **Total Capacity** | **Details** |
|---|---|---|---|---|
| 1 | PV Gen. | 228<br>(310 Wp) | 70.68 kWp | PV Gen. Surface: 442.4-meter square<br>Installation type: Mounted – open space<br>Annual Generation: 115,246 kWhr/yr<br>Customer Consumption: 52,856 kWhr/yr<br>Grid Feed-in: 39,240 kWhr/yr<br>Battery Charging: 23,150 kWhr/yr |
| 2 | Battery | 2 | 5360 Ah | Power rating: 72 Kw<br>DC Battery system voltage: 51.2 V |
| 3 | Inverter | 3 | 75 kW | AC Nominal Voltage: 400 V<br>Grid Frequency: 50 Hz |

### 4.5 The Levelized Cost of Electricity from the Solar PV System

The LCOE is one of the most important financial benchmarks for energy – in this case, electricity producing – projects because there is ready comparison with what consumers will pay assuming they get their electricity from a local utility. As previously shown, LcoE measures the average net present cost of electricity generation over the lifetime of a plant, an easy way to compare technologies of different characteristics such as capacity factor, capital cost, fuel cost, operations and maintenance cost, and plant life.

As seen in Section 4.4, the solar PV plant has an annual generation of 115,246 kWhr/yr with an expected lifetime of 25 years. Further, for a system of 70.68 kWp, the estimated capital cost, based total installed cost of USD 1,500/kW, stands at an estimated USD 106, 020.00. It is noted here that the total installed cost per kW is deliberately higher because Kenya is an importer of solar PV technology and costs come in former of foreign exchange, transportation and other factors. Amortization of this capital cost over a 25-year period at an annual interest rate of 10% gives annual capital cost of USD 11,680.00. The annual operation and maintenance cost is an estimated 25.7% of the capital cost (Phillip, 2021), in this case amounting to USD 3,001.76. The total annual cost (capital plus O&M) of USD 14,681.76 is spread over 115,246 kWhr/yr, giving an LCoE of USD 0.127/kWhr, equivalent to Kshs. 14/kWhr at an exchange rate of Kshs 110 per USD. The rest of the cash flow data for the Project is shown in Appendix A.

### 4.5 Conclusion

This Chapter provides a documentation of the data/results, analysis and discussions. We found that the data generated from the RALPT corresponds very closely to what we expect, an aggregate load that is mostly residential in nature with low load factor, in this case 40.7%. It is for this reason (low load factor) that utilities in Africa and other parts of the world find rural consumers to be unattractive customers. On the other hand, the solar energy resource at the case study site is favorable, with an annual DNI of 1658 kWhr/m$^2$/year and can support adequate electricity generation throughout the year, aided by battery energy storage. A solar PV system design of 70.68 kWp was realized, with a LCoE of USD 0.127/kWhr.

# CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Introduction

There is a significant trend underway, worldwide, whereby consumers of electricity are switching from utility-provided electricity to own-generated electricity. For those who have no grid-connection and where it is not economical to extend the grid to serve the, the choice is use of renewable energy technologies, mostly solar PV due to its modular nature. Many reasons exist for this trend.

In line with this shift in the electrical energy sub-sector, this study had as its focus the techno-economic evaluation of solar PV electrification, Case Study of Kalisasi Village, Mwingi Sub-County, Kitui County. To realize this objective, it was necessary to first determine and characterize the electrical load at the case study site, followed by an assessment of the potential of the solar resource in the area. After this, the solar PV system and associated components (battery and inverter) were sized. Finally, a levelized cost of energy analysis was done. The following two sections document the conclusions and recommendations arising from the study, respectively.

## 5.2 Conclusions

Electrical energy is one of the most popular forms of energy owing to its versatility in terms of diversity of applications. It is also a clean form of energy though often generated from unclean primary forms. Consumers of electricity use different amounts and also at different times, leading to load profiles that differ depending on whether the consumer is residential, commercial or industrial. This study established that the household (residential) load is significantly low most of the day, but rises in the evening, peaking at around 20.00 pm. This load type generally has low load factor and is mostly undesirable type of consumer. The site in question has an overall load factor of 40.7%, peak daily load of 26.42 kW, daily average load of 10.75 kW and daily energy consumption of 258 kWhrs.

The solar energy resource at the study site is very promising too, except for the months of June, July and August. For this reason, solar energy potential can be utilized practically throughout the year, with an annual average DNI of 1658 kWh/m$^2$/year. Solar PV plants have been approved and developed in areas with equivalent or even inferior solar energy resource.

Based on the electrical load and the solar energy resource at the study site, it was established that a solar PV system of capacity 70.68 kWp is sufficient, capable of generating enough electrical energy for customer consumption (52,856 kWhr/yr), charging the battery (23,150 kWhr/yr) and feeding to the grid (39,240 kWhr/yr). The system in question is comprised of 228 solar panels, each 310 Wp. For this number of solar panels, the total PV generation surface is 444.2 $m^2$, roughly equal to a space of 21 m by 21 m. The design provides for two batteries of total rating 5360 Ah and three inverters each rated 25 kW, 400 V, 50 Hz, delivering a total of 75 kW rating.

The capital cost, based on total installed cost of USD 1,500/kW, stands at an estimated USD 106,020.00. Amortization of this capital cost over a 25-year period at an annual interest rate of 10% gives annual capital cost of USD 11,680.00. The annual operation and maintenance cost amounts to USD 3,001.76. The total annual cost (capital plus O&M) of USD 14,6811.76 is spread over 115,246 kWhr/yr, giving an LCoE of USD 0.127/kWhr, equivalent to Kshs. 14/kWhr at an exchange rate of Kshs 110 per USD. This compares favourably with the power from Kenya Power; future trends show that solar PV electricity will soon be cheaper than grid electricity.

### 5.3 Recommendations

This work has shown that solar PV electricity compares favourably with grid-supplied electricity on LCoE basis and should be pursued for the area in question and other sites, both grid connected and off-grid. Further studies could examine, as an extension to this, the optimal distribution network to minimize capital costs, power losses and voltage drops.

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## Appendices

**Appendix 1: Table A. 1: Cash Flows for the Kalisasi Solar PV Project**

| YE AR | CAPITAL COST (USD) | O&M COST (USD) | FEED-IN REVENUE (USD) | ENERGY SAVINGS (USD) | ANNUAL CASH FLOW (USD) | ACCRUED CASH FLOW (USD) |
|---|---|---|---|---|---|---|
| 1 | -247,380.00 | -6998.0 | 2,231.69 | 19,888.65 | -232,257.69 | -232,257.69 |
| 2 | 0.0 | -6928.7 | 2,232.24 | 19,883.62 | 15,187.13 | -217,070.55 |
| 3 | 0.0 | -6860.1 | 2,187.67 | 19,876.55 | 15,204.09 | -201,866.46 |
| 4 | 0.0 | -6792.2 | 2,143.76 | 19,867.39 | 15,218.94 | -186,647.52 |
| 5 | 0.0 | -6725.0 | 2,100.51 | 19,856.10 | 15,231.65 | -171,415.86 |
| 6 | 0.0 | -6658.4 | 2,057.91 | 19,842.64 | 15,242.17 | -156,173.70 |
| 7 | 0.0 | -6592.5 | 2,015.94 | 19,826.96 | 15,250.44 | -140,923.25 |
| 8 | 0.0 | -6527.2 | 1,974.60 | 19,809.03 | 15,256.45 | -125,666.80 |
| 9 | 0.0 | -6462.6 | 1,933.88 | 19,788.80 | 15,260.12 | -110,406.68 |
| 10 | 0.0 | -6398.6 | 1,893.78 | 19,766.23 | 15,261.44 | -95,145.24 |
| 11 | 0.0 | -6335.2 | 1,854.28 | 19,741.26 | 15,260.32 | -79,884.92 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 12 | 0.0 | -6272.5 | 1,815.37 | 19,713.87 | 15,256.75 | -64,628.17 |
| 13 | 0.0 | -6210.4 | 1,777.06 | 19,684.01 | 15,250.68 | -49,377.49 |
| 14 | 0.0 | -6148.9 | 1,739.32 | 19,651.62 | 15,242.04 | -34,135.44 |
| 15 | 0.0 | -6088.0 | 1,702.16 | 19,616.65 | 15,230.79 | -18,904.65 |
| 16 | 0.0 | -6027.7 | 1,665.56 | 19,579.06 | 15,216.89 | -3,687.76 |
| 17 | 0.0 | -5968.1 | 1,629.53 | 19,538.82 | 15,200.28 | 11,512.52 |
| 18 | 0.0 | -5909.0 | 1,594.04 | 19,495.85 | 15,180.91 | 26,693.43 |
| 19 | 0.0 | -5850.5 | 1,559.09 | 19,450.11 | 15,158.74 | 41,852.18 |

**Appendix 2: Table A. 2: Cash Flows for the Kalisasi Solar PV Project (cont'd)**

| YEAR | CAPITAL COST (USD) | O&M COST (USD) | FEED-IN REVENUE (USD) | ENERGY SAVINGS (USD) | ANNUAL CASH FLOW (USD) | ACCRUED CASH FLOW (USD) |
|---|---|---|---|---|---|---|
| 20 | 0.0 | -5792.5 | 1,524.68 | 19,401.57 | 15,133.71 | 56,985.89 |
| 21 | 0.0 | -5735.2 | 1,490.80 | 19,350.15 | 15,105.76 | 72,091.65 |
| 22 | 0.0 | -5678.4 | 1,457.44 | 19,295.81 | 15,074.85 | 87,166.50 |
| 23 | 0.0 | -5622.2 | 1,424.60 | 19,238.51 | 15,040.92 | 102,207.42 |
| 24 | 0.0 | -5566.5 | 1,392.26 | 19,178.16 | 15,003.91 | 117,211.32 |
| 25 | 0.0 | -5511.4 | 1,360.42 | 19,114.75 | 14,963.77 | 132,175.09 |
| 26 | 0.0 | -5456.8 | 1,329.08 | 19,048.19 | 14,920.44 | 147,095.53 |

## Appendix 3: ISSUES AND RESPONSES DURING PROJECT PRESENTATION ON 13TH JUNE 2022

**Name:** Nickson Kitungu Musyoka

**Reg No:** F56/8395/2017

**Project title:** System design and levelized cost of electricity assessment for Solar PV Electrification: Case study of Kalisasi Village, Mwingi Sub- County, Kitui county.

**ISSUES AND RESPONSES DURING PROJECT PRESENTATION ON 13TH JUNE 2022**

| | **Issue** | **Response** |
|---|---|---|
| 1. | Specification of the power utility company i.e Kenya power | Amendment was done on the report page V and 38 |
| 2. | The assumed lifetime of the project i.e 25years | The standard solar project lifetime is 25years was picked to allow for computation of the various variables |
| 3. | Publication of the work | This is been worked on in collaboration with the supervisors |

## Appendix 4: Turnitin Originality Report

**Submission date:** 08-Nov-2022 08:21PM (UTC+0300)
**Submission ID:** 1948345935
**File name:** Project_Final_Nickson_Kitungu_Musyoka_-reducted.docx (1.52M)
**Word count:** 7192
**Character count:** 38516

ORIGINALITY REPORT

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Prof Cyrus Wekesa  **17/11/2022**