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MASTER OF SCIENCE IN ENERGY MANAGEMENT

PROJECT REPORT

Solar-Diesel-Storage Hybrid Electrical Energy Access System Design and Optimization: Case of UNHCR Sub-Office in Dadaab, Garissa County, Kenya

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DEDICATION

I dedicate this work to my parents and siblings for the belief, support, and encouragement they have always given me to pursue higher education. Special dedication to my dad, Wilfred Ashitiva Muhanji who is an education enthusiast for always challenging me to achieve the highest education level possible.

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ABSTRACT

The world’s latest strive involves the eradication of conventional fossil fuel utilization in electricity production. This is not only expensive but contributes a lot towards climatic change through the increased production of greenhouse gases that would have an eventual effect on global warming thus climatic change. Further effects also include environmental pollution and acidic rain which would cause corrosion. The existence of fossil fuels is also in doubt considering their extinction and security risk. In this spirit, governments across the world have been encouraging the venture into green energy supplies such as Solar Photovoltaic systems through the introduction of incentives to cushion the high prices of solar modules and their associated accessories which can be evidenced by the 21% increase in Solar PV penetration from 156 TWh in 2019 to 821 TWh in 2020. This research covers the UNHCR Sub-Office in Dadaab henceforth referred to as the facility. The analysis of the utilization of fossil fuels at the facility has proven to be expensive with cumulative costs approximated at as much as $493,853 annually translating to a unit electricity cost of about $0.362/kWh in the years 2020 and 2021. The carbon emissions have also skyrocketed thus increasing the carbon footprint to over 1,084 tCO_2/yr. Over 1,158 simulations run by the HOMER software yielded 868 feasible solutions with a preferred hybrid solar PV system capacity of 756-kWp encompassing 443-kWh battery storage and one of the 550-kVA generators already installed at the facility. The system would command a renewable energy penetration of 60% with the remaining energy supplied by the diesel generator. The Energy conservation measures applicable at the facility were also explored with LED lighting retrofit coming out as a low-hanging fruit due to the huge amount of conventional fluorescent and incandescent luminaires currently installed. The economics of the proposed solar PV system is attractive for investment with the simple and discounted payback periods at 5.42 and 6.85 years respectively depicting a short time considering a 25-year lifetime. The simulated LCOE incurs a significant 21% drop from $0.31 to $0.246 for the base and proposed system respectively with a 17.5% IRR and 13% ROI further making a case for the feasibility of a renewable energy hybrid system over the sole conventional diesel power generation. The annual carbon emissions reduction is impressive at a 46% reduction.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

Abbreviation	**Definition**
AC	Alternating Current
A/C	Air Conditioning
AM	Air Mass
BES	Battery Energy Storage
BoS	Balance of System
CCA	Cold Cracking Amps
CO_2	Carbon Dioxide
C-PCS	Control and Power Conditioning System
DC	Direct Current
ECM	Energy Conservation Measure
ESS	Energy Storage System
GCV	Gross Calorific Value
GHG	Greenhouse Gases
HHV	Higher Heating Value
HOMER	Hybrid Optimization of Multiple Energy Resources
HRES	Hybrid Renewable Energy System
IRR	Internal Rate of Return
kWh	Kilowatt hour
KOSAP	Kenya Off-grid Solar Access Project
Li-ion	Lithium-ion
LCOE	Levelized Cost of Energy
MPPT	Maximum Power Point Tracking
NPC	Net Present Cost
NPV	Net Present Value
O&M	Operation and Maintenance
PV	Photovoltaic
PWM	Pulse Width Modulation
REREC	Rural Electrification and Renewable Energy Corporation
RE	Renewable Energy
ROI	Return on Investment

SHS	Solar Home System
SLI	Starting, Lighting and Ignition
Solar PV	Solar Photovoltaic
SPB	Simple Payback
STC	Standard Test Conditions
UNHCR	United Nations High Commission for Refugees
VAT	Value Added Tax

CHAPTER ONE: INTRODUCTION

1.1 Background

Renewable energy (RE) has acquired much traction recently due to increasing environmental concerns in terms of greenhouse gas emissions, energy demand growth due to population increase, fuel prices, and exhaustion of fossil fuel resources. The sustainability and environmental conservation nature of solar photovoltaic energy systems has made them a priority for power supply in isolated and off-grid locations [1]. Augmented use of relic fuels with minimal action to mitigate greenhouses will lead to global climate change implications, and environmental pollution and could lead to the formation of acidic rain as some of the emitted gases are absorbable in rain water. The world at large has put in a concerted effort to curb the effects of greenhouse gases (GHG) under the Sustainable Development Goal 7 (SDG 7) where energy efficiency and enhanced utilization of renewables are promoted as climate change moderation and disaster risk decline. The main intent is to warrant accessibility to inexpensive, dependable, maintainable, and modernistic energy for all [2].

Kenya has a huge potential for solar considering its geographical location astride the equator with solar insolation levels good across the year combined with modest to high temperatures projected at 4-6 kWh/m^2/day [3]. Currently, the estimated installed solar power resource is more than 100 MW which is still below the approximated solar potential (15000 MW) for the country. The government's efforts towards tapping into the solar resource have enabled the construction of the Garissa Solar Power Plant which is operated by the Rural Electrification and Renewable Energy Corporation (REREC) being the largest with a 55 MW installed capacity [3]. Standalone off-grid Solar Home Systems (SHS) are more prevalent in the remote parts that are isolated from the grid and help provide rapid and independent electricity access.

The energy storage factor is prevalent in the off-grid and standalone SHS where there is a need for energy at night when insolation is non-existent. The Battery Energy Storage (BES) technology helps to better the quality of power and dependability of the power system. Primarily, it comprises of battery-storage, control, and power conditioning system (C-PCS). The evolution of BES technology has realized the development of the widely used deep-cycle batteries with a great range of energy capacity (17 – 40 MWh) and high efficiencies (70% -80%) [4].

Across the world, governments have taken initiatives to incentivize solar modules and their accessories to reduce their high prices with the ripple effect being an increase in Solar power penetration by 21% from 156 TWh in 2019 to 821 TWh in 2020 [5]. The government through the ministry of Energy has put in resources ranging from tariffs, policies, and regulations to funding through partnerships in support of RE technology. The Energy Management Regulations 2012 exempted solar products from Value Added Tax (VAT) as an incentive to lower the prices. The Kenya Off-grid Solar Access Project (KOSAP) funded by the world bank has been established to spearhead the solarization of marginalized counties. The target is the provision of 250,000 standalone solar photovoltaic (PV) systems and 150,000 clean cooking stoves in the target period (2018-2023) [3].

1.2 Problem Statement

Electricity is an essential commodity utilized across all sectors of the economy including industrial, commercial, and residential. All the sectors have electrical equipment that eases the workload on people. The only issue comes with the utilization of electrical energy where less efficient equipment tends to increase the carbon emissions due to their demand for more power.

The method through which electricity is generated is key to the level of GHG emissions realized, with the combustion of fossil fuels being the largest contributor. Facilities that rely on a diesel generator to produce their electricity will therefore have higher GHG emissions thus contributing a lot to rising the country’s overall carbon footprint. The aggregation of these emissions will eventually lead to climatic changes and global warming at large. Data from 2016 indicates that Kenya had annual CO_2 emissions totaling 16,334,919 tons, a 0.05% share of the World’s CO_2 emissions. This subsequently represents 0.33 tons per capita which is 0.33 tons of CO_2 per person annually [6].

As the country pledges to reduce its carbon footprint by 30% come 2030 [7], it's vital to substitute or complement the fossil fuel-based electricity generators with renewable Solar PV systems which are green with zero GHG emissions. In addition, the high and rising prices of diesel fuel coupled with uncertainties in the supply security make the cost of electricity production to be highly expensive.

1.3 Research Objectives

1.3.1 Main Objective

The main objective of the study is to design and evaluate a solar PV-based electrical energy supply system for the off-grid UNHCR Sub-Office at Dadaab.

1.3.2 Sub-Objectives

The specific sub-objectives include:

i.) Perform energy supply and demand analysis for the facility
ii.) Propose energy conservation measures and evaluate their economic analysis
iii.) Size Solar PV generation and battery energy storage systems
iv.) Evaluation of the base and proposed system greenhouse gas emissions.

1.4 Research Question

The research seeks to clarify the following research question

i. What is the energy supply and demand of the UNHCR facility at Dadaab?
ii. What size of the solar PV system will be sufficient to supply the energy demanded?
iii. How can energy efficiency be achieved at the facility?
iv. How do the base and proposed system parameters compare?

1.5 Justification

Research points out that the diesel generator produces 2.4 - 2.8 kgs of CO_2 for every litre of diesel consumed which is dependent on both the generator engine and fuel characteristics [8]. The average definite fuel utilization of a diesel generator is 0.33 L/kWh making the estimated CO_2 emission generated by a diesel generator range from 0.8 - 0.93kg CO_2/kWh [9]. To add to this, fuel prices are on the rise making it expensive to generate electricity through diesel-powered generators. The diesel generator's Levelized cost of energy (LCOE) will therefore be higher.

UNHCR Sub-Office Dadaab runs on a diesel generator on a 24-hour basis to enable a constant supply of electrical power for use in the diverse activities within the compound. This is extremely expensive with the facility spending approximately $493,853 annually on generator diesel fuel.

Moreover, since UNHCR is committed to reducing its global environmental footprint and particularly GHG emissions [10], it's vital to adopt the use of renewable energy for the production of electricity at this facility. The area has a huge solar potential with insolation levels of 5.627 kWh/m^2/day making the Solar PV system a viable green option for the generation of electricity.

1.6 Research Contribution

This research contributes to the global strive towards achieving clean and sustainable energy as is the primary objective under SDG 7. It proves that electricity generation by the use of fossil fuels is not only expensive and unaffordable but also has a hazardous effect on the environment due to the production of GHG emissions that if not controlled would lead to climate change as a consequence of global warming. Additionally, the research demonstrates the need for the world to venture into renewable energy resources for power production as they are clean, reliable, and inexpensive. The findings from this research make a concrete and dependable conclusion that solar photovoltaic systems are way superior in terms of environmental protection and low cost of energy production in comparison to fossil fuels. It goes further on to propose energy conservation measures that not only affect the case study but also cut across several facilities globally.

1.7 Scope

The research scope is focused on the existing situation and does not take into consideration load forecasting due to the lack of plans to expand operations by the facility. The generation and power demand are the main focus of the study without considering the reconfiguration of the distribution network. Additionally, electrical line load balancing at the facility was not evaluated in the study.

1.8 Report Structure

This report is structured as follows;

Chapter 1	The introduction provides the background and justification of the research, the purpose for the proposed research, and its scope and objectives
Chapter 2	The literature review discusses the existing literature on predominant algorithms, establishes research gaps, their extent, and research limitations

Chapter 3	The methodology section provides the framework for designing and evaluating a Renewable Energy based Off-Grid Electrical Energy Access System for the UNHCR facility in Dadaab.
Chapter 4	Summarizes the actual results

CHAPTER TWO: LITERATURE REVIEW

This chapter mainly introduces the facility on which the research focuses and the literature review which covers the various aspects of the PV systems including solar PV technology, inverter technology and batter energy storage technology. It goes further to look at the various solar PV system configurations together with the related studies and research gaps.

2.1 Introduction

Solar PV adoption has been on the ascent due to technological enhancement, a decrease in the cost of materials, and government support through incentives and drafted policies. The growing world population with a higher energy demand has raised the status of Solar PV systems in supplementing other energy sources including fossil fuels such as coal, gas, and oil in meeting the existing deficiency in energy supply [11].

The UNHCR Sub-Office in Dadaab is located in Dadaab town, Garissa County under the coordinates: 0° 2’ 52’’ N, 40° 18’ 38’’ E. The facility plays host to the UNHCR staff who give services to the refugees located in camps a few miles from the sub-office. The facility is diverse containing amenities including offices, accommodation houses, workshop, gymnasium, medical clinic, and food eatery sections. The facility’s satellite map with the compound demarcated in green is shown in Figure 2.1 below. The site’s weather and solar resource data are attached in Figure 6.1, Appendix A.

Figure 2.1: Facility Satellite Map. Adapted from [Google Earth]

2.2 Solar PV Technology

2.2.1 Background

Studies in Solar technology date back to the nineteenth century with the first development of a silicon PV cell recorded in 1954 at Bells lab. Solar PV utilizes the world's free solar resource to generate electricity through the photovoltaic effect discovered way back in 1839 by Edmond Becquerel [12]. It involves the direct conversion of the sun's radiation into electrical power by the use of cells built from semi-conducting material layers (N-type and P-type). An electric field is established around the layers when light falls on the cells triggering electricity to flow due to the interaction between the electrons (e) and holes (h). The generated power is directly proportional to the light intensity [11].

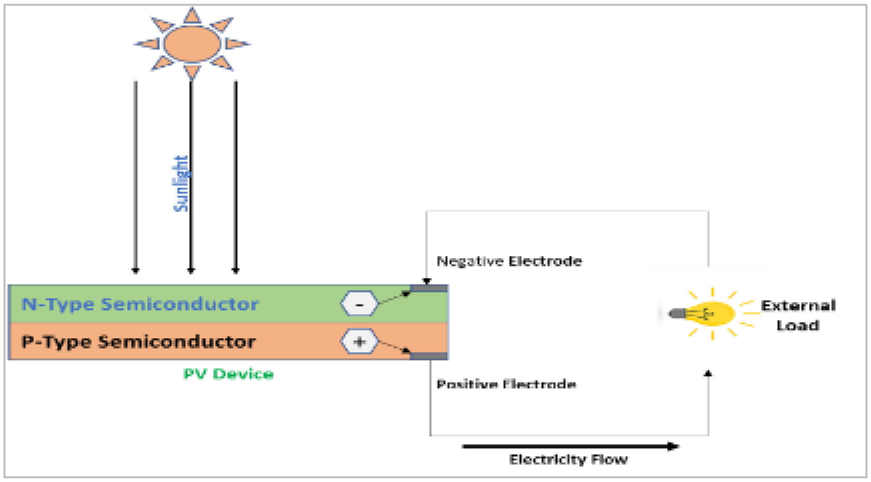


Figure 2.2: Photovoltaic Effect. Adapted from [13]

Researches indicate that the hourly energy absorbed by the earth's atmosphere from the sun is sufficient to serve the global energy demand annually. There is a need to tap and utilize this energy most efficiently and cost-effectively considering solar power is a green energy resource accessible in all parts of the world. PV technologies are small and modular with the ability to be integrated virtually anywhere. Unlike the conventional power plants utilizing nuclear, coal, oil, and gas, solar PV has no fuel costs and relatively low operation and maintenance (O&M) costs [14].

2.2.2 Solar Cells

The PV technological system involves the interconnection of components that convert energy from the sun into electricity, utilize the generated energy, store it or invert it since the PV device produces direct current (DC) only. The system is mainly comprised of solar cells and balance of system technologies (BoS). While the solar cells generate electricity from the solar irradiation, the BoS are essential for connection, chemical protection, mechanical mounting of the cells into the panel, and regulation of the output energy from the solar cells which is utilized, stored, or supplied to the power utility grid. The testing and monitoring equipment together with the portable devices utilizing the generated electricity also form part of BoS [15].

The solar cells or photovoltaic cells form the most integral part of the solar PV system acting as the main building blocks. The cells are electrical devices that directly transform the energy of photons into direct current (DC) electricity through the photovoltaic effect. Absorbed photons from the sun's irradiation excite the charge carriers in the cells causing an interaction between the holes and electrons and thus electric current and voltage. The conversion efficiency of the cells is a factor representing the amount of incident light power that is converted to electricity under standard test conditions (STC) [15]. The STC are offered by manufacturers and are compliant with the IEC 60904-1 norm. They are as follows; 1000 W/m^2 irradiance, 25 °C cell temperature, and air mass (AM) 1.5 spectral distribution at normal incidence [16].

Scientific research is continuous in solar cell technologies intending to further increase cell conversion efficiency. Solar cells are categorized into three groups which are dependent on the basic material used and the commercial maturity level that is; first, second and third generations.

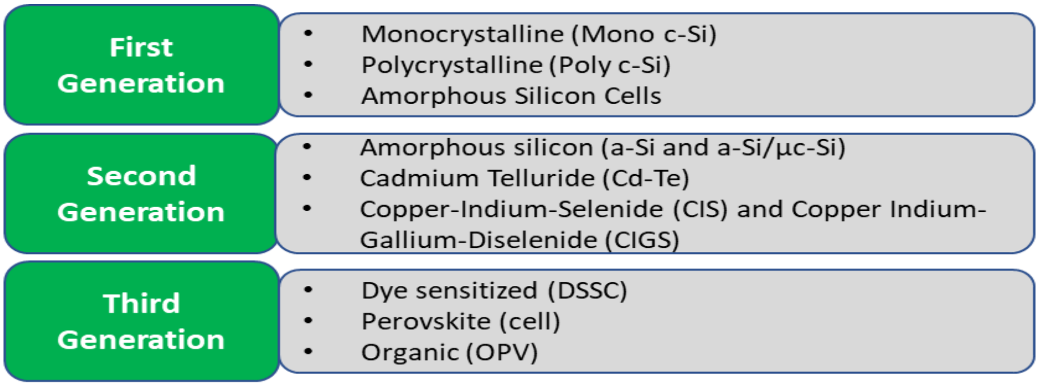


Figure 2.3: Categorization of PV Cells. Adapted from [14]

First-generation solar cell technology still ranks as the most prevalent and effective solar cell built from thin silicon wafers. Silicon solar cells are used extensively in the residential sector accounting for above 80% of all solar cells sold around the world. They are most efficient in terms of single-cell photovoltaic devices with the advantage of the availability of silicon being abundant. Monocrystalline silicon solar cells are the most efficient in comparison with other silicon solar cells having an efficiency of up to 26%. Polycrystalline and amorphous silicon are less pure and hence have low efficiency and come at a cheaper price [14].

Commercial production of c-Si modules kicked off in 1963 as Sharp Corporation of Japan began producing commercial PV modules and installed a 242-Watt (W) PV. The silicon solar cells comprise a Positive (P-Type) and negative layer (N-Type) which are made through doping silicon with boron and phosphorous respectively. Boron introduces more holes while phosphorous creates more electrons [14].

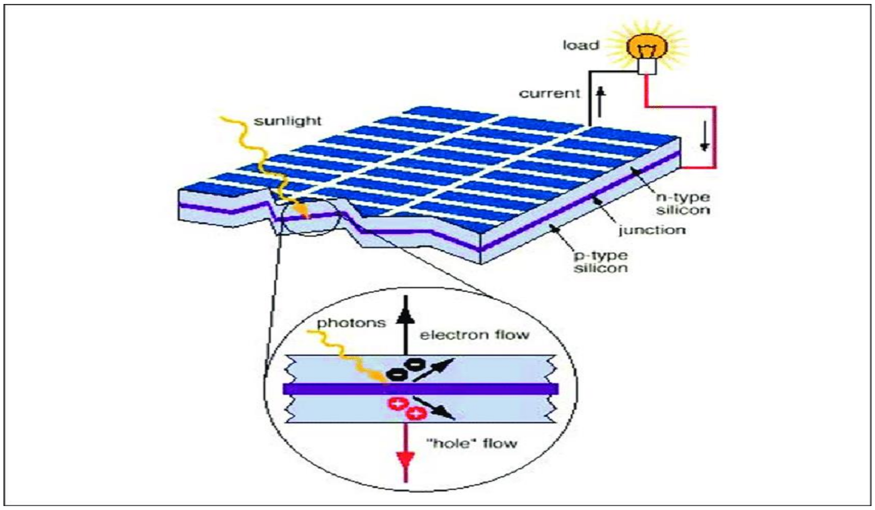


Figure 2.4: Representation of the key structure of a silicon solar cell. Adapted from [14]

2.2.3 P-V and V-I Characteristics of a Photovoltaic Cell

The photovoltaic effect mainly involves the generation of a potential difference at the p-n junction of a solar cell when exposed to visible or other radiations. The P-V and I-V curves of the solar module are essential since different techniques and algorithms are applied based on their analysis inclusive of Maximum Power Point Tracking (MPPT) [17]. Figure 2.5 shows the P-V and I-V characteristics curves where: I_{SC} is the short circuit current; I_{mp} is the current at maximum power point; V_{OC} is the open-circuit voltage and V_{mp} is the voltage at the maximum power point.

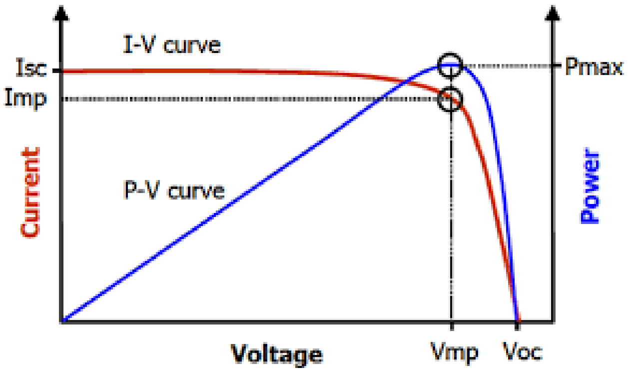


Figure 2.5: P-V and V-I Characteristics of a solar cell/module. Adapted from [17]

2.3 Battery Energy Storage Technology

The BES system consists of the batteries, control and power conditioning system (C-PCS), and the rest of the plant. The battery and C-PCS form an integral part of the BES system and have been fast-evolving in recent years [4]. The BES system is applicable both in the off-grid and grid-tied solar PV systems. Its main function is to store surplus power generated from the solar PV system for utilization at times when the solar energy output is low and at night when there is no sunlight. This ensures the supply of uninterruptible power regardless of when the solar PV power goes down. In grid-tied solar PV systems, it helps incorporate solar power into the grid. The system can deliver both active and reactive power with sub-second time response and hence can help in the mitigation of arising issues from solar generation such as ramp rate, frequency, and voltage fluctuations. It also helps to improve the overall power efficiency and system reliability [18]. Figure 2.6 shows the BES system including the power conditioning system.

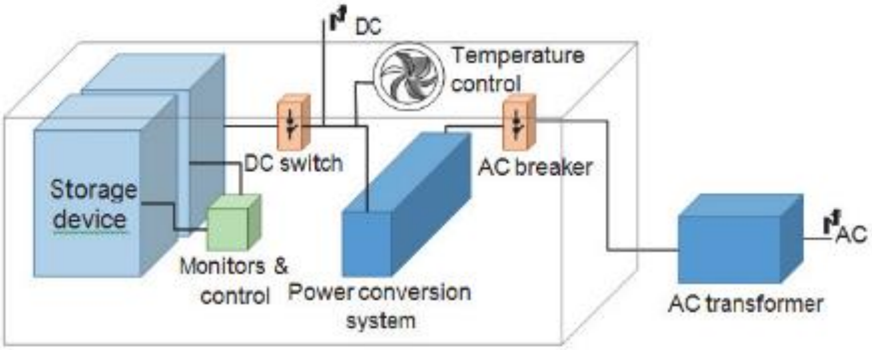


Figure 2.6: Battery Energy Storage System including C-PCS. Adapted from [19]

Batteries comprise stacked cells where there is the conversion of chemical energy into electrical energy producing a voltage across the terminals. Rechargeable batteries also convert electrical energy into chemical energy when discharging. The electrochemical system, therefore, has to work in dual directions that is it must be rechargeable to ensure the effective operation of the PV system. The electrical connection of the cells in series or parallel achieves the desired voltage or current. The rating of a battery is dependent on its energy and power capacities. Currently, different types of batteries have been developed with some commercially available and others still in the experimental phase [4].

The main functions of batteries in a PV system include Autonomy – supplying the load when there is no solar irradiance due to nightfall, overcast, or low solar output in the winter; Surge current capability – supply of high currents that the PV cannot supply to start machines like motors; Voltage control – curbs large voltage fluctuations which may cause damage to the load [20].

There exist several types of batteries that can be used in the PV system for power storage. The Lead-Acid type batteries are most common but Lithium-ion (Li-ion) batteries are gaining more popularity. Other types of rechargeable batteries include; nickel-cadmium (NiCad), nickel-metal hydride (NiMH), nickel-iron (NiFe), and lithium polymer. The solar PV systems use deep cycle batteries rather than the starting, lighting, and ignition (SLI) type. The SLI batteries give out a high amperage output within a short time with a repetition of deep discharges causing performance deterioration. The rating of such batteries is by cracking amps, or cold cracking amps (CCA). Deep cycle batteries on the other side are meant to discharge low currents for a long period with the ability to withstand several deep discharges without damage. The deep-cycle battery's amount of charge storage is referred to as its capacity [20]. The most important parameters considered in the selection of the type of battery to be used in a solar PV system include; battery capacity, depth of discharge, and state of charge (SOC).

2.4 Inverter Technology

Electrical loads comprise both DC and AC thus the importance of an inverter that converts the solar PV DC power into AC power for utilization by AC equipment in the residential, commercial, and industrial sectors. The classification of inverters is mainly based on the type of waveform produced. The three main types include; square wave, pure sine wave, and modified sine wave inverters.

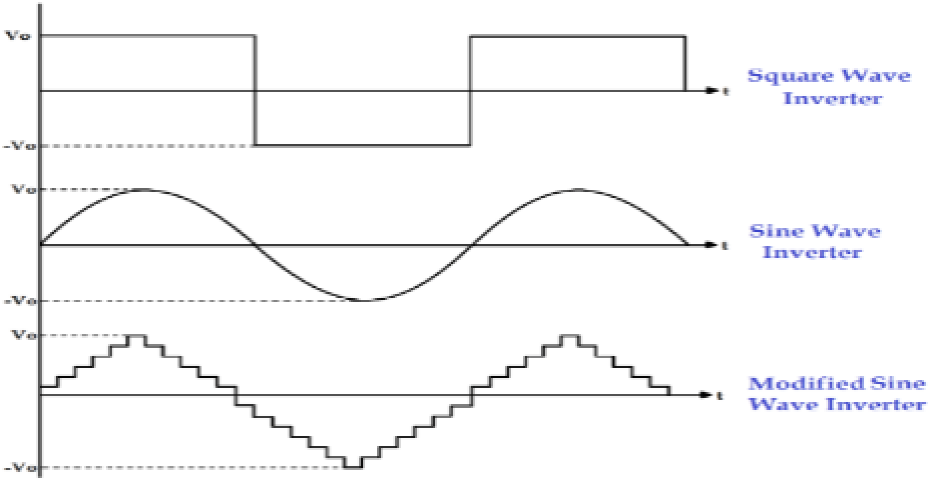


Figure 2.7: Inverter Types. Adapted from [21]

The recent inverters have an inbuilt solar charge controller enabling them to be classified into MPPT or pulse width modulation (PWM) techniques. The MPPT technology ensures that maximum power is extracted from the solar panels by making them operate close to the maximum power point. MPPT inverters are the latest technology with a high conversion rate of up to 97% efficiency. The PWM technology is best suited for small-size inverters with a maximum output efficiency of about 70%. They are a good low-cost solution for all home solar systems and work more efficiently when the solar panel is shaded.

2.5 Solar PV System Types

Solar PV systems are mainly classified into two main categories that are; Grid-connected and Stand-alone PV systems as indicated in Figure 2.8.

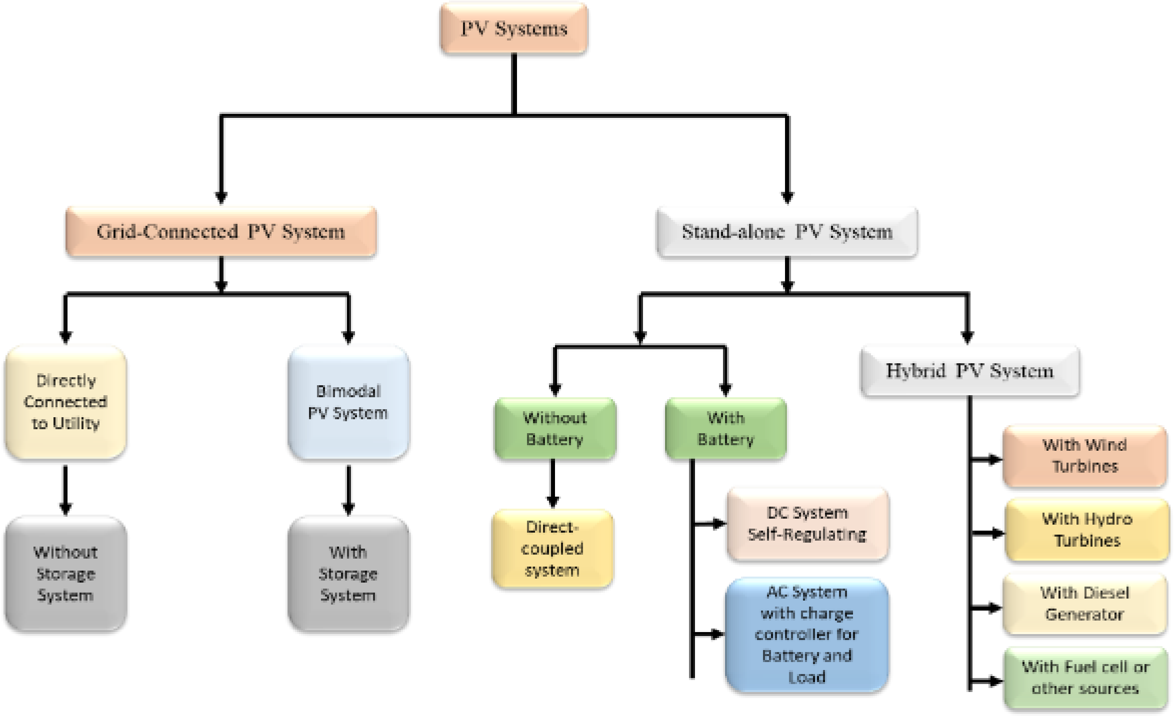


Figure 2.8: Solar PV system types and components. Adapted from [22]

2.5.1 Stand-Alone PV Systems

These encompass Solar PV systems that work independently of the grid (off-grid). Such systems mainly consist of PV generators, ESS, AC and DC loads, and power conditioning elements [23]. The ESS mainly comprises the batteries for storage of excess energy when the PV production exceeds the load requirement and releases it back as the PV production becomes inadequate to serve the load. The power conditioning elements act as an interface between all the components of the PV system giving protection and control with the frequent elements being blocking diodes, charge regulators, and DC-AC converters [23]. 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 PV System” [22]. 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. Figure 2.9 shows the components of a stand-alone PV system.

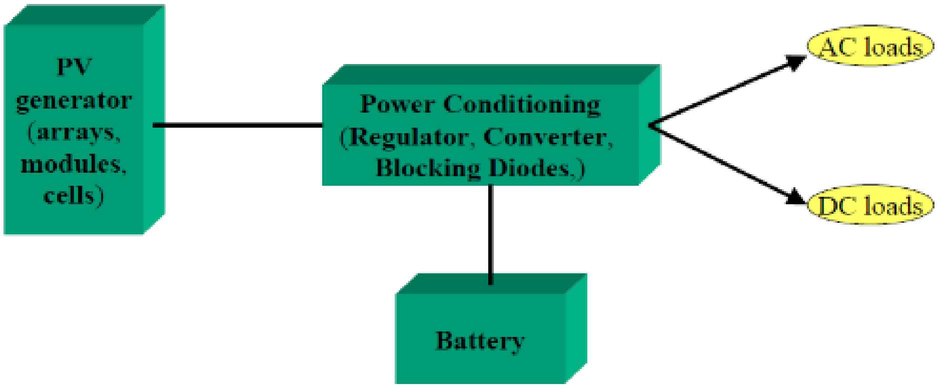


Figure 2.9: Stand-Alone PV system components. Adapted from [23]

2.5.2 Grid-Connected PV Systems

It's the most common type in applications where consumers want to save energy on their utility bills with the utility being utilized at times when there is no production from the PV system [22]. A directly coupled PV array to the utility without storage is known as a "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 [22].

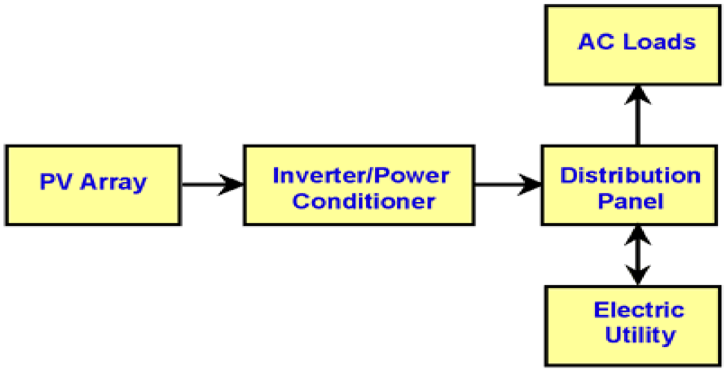


Figure 2.10:Grid Connected PV System Schematic. Adapted from [24]

2.5.3 PV System Configurations

The state-of-the-art technology determines the PV configuration which can be classified as: module, string, multi-string, and central as depicted in Figure 2.11 [25].

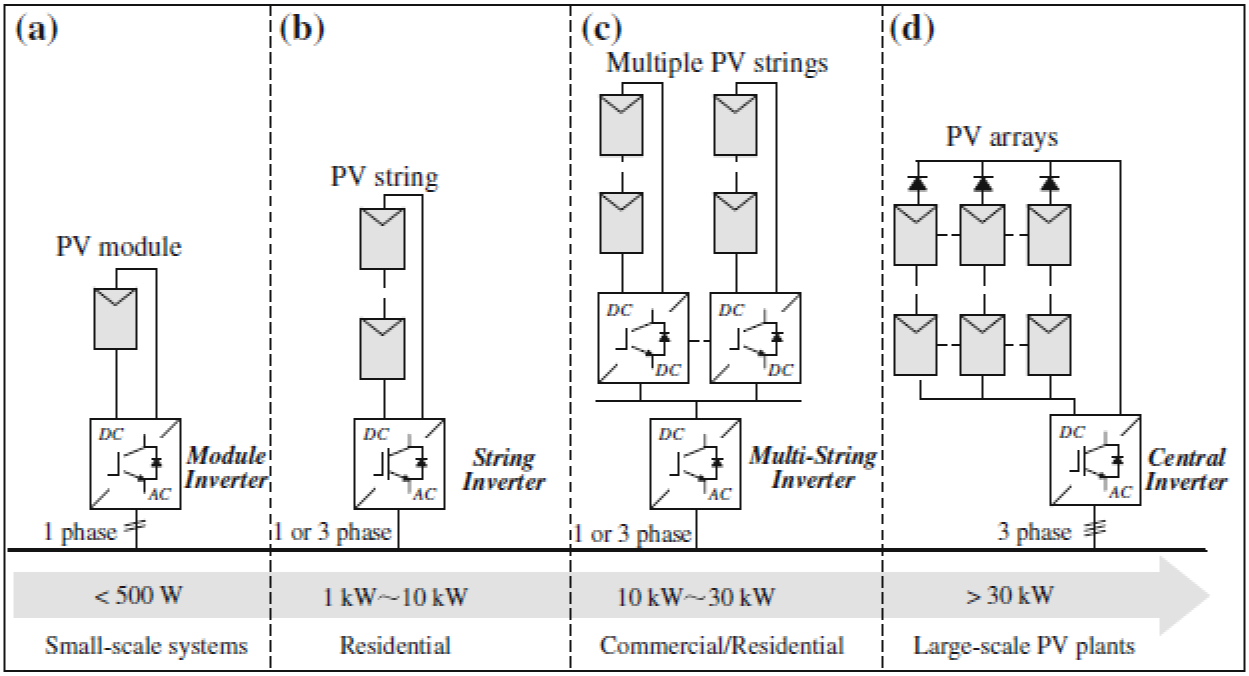


Figure 2.11: Organization of PV Techniques: ***a*** *module inverter,* ***b*** *string inverter,* ***c*** *multi-string inverter,* ***d*** *central inverter* (Adopted from [25])

Centralized Design: Huge quantity of PV modules are interfaced with a single three-phase inverter as in Figure 2.11d hence referred to as a central inverter. Series connection of the PV connection to form strings is done to achieve high voltage. The strings are then paralleled to form strings hence achieving a high-power level. This configuration is more applicable in large-scale PV plants due to its cost-effectiveness. There is however an advanced mismatch loss between the PV modules due to the application of a common MPPT for the whole PV arrays. This power generation loss becomes apparent when there are inverter outages. The difficulty is also experienced in the expansion of the power plant at a centralized level [25].

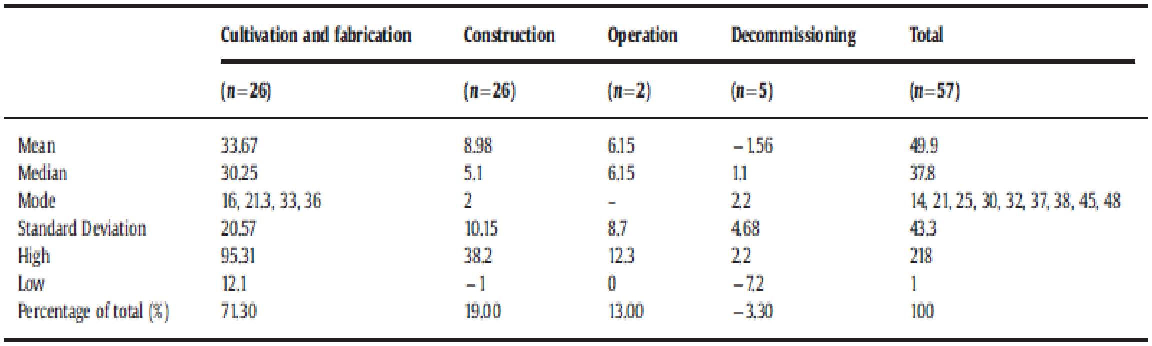
Module Design: Also known as a micro-inverter and is devoted to a single PV module as in Figure 2.11a which is in contrast with the centralized configuration. The one PV module one inverter concept ensures that the mismatch loss between the PV modules is eradicated thus greater energy yields. The incorporation of a DC-DC converter is essential to boost the low voltage of the PV module to meet the grid requirement. The system is modular allowing ease in expansion and installation [25].

String Design: In this design, each inverter is linked to only one PV string thus avoiding the use of blocking diodes as can be seen in Figure 2.11b. Higher energy yield is realized through MPPT operation at string level hence the mismatch loss between the PV modules is reduced likened to the centralized configuration. With one string per inverter, the string inverter is designed for low-power applications mostly in the residential rooftop category [25].

Multi-string Design: Composed of combination between central and string configuration as in Figure 2.11c. Multiple PV strings with a dedicated DC-DC converter (MPPT) are connected to a common inverter. The simple structure and economical dynamics of the centralized configuration are retained but with minimal loss amongst the PV modules with individual MPPT per PV string [25].

2.5.4 PV System GHG Emissions

Statistically, analysis carried out on over 23 relevant and complete solar PV studies has indicated the presence of greenhouse gas emissions over the lifecycle of a solar PV system. These emissions range at an extremely minimum end of 1 g CO_2-eq/kWh and a maximum end of 218 g CO_2-eq/kWh. The average emission accounting for each component of a solar PV's lifecycle was reported as 49.9 g CO_2-eq/kWh [26].



	Cultivation and fabrication	Construction	Operation	Decommissioning	Total
	(n=26)	(n=26)	(n=2)	(n=5)	(n=57)
Mean	33.67	8.98	6.15	−1.56	49.9
Median	30.25	5.1	6.15	1.1	37.8
Mode	16, 21.3, 33, 36	2	-	2.2	14, 21, 25, 30, 32, 37, 38, 45, 48
Standard Deviation	20.57	10.15	8.7	4.68	43.3
High	95.31	38.2	12.3	2.2	218
Low	12.1	−1	0	−7.2	1
Percentage of total (%)	71.30	19.00	13.00	−3.30	100

Figure 2.12: Solar PV summarized statistics on projected greenhouse gas emissions. Adopted from [26]

2.6 Design Software Packages

Several software programs have been developed to enhance the design and simulation of solar systems including HOMER Pro, RETScreen, Helioscope, Ecotect, Solar pro, PVsyst, SolarGis PV planner, and Sombrero were specifically designed for urban applications of solar systems [27].

HOMER Pro: HOMER which stands for Hybrid Optimization for Multiple Energy Resources was initially developed by National Renewable Energy Laboratory USA and later on distributed by Homer Energy as a simulation and optimization software. It performs three key functions including simulation, optimization, and sensitivity analysis of several energy resources. It encompasses a project wizard with the ability to calculate both capital expenditure (CAPEX) and operation expenditure (OPEX). Locational search by name of the specific site has been enabled within the software. Some of the limitations of HOMER include; its sophistication and time-consumption, incapacity to guest missing sizes or values, and requirement of thorough input data [28].

RETScreen: Excel-based software for analyzing clean energy projects developed by National Resources Canada. Gives technical and financial potential to renewable energy, co-generation, and energy efficiency projects. The software has preloaded historical weather data from the NASA database covering major cities around the world. However, it has no scope for the addition of other data sources or customized data. Additional limitations include; the inability to print, save and export files when using the view mode version, problem with sharing data, lack of option to import time series data files, and more advanced calculations are not supported [28].

PVSYST: The software was developed at the University of Geneva as a tool to study, simulate and design PV systems. Its key features include estimation of production at the project planning stage, sizing, comprehensive study, hourly estimation, and generation of the simulation report. Its inputs include but are not limited to plane orientation, PV array (modules in series and parallel), battery pack, inverter model, and system components. Some its limitations are that the software cannot be maximized and hence there is difficulty in seeing all the parameters, inability to give detailed shadow analysis, and lack of a single line diagram [28].

Helioscope: Was introduced by Folsom Lab USA for designing the photovoltaic system. The software encompasses PVSyst features with the design functionality of AutoCAD hence the ability to do the full design with one package. Its limitations are that it does not support financial and feasibility analysis. Moreover, there is no support for advanced feasibility analysis. Additionally, there is a need for internet connectivity for the software to run the simulations.

SolarGis pvPlanner: It is a map-supported online simulation tool for the optimization and planning of solar PV systems. It has high-performance algorithms and climatic and geographical data at a good temporal and spatial resolution. Its limitations are that it is not suited for financial analysis and has

HOMER Pro software was chosen for this study due to its robust features in design, simulation, optimization, and sensitivity analysis. The software has the capability of simulating multiple energy resources ranging from wind, solar, diesel generators, biomass, and grid among others making it relevant for this research. Additionally, the software is easily available and low cost compared to other similar software that comes at a high cost.

2.7 Related Studies

Several types of research have been done on the use of renewable energy-based off-grid systems across the world. In most of the research, the aspect of using green energy sources in the generation of electricity has proved to be successful in terms of reducing the unit cost of electricity and decreasing GHG emissions associated with energy generation.

2.7.1: Solar PV Systems to eliminate or decrease the usage of diesel generators at no added cost: A case study of Lagos, Nigeria

According to this research, the utilization of home solar PV systems as a replacement of the diesel generators can achieve cost savings of 60-65% across the project life. It goes further to determine that the solar PV system will produce cleaner electricity and increase access to more reliable power[29].

2.7.2: Optimum Sizing and Performing Evaluation of a Hybrid Renewable Energy System for an Off-Grid Power System in Northern Canada

In this exploration, the HOMER software was applied in the design and optimization of a Hybrid Renewable Energy System (HRES) as a substitute for the primarily diesel-based generation resources. The analyzed topologies included; Storage-Diesel, Solar-Diesel, and Solar-Diesel-Storage based on different scenarios to come up with an optimal retrofit for the primary diesel-centered generation resource. The PV-Diesel-Storage configuration came on top with a 21% renewable penetration, fuel savings of up to 22%, and a 0-5% reduction in the Levelized cost of electricity (LCOE) [30].

2.8 Inferences Drawn

Renewable energy-based electrical energy access systems are gaining popularity across the world due to their pros such as low unit electricity cost, zero GHG emissions, and reliability. The generation of electrical energy from fossil fuels is expensive and has a long-term negative effect on the climate due to the production of GHG emissions which include gases for example Nitrogen oxide (NO_X), Carbon dioxide (CO2), and Sulphur Oxides (SO_X). Excessively quantity of these gases in the atmosphere may lead to global warming and thus influence the climate. It is therefore important to find and design renewable energy solutions for electrical generation in areas depending solely on the use of fossil fuel fuels in a generation. This research will help bring out the cost and environmental benefits of venturing into green energy.

CHAPTER 3: METHODOLOGY

This chapter gives an introduction to the sources of energy at the facility, the proposed research method, and tool, the design approach of the various system components, the economic analysis parameters employed including the HOMER software inputs, the research conceptual framework, and the assumptions in the design process.

3.1 Facility Sources of Energy

The main source of energy utilized at the UNHCR Dadaab Sub-Office is diesel oil. Diesel fuel is used to run the facility's two identical generators rated 550kVA each. The generator's three-phase electrical power is supplied to various sections within the facility via underground electrical cables to the low voltage (LV) room from where electrical loads are fed. The generators operate on a 12-hour basis, one during the day and the other at night. The installed generators at the facility are as shown in Figure 3.1.

2 x 550kVA Generators

Figure 3.1: Facility Installed Generators

The technical specifications of the installed generators are as depicted in Appendix A-1 Table 6.1. The generation of electrical power from diesel oil is not only expensive but also hazardous to the environment due to GHG emissions. The main electrical loads at the facility include lighting systems, plug loads, and air conditioning systems. The demand for conditioned air is high considering the area is characterized by high temperatures averaging 34 °C annually [31]. The operation of the air conditioning equipment is therefore almost on a 24-hour basis with cooling needed during the day and night.

3.2 Proposed Method

The research focused on descriptive and historical research approaches of study on real-time measurement and historical data supplied by the UNHCR Sub-Office Dadaab facility. The study focused on the analysis of energy production, utilization, and management at the facility with an eventual Solar PV system design that would sufficiently serve the load demand to cut down on the energy costs and GHG emissions.

3.2.1 Research Methods and Tools

3.2.1.1 Documents and Records

The researcher obtained data from the facility containing the monthly diesel consumption from the past two years (2020 and 2021). From the generator fuel consumption, the following parameters were determined; monthly average diesel consumed (L), monthly average cost of diesel, primary and electrical diesel energy, the facility's consolidated cost of electricity (CEC), and the monthly average CO2 emissions. An inventory of all the electrical loads including lighting systems, plug loads, and air conditioning systems at the facility was also taken into account.

The diesel fuel consumption was converted to its equivalent primary and electrical energy factoring in the fuel density, higher heating value (HHV), and the generator's efficiency.

3.2.1.2 Measurements

Power measurement was a key element of the data collection process to find out the facility's energy consumption. The main logging was done on the main incomer for 14 days.

3.2.1.3 Observation

The observation was applied by the research in terms of finding out the technical properties of electrical equipment and behavioral practices among the staff in terms of energy management within the facility to help establish possible energy efficiency measures.

3.2.1.4 Data Collection and Analyzing Tools

The following tools were used in the collection and analysis of data;

PEL 103 Energy Logger: This instrument was connected to the facility's electricity main incomer line to measure the real-time energy consumption over 14 days. The equipment records various power parameters including the demand power, voltages, currents, total harmonic distortions (THD), power factor, and total energy consumption over the logging period. Figure 3.2 shows the PEL 103 Energy Logger as was installed at the facility. High precision instruments were applied in a recording of measurements with yearly calibration done on equipment. The equipment specifications and accuracy are as indicated in Table 6.4 Appendix B.

Typical PEL 103 Energy Logger

Installed PEL 103 at UNHCR Sub-Office

Figure 3.2: Installed PEL Energy Logger at the facility

Clamp Meter: This was used to measure the line currents in the main power distribution cables.

PEL Software: The PEL software was utilized in the extraction of logged data from the PEL Energy Logger equipment.

Data View Software: The Data View Software was deployed in the extraction of pdf reports and exportation of the PEL 103 Energy Logger to the excel spreadsheet for analysis.

Excel Spreadsheet: The excel spreadsheet was deployed in the analysis of the facility's fuel consumption and costs over the baseline period (2020 and 2021). From this, the facility's unit cost of electricity (USD/kWh) and the subsequent average CO_2 emissions were calculated and analyzed.

HOMER Pro: The Hybrid Optimization of Multiple Energy Resources (HOMER) software was employed in the design of the hybrid solar PV system to be employed at the facility. The software has three main functions which include; simulation, optimization, and sensitivity analysis.

3.3 Design Approach

3.3.1 Solar Photovoltaic Array

The photovoltaic power is given by Eq.(3.1); [32]

$$P_{pv} = P_{STC} DF \left(\frac{IR}{IR_{STC}}\right)\left[1 + \hat{a}p\left(T_{mod} - T_{mod,STC}\right)\right] \qquad (3.1)$$

where,

P_{STC}	solar photovoltaic power under STC (IR_{STC}=1000W/m^2, $T_{mod,\ \mathrm{STC}}$= $25°C$, and no wind)
T_{mod}:	the temperature of the solar PV module
IR_{STC}:	irradiance under STC
$T_{mod,\ \mathrm{STC}}$:	solar PV module temperature under STC
$\hat{a}p$:	power temperature coefficient
IR:	solar irradiance
DF:	the factor that accounts for the solar PV power reduction due to dust buildup, shading, aging, and wiring losses

The module's power is as in Eq.(3.2);

$$P_{STC} = (N_{series} x\ N_{strings\ parallel}) P_{m,STC} \qquad (3.2)$$

where the rated PV module power output is $P_{m,STC}$, N_{series} is the module number in series per string, and $N_{strings\ parallel}$ is the number of the parallel string.

The conversion of the sun's radiation to electrical energy could also be referred to as efficiency if given by Eq.(3.3).

$$\eta_{m,STC} = \frac{P_{m.STC}}{A_{PV} IR_{STC}} \qquad (3.3)$$

where A_{PV}, is the solar PV panel area (m^2).

3.3.2 Battery Storage

Regulation of the solar PV system power output and AC load appliances was achieved through the charge and discharge of power into or out of the battery storage. The state of charge (SOC) of the battery at a specific time is expressed as in Eq.(3.4);

$$SOC(t) = SOC(0) + \eta_c \sum_{k=0}^{t} P_{CB}(k) + \eta_d \sum_{k=0}^{t} P_{DB}(k)s \qquad (3.4)$$

where $SOC(0)$ is the initial battery's state of charge at *t=0*, P_{CB} is the electrical power charged in the battery, P_{DB} is the discharged electrical power from the battery and η_c and η_d are the charging and discharging efficiencies respectively. The available battery capacity constraints (see Eq.(3.5)) are given by;

$$\begin{cases} B_{min} \leq SOC \leq B_{max} \\ B_{min} = (1 - DOD)B_{max} \end{cases} \qquad (3.5)$$

Where,

B_{min} and B_{max}: Minimum and Maximum battery capacities

DOD: Depth of Discharge

The battery's discharge power has the following constraint (see Eq.(3.6))

$$0 \leq P_{DB}(k) \leq P_{max} \qquad (3.6)$$

where P_{max} represents the maximum hourly discharging power.

3.3.3 Converter

It acts as an inverter (DC/AC) to convert the DC solar power output and battery storage discharge to the AC load. It is normally connected in-between the DC and AC busbars of the system with its efficiency (η_{Inv}) taken as a constant. The inverter's output power is given by (see Eq.(3.7))

$$P_{InvOut} = P_{InvIn}\eta_{Inv} \qquad (3.7)$$

For an off-grid solar PV system (Eq.(3.8));

$$P_{InvIn} = P_{PV} + P_{DB} \qquad (3.8)$$

For the grid-tied solar PV system (Eq.(3.9));

$$P_{InvIn} = P_{PV} \tag{3.9}$$

3.3.4 Electric Load

The electrical load at the facility is mainly composed of the lighting systems, plug loads, and the air conditioning systems The AC power demand of the appliances [see Eqs. (3.10) and (3.11)] is supplied by the solar and battery storage for the off-grid solar system and the solar PV and grid for the grid-tied solar PV;

Grid-tied solar PV system;

$$P_L(k) = P_{PV}(k) + P_{DB}(k) \tag{3.10}$$

Stand-alone solar PV system;

$$P_L(k) = P_{PV}(k) + P_{GRID}(k) \tag{3.11}$$

3.3.4 GHG Emissions

The research focused on CO_2 emissions due to the combustion of diesel in the generator. The equivalent amount of CO_2 in a litre of diesel was taken as 2.6 kgs. Approved research has indicated that 2.4 – 2.8 kgs of CO_2 are emitted per litre of diesel fuel consumed in a generator hence an average value of 2.6 kgs CO_2/litre of diesel used is within that range.

Solar PV GHG emissions are mainly a result of their life cycle mainly entailing the energy utilized in manufacturing the modules and the BoS and was taken as 49.9 g CO_2-eq/kWh as indicated in over 20 relevant, approved, and peer-reviewed studies.

3.3.5 Diesel Conversion

The diesel density and higher heating value (HHV) that is, Gross Calorific Value (GCV) were used to calculate the equivalent primary and electrical energy in kilowatt-hours (kWh). The efficiency of the diesel generator was also put into consideration. The properties of the diesel fuel are as depicted in Figure 6.2, Appendix A-4.

3.3.5 Simulation and Optimization

The Hybrid Optimization of Multiple Energy Resources (HOMER) software was adopted in the design, simulation, optimization, and performance analysis of the solar PV off-grid system to be set up at the facility. For optimization, the software samples accurately for the optimal combination of various parameters including costing, reliability, solar PV, storage, and inverter sizes ensuring no oversizing nor downsizing of the system [32]. The software provides a search space taking into consideration the different sizes of power system components for sensitivity analysis.

The dispatch strategies applied in the software included cycle charging (CC) and load following (LF).

3.4 Economic Analysis

The following financial metrics are applied in the modeling of the system and financial analysis of the energy efficiency measures that could be implemented at the UNHCR Sub-office Dadaab to save on energy.

3.4.1 Simple Payback Period (SPB)

This is the period that a project takes for the initial investment cost to be accrued as a result of cost savings. It is where a breakeven point is reached and is calculated as in Eq.(3.12). A project with the shortest SPB is more attractive while that with a longer SPB is undesirable.

$$SPB = \frac{Initial\ Investment\ Cost}{Annual\ Cost\ Savings} \tag{3.12}$$

3.4.2 Net Present Value (NPV)

It represents the future value cash flows including the cash inflows and outflows over some time as applied in capital investment and budgeting to evaluate the viability of a projected investment or project. A negative NPV simplifies a project that is not viable and not worth investing in while a positive NPV implies that the investment is beneficial and worth investing in. The NPV is calculated as shown in Eq.(3.13)

$$NPV = -I_o + \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} \tag{3.13}$$

where, I_o is the initial investment cost, t is the time of cash flow, r is the discount rate annually and CF_t is the net cash flow at time t.

3.4.3 Internal Rate of Return (IRR)

This represents the discount rate (r) that causes the net present value (NPV) of all cash flows to be equal to zero in a discounted cash flow analysis. It helps determine if a potential project adds value and its suitability to be undertaken. A greater IRR value than the used discount rate depicts a project that adds value to the business.

3.4.4 Return on Investment (ROI)

This is a financial metric for determining the likelihood of accruing a gain from an investment. It is a ratio that compares and contrasts gain or loss from an investment relative to its cost [33] A positive ROI implies that the returns are gained since the total returns exceed the total costs while a negative ROI implies returns are not gained since the total costs exceed total returns. The ROI can be calculated as in Eq.(3.14) or Eq. (3.15).

$$ROI = \frac{Net\ Return\ on\ Investment}{Cost\ of\ Investment} \times 100\% \qquad (3.14)$$

$$ROI = \frac{FVI - IVI}{Cost\ of\ Investment} \times 100\% \qquad (3.15)$$

where FVI is the *Final Value of Investment* and IVI is the *Initial Value of Investment.*

3.4.5 Discounted Payback Period

This is an adjusted payback period taking into account the time worth of money that is; the "*financial concept with the perspective that money in the present is worth greater compare to the same sum of money to be received in the future"*[34]. It shows the amount of time a project would take to break even hence evaluation of its profitability and feasibility. The discounted payback period is given in Eq.(3.16).

$$Discounted\ Payback\ Period = A + \frac{B}{C} \qquad (3.16)$$

where A is the latter period with a negative discounted cumulative cash flow, B is the absolute value of discounted cumulative cash flow at the end of the period A and C is the discounted cash flow in the period after A.

3.4.6 Levelized Cost of Electricity (LCOE)

The LCOE takes into account the lifetime net costs divided by produced energy and is expressed in cost per unit of electricity produced. The calculation involves the current value of the overall cost of building and operating an electricity production plant across its estimated lifetime [35]. LCOE is given by Eq. (3.17).

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \tag{3.17}$$

Where,

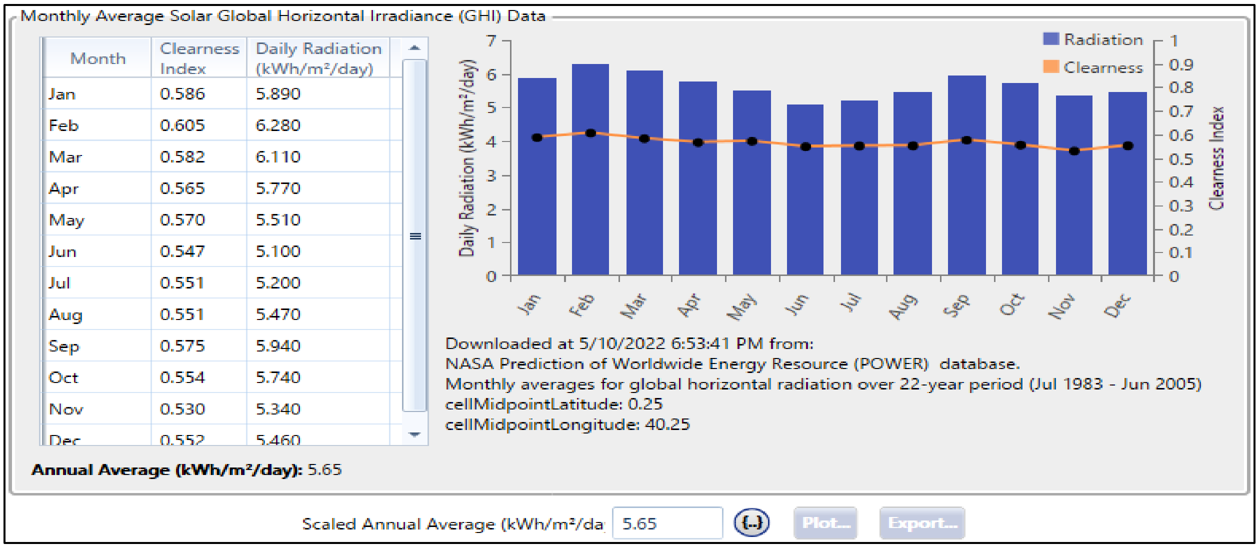
I_t: investment expenses in year t
M_t: operations and maintenance expenses in year t
E_t: electricity production in year t
F_t: fuel expenses in year t
r: discount rate
n: system lifetime

3.5 HOMER Inputs

The HOMER software inputs mainly include the solar irradiation data, the measured load profile, and the economics and specifications of the various system components solar PV modules, the generator, grid-tied inverters, converters, and the battery bank including the projected lifetimes.

3.5.1 Solar Insolation

The solar insolation of the area was obtained from the HOMER software’s irradiance resources which include NASA Prediction of Worldwide Energy Resource and the National Renewable Energy Laboratory. The average daily radiation was taken as 5.65 kWh/m^2/day as depicted in Figure 3.3.



Monthly Average Solar Global Horizontal Irradiance (GHI) Data

Month	Clearness Index	Daily Radiation (kWh/m²/day)
Jan	0.586	5.890
Feb	0.605	6.280
Mar	0.582	6.110
Apr	0.565	5.770
May	0.570	5.510
Jun	0.547	5.100
Jul	0.551	5.200
Aug	0.551	5.470
Sep	0.575	5.940
Oct	0.554	5.740
Nov	0.530	5.340
Dec	0.552	5.460

Downloaded at 5/10/2022 6:53:41 PM from:
NASA Prediction of Worldwide Energy Resource (POWER) database.
Monthly averages for global horizontal radiation over 22-year period (Jul 1983 - Jun 2005)
cellMidpointLatitude: 0.25
cellMidpointLongitude: 40.25

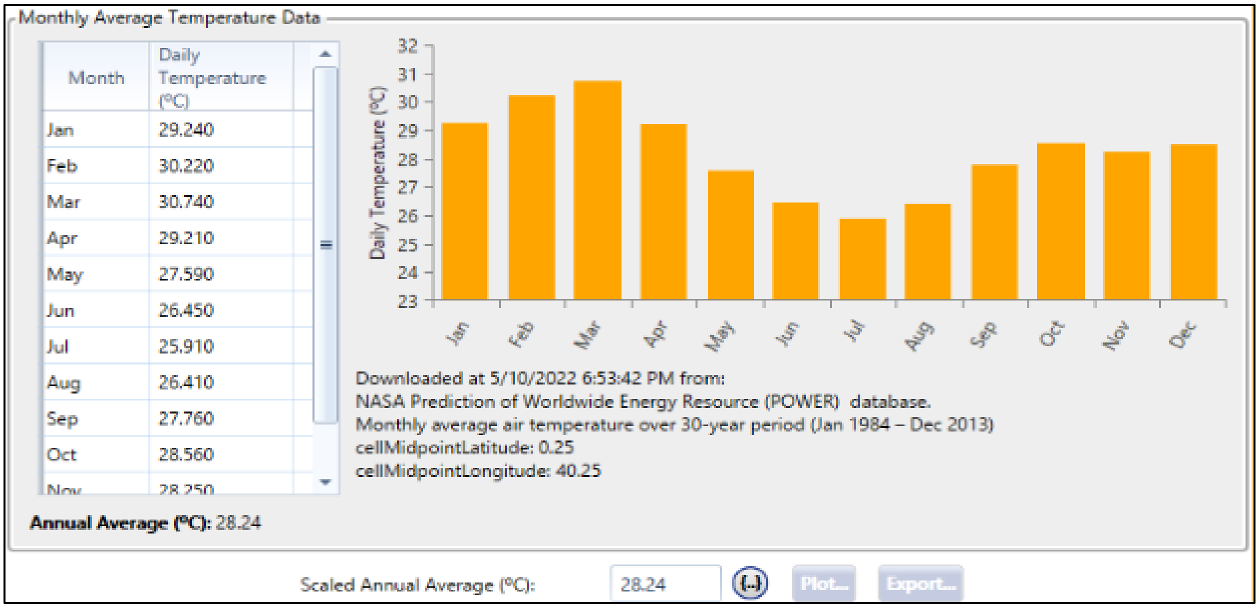
Annual Average (kWh/m²/day): 5.65

Scaled Annual Average (kWh/m²/da 5.65

Figure 3.3: Monthly average Solar Global Horizontal Irradiance (GHI) – HOMER

3.5.2 Ambient Temperature

The temperature has a direct effect on the energy produced by a solar panel thus the importance of factoring in the area's ambient temperature in the design. The temperature fluctuates across the months with an annual average of 28.24°C as shown in Figure 3.4.



Monthly Average Temperature Data

Month	Daily Temperature (°C)
Jan	29.240
Feb	30.220
Mar	30.740
Apr	29.210
May	27.590
Jun	26.450
Jul	25.910
Aug	26.410
Sep	27.760
Oct	28.560
Nov	28.250

Downloaded at 5/10/2022 6:53:42 PM from:
NASA Prediction of Worldwide Energy Resource (POWER) database.
Monthly average air temperature over 30-year period (Jan 1984 – Dec 2013)
cellMidpointLatitude: 0.25
cellMidpointLongitude: 40.25

Annual Average (°C): 28.24

Scaled Annual Average (°C): 28.24

Figure 3.4: Monthly Average Temperature – HOMER

3.5.3 Economic Inputs

The economic inputs for the various components were sourced from various manufacturers and suppliers are reflect the current market prices inclusive of the balance of system (BoS), labour and transportation costs. The design economic inputs were as in Table 3.1.

Table 3.1: Economic Inputs

Parameter	Unit	Input
Solar PV Modules	USD/kWp	646
PV Dedicated Inverter	USD/kWp	232
Converter	USD/kW	255
Battery Storage	USD/kWh	610
Nominal Discount Rate	%	12
Expected Inflation Rate	%	5

3.6 Conceptual Framework

This research aims to solve the issue of GHG emissions due to the production of electricity from fossil fuels using diesel generators. The generation of electricity from diesel fuel is also expensive due to the high costs of fuels. All this coupled with the uncertainty in the availability of fossil fuels in the coming years makes a valid case to move towards green renewable energy sources to meet the daily energy demand. The approach involved analysis of the historical energy consumption of the facility together with the fuel and operation costs. Identification of possible energy conservation measures was also given priority to promoting energy efficiency at the facility. The final step was to design an optimized solar PV system capable of supplying enough energy to meet all the electrical load demands. The economics involved in such a project was also captured. The conceptual framework is shown in Figure 3.5.

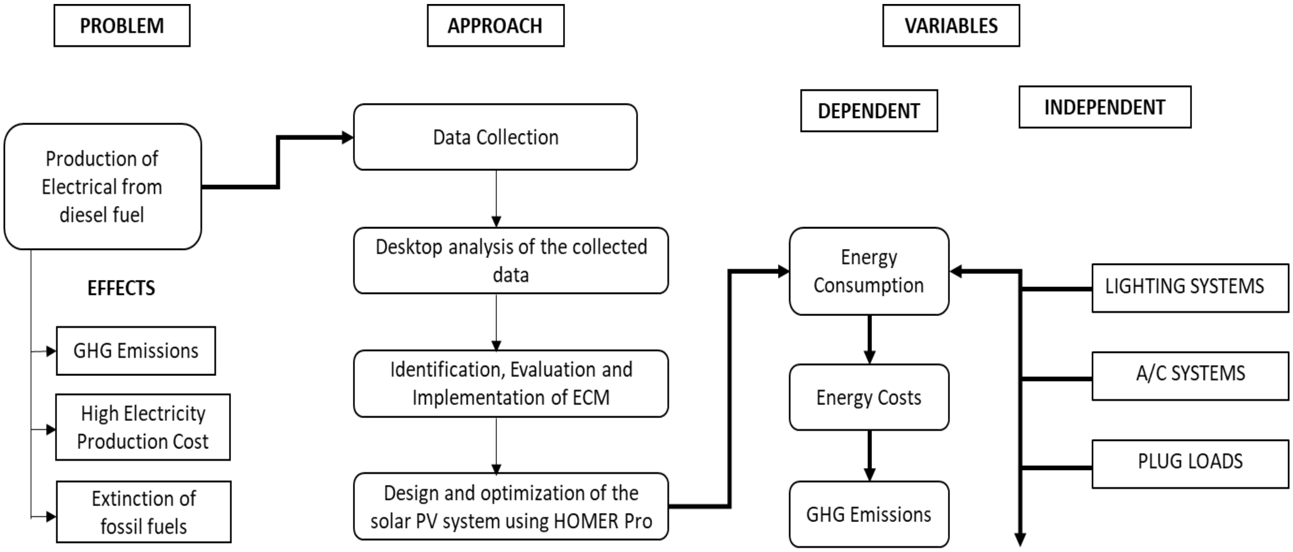


Figure 3.5: Research Conceptual Framework

3.7 Assumptions

The following assumptions were made during the study;

i. The unit cost of electricity generation over the baseline period was USD 0.362. This cost was applied in the tabulation of the cost savings that will be accrued when the energy conservation measures (ECMs) are implemented.
ii. The diesel fuel has a gross calorific value of 45.6 MJ/Kg (12.67 kWh/kg) and a density of 846 kg/m3
iii. The efficiency of a diesel combustion engine was taken to be 25% for a diesel generator.
iv. The carbon emission factor was taken as 2.5 $kgCO_2$ per litre of diesel consumed.
v. 1 USD = 116.65 Kenyan Shillings

3.8 Summary

The research initial phase was the data collection exercise where all electrical loads at the facility were taken into account and the respective cumulative electrical energy demand was calculated. Further real-time energy demand measurement was done on the main incomer electrical line for 14 days to determine the actual load. The diesel consumption at the facility by the installed generators was also analyzed together with costs for a baseline of 24 months (2020 and 2021) and the average monthly consumption, cost, and unit cost of electricity were determined. The data collected from the logging of the mains was then used as HOMER Pro software input to simulate and optimize the solar PV system.

CHAPTER FOUR: RESULTS AND ANALYSIS

4.1 Electrical Loads

A detailed inventory of the electrical loads at the facility shows that the main loads include; lighting systems, plug loads, and air conditioning (A/C) systems. The installed electrical loads contribute to approximately 914.35kW load demand. The plug loads and A/C systems form the largest of the installed electrical loads at the facility.

LOAD	kW
Plug Loads	456.38
Lighting Systems	37.38
A/C Systems	420.584
TOTAL	**914.35**

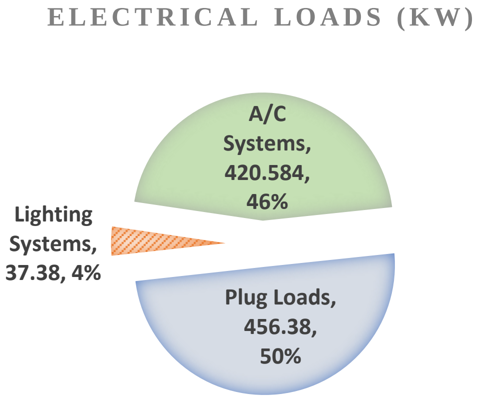


Figure 4.1: Installed Electrical Loads

4.2 Historical Energy Data

The historical energy data was derived from the diesel consumption at the facility over the baseline period (January 2020 – December 2021) in litres. The diesel costs over the baseline period were also obtained.

4.2.1 Diesel Consumption

The facility's summarized historical energy data as calculated from the fuel consumption data is depicted in Table 4.1. The facility's average monthly diesel consumption is 42,427.21 L at an average monthly cost of USD 41,154.39. The daily energy consumption at the facility is equivalent to 3,737.37 kWh/Day as calculated from the diesel fuel data. The facility's unit cost of electricity was USD 0.362 per kWh. Detailed diesel consumption data is attached in Appendix A.

Table 4.1: Facility Baseline Energy Consumption

Baseline Energy Consumption (Monthly Average)			
BASELINE PERIOD		**January-2020 - December-2021**	
Energy Source	**Parameter**	**Unit**	**Value**
DIESEL	Consumption	L	42,427.21
	Primary Energy	kWh	505,166.63
	Electrical Energy	kWh	113,662.49
	Cost	USD	41,154.39
	CEC	USD/kWh	0.362
	Daily Electrical Energy	kWh/Day	**3,737.37**

The historical fuel consumption trend is shown in Figure 4.2. The highest diesel consumption was observed in March 2021 at 44,765 L while the lowest consumption was in February 2020 at 38, 976 L.

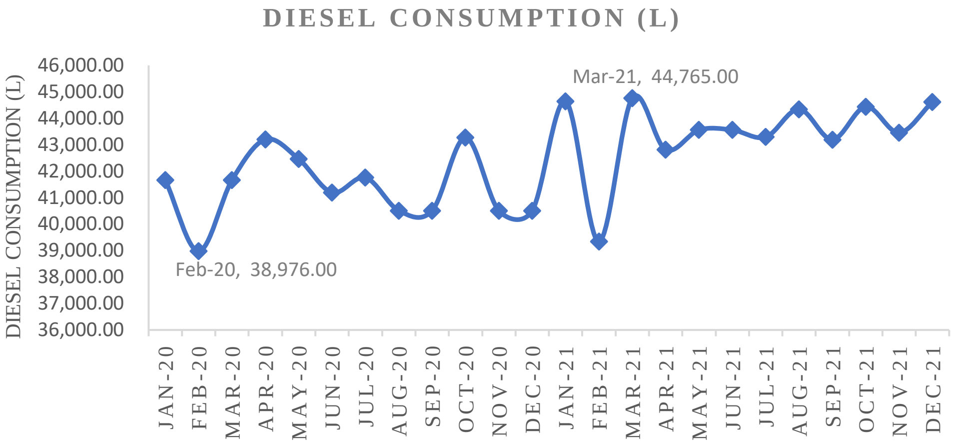


Figure 4.2: Facility Baseline Fuel Consumption Trend

Diesel consumption has been on the rise over the baseline period with the facility recording a high consumption in 2021 compared to 2020 as shown in Figure 4.3.

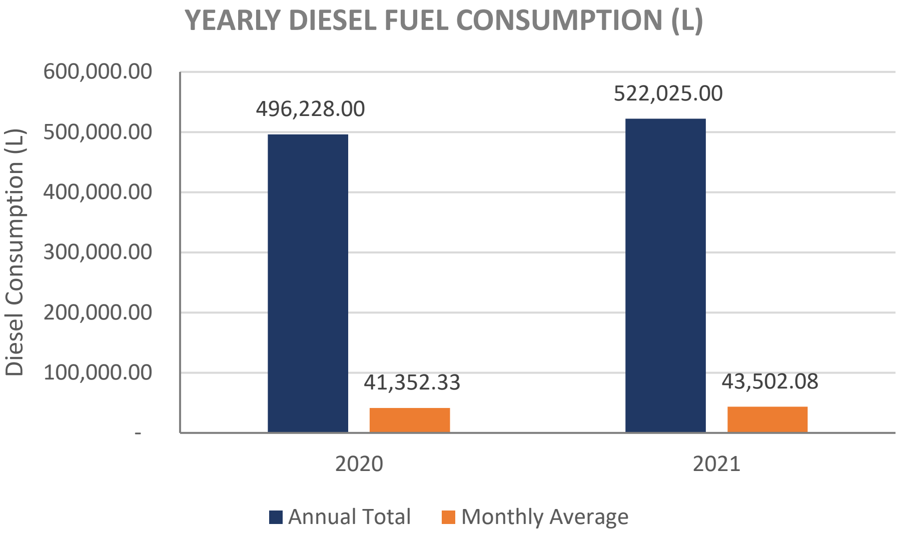


Figure 4.3: Facility Diesel Consumption

4.2.2 Energy Consumption

The monthly average electrical energy was 113,662.49 kWh showing an increase in 2021 which can directly be attributed to increased fuel consumption. The facility uses close to 1.4GWh of electrical energy annually.

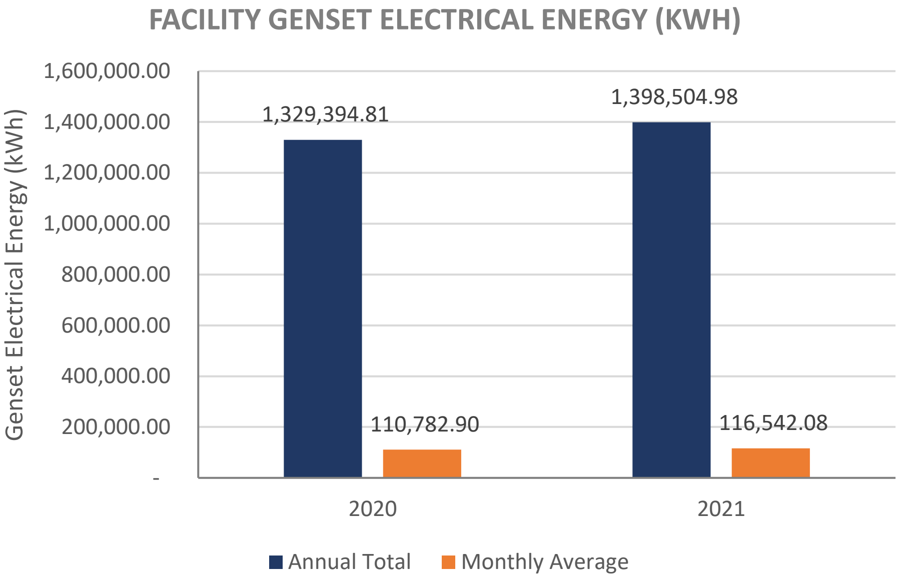


Figure 4.4: Facility Electrical Energy

4.2.3 Energy Costs

The monthly average diesel fuel cost was USD 41,154.39 with the total annual electricity cost over USD 480,000.

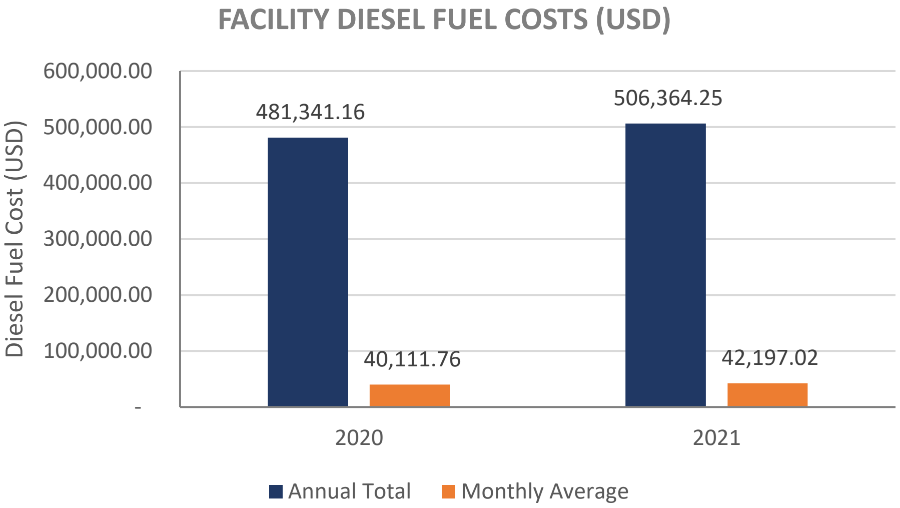


Figure 4.5: Facility Diesel Fuel Cost

4.2.4 Carbon Emissions

The monthly average carbon emissions were 110,310.74 Kgs with the emissions translating to over 1.3 T in 2021. The annual average carbon emissions translate to 1,323,728.90 Kgs of CO_2.

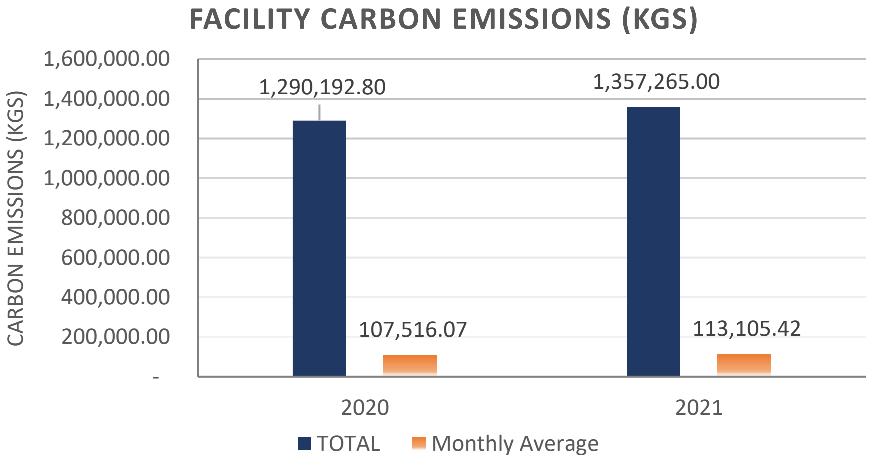


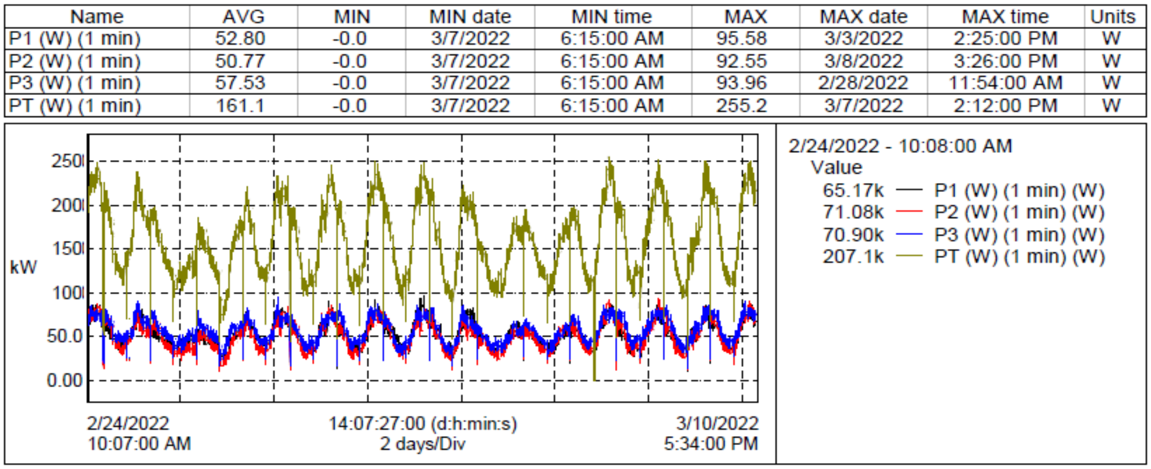
Figure 4.6: Facility Carbon Emissions

4.3 Real-time Energy Measurement

Real-time power and energy measurements were recorded using the PEL 103 energy logger for 14 days (From 24/02/2022 – 10/03/2022).

4.3.1 Real Power Demand

The facility’s average power demand was 161.1kW with a maximum power demand of 255.2kW. Consumption was highest during the weekdays with the weekends exhibiting low power consumption. This could be attributed to the factor that over the weekends the staff offices are not in use hence most of the power that is utilized by plug loads and air conditioning equipment is eliminated or minimized. The load is also noted to drop during the night compared to consumption during the day.

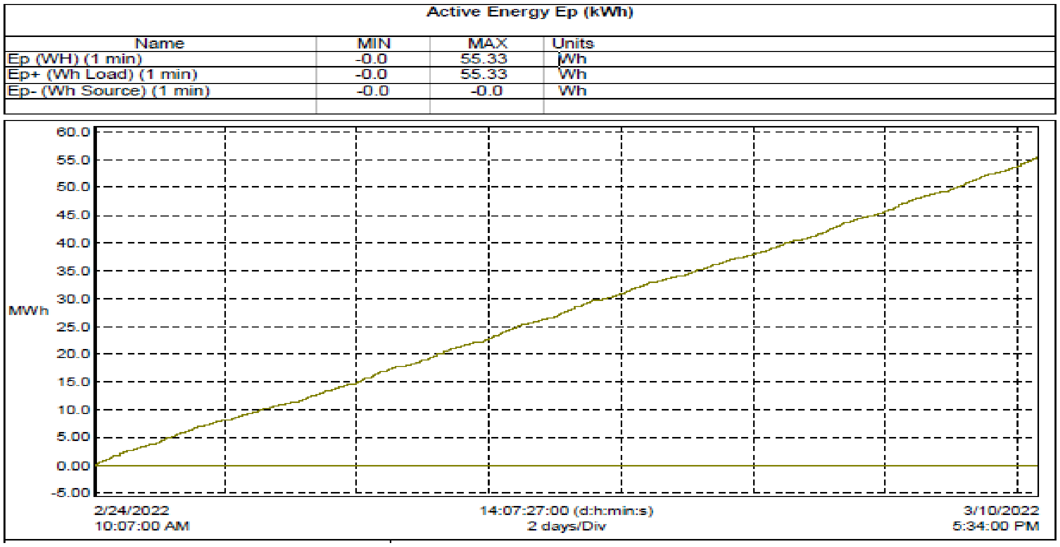


Name	AVG	MIN	MIN date	MIN time	MAX	MAX date	MAX time	Units
P1 (W) (1 min)	52.80	-0.0	3/7/2022	6:15:00 AM	95.58	3/3/2022	2:25:00 PM	W
P2 (W) (1 min)	50.77	-0.0	3/7/2022	6:15:00 AM	92.55	3/8/2022	3:26:00 PM	W
P3 (W) (1 min)	57.53	-0.0	3/7/2022	6:15:00 AM	93.96	2/28/2022	11:54:00 AM	W
PT (W) (1 min)	161.1	-0.0	3/7/2022	6:15:00 AM	255.2	3/7/2022	2:12:00 PM	W

Figure 4.7: Facility Real Power Demand

4.3.1 Energy Demand

The total energy demand as measured during the 14-day logging period was 55.33 MWh as indicated in Figure 4.8



Active Energy Ep (kWh)

Name	MIN	MAX	Units
Ep (WH) (1 min)	-0.0	55.33	Wh
Ep+ (Wh Load) (1 min)	-0.0	55.33	Wh
Ep- (Wh Source) (1 min)	-0.0	-0.0	Wh

Figure 4.8: Facility Total Measured Energy Demand

The summarized measured energy consumption by the facility is shown in Table 4.2. The measured daily average energy was 3,866.41kWh with an annual projection of slightly over 1.4GWh. This projection was quite close to the annual energy calculated from the provided diesel consumption data.

Table 4.2: Facility Measured Energy Consumption

Measured Energy Consumption		
Logging Time	Days	**14.3**
Total Active Energy	kWh	**55,330.00**
Daily Average	kWh	**3,866.41**
Monthly Average	kWh	**115,992.43**
Annual Projection	kWh	**1,411,241.23**

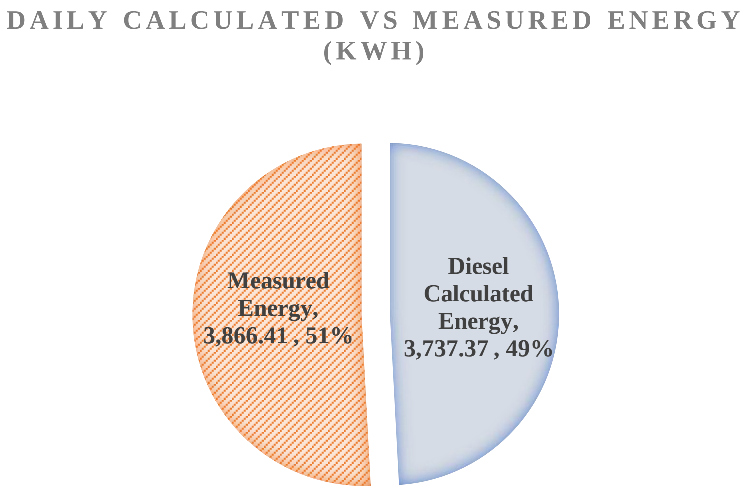


Figure 4.9: Facility Measured vs Calculated Energy Demand

4.4 Energy Conservation Measures

4.4.1 Implemented Energy Conservation Measures

UNHCR Sub-Office has implemented some energy conservation measures (ECMs) which are essential in ensuring there is an optimal use of electrical energy. Some of the implementation measures include;

I. **Energy Star-Rated Equipment**: Energy star-rated equipment such as refrigerators, printers, deep freezers, and air conditioners were observed in various sections of the facility. The energy star-rated equipment consumes less power compared to conventional equipment. The energy and petroleum regulatory authority (EPRA) has put in place measures to boost the utilization of efficient equipment through the introduction of energy labels. The more the stars, the more energy-efficient and equipment will be.

II. **Use of LED Lighting**: Some LED lighting systems have been installed for indoor and security lighting. LED lights are more efficient and consume less energy compared to their equivalent conventional lights including fluorescent and incandescent tubes/lamps

4.4.2 Proposed Energy Conservation Measures

4.4.2.1 Light Improvement by Use of LED Lighting

Lighting improvement is a low-hanging fruit observed at the UNHCR Sub-Office Dadaab since most of the installed luminaires are conventional fluorescent and incandescent lamps. These conventional luminaires consume more electrical energy compared to their equivalent LED luminaires. The conventional luminaires form the largest percentage and contribute to the highest lighting load demand. A summary of the installed luminaires at the facility is attached in Appendix A-2 Table 6.3.

Type of Lighting	Number	Lighting Load (kW)
FLUORESCENT	1,224	34.82
INCANDESCENT	51	2.04
LED	37	0.52
TOTAL	**1,312**	**37.38**

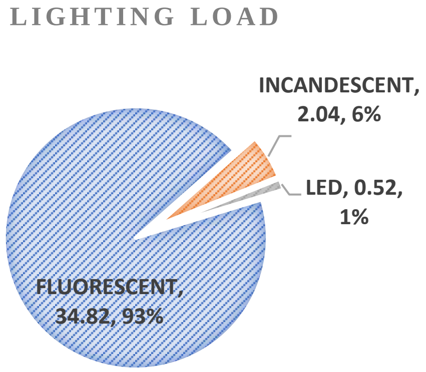


Figure 4.10: Facility Lighting Composition and Load

The existing conventional luminaires could be retrofitted with their equivalent LED luminaires as indicated in Table 4.3.

Table 4.3: Proposed LED Lighting Retrofits

Existing Lighting	Total Wattage	Equivalent LED Lighting	LED Wattage	Projected Savings per Fixture/Lamp		LED Cost
	W	W	W	W	%	USD
Single 4ft. Fluorescent Tube (T8)	46	Single 4ft. LED Tube (T8)	18	28.0	60.87	21.43
14 W Compact Fluorescent Lamp	14	5W LED Bulb	5	9.0	64.29	4.29
Single 2ft. Fluorescent Tube (T8)	28	Single 2ft. LED Tube (T8)	9	19.0	67.86	10.29
20 W Compact Fluorescent Lamp	20	5 W LED Bulb	5	15.0	75.00	4.29
4No. 2ft. x 2ft. Fluorescent Tube (T8)	82	4No. 2ft. x 2ft. LED Tube (T8)	36	46.0	56.10	41.15
40 W Incandescent Lamp	40	5 W LED Bulb	5	35.0	87.50	10.29
18 W Compact Fluorescent Tube	18	10 W LED Bulb	10	8.0	44.44	6.00

Retrofitting all the conventional luminaires with their equivalent LED luminaires will reduce the total load from 37.38kW to 14.00kW (63%).

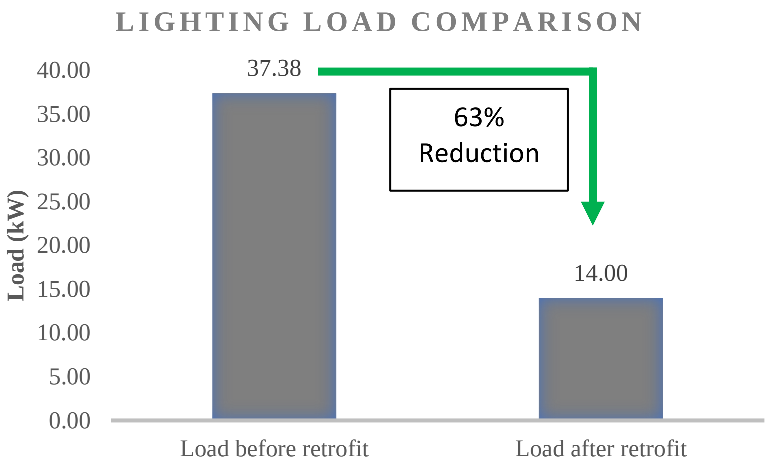


Figure 4.11: Lighting Load Comparison

The annual energy savings, cost savings, and investment costs associated with retrofitting the conventional luminaires with LED are as in Table 4.4. The simple payback period is less than a year at 0.90 years.

Table 4.4: LED Retrofitting Energy and Cost Savings

Parameter	Unit	Values
Consolidated Electricity Cost	USD/kWh	**0.362**
Facility Annual Operating Time	Days	**365**
Estimated Annual Energy Savings	kWh	**60,813.02**
Estimated Annual Energy Cost Savings	USD	**21,577.80**
Installation Cost (Labour)	USD	**4,475.70**
LED Purchase, Installation and Commissioning Cost	USD	**19,394.68**
Simple Payback Period	Years	**0.90**

The summarized financial analysis is given in Table 4.5. The lighting retrofit would be a good investment for the facility considering the return on investment is great at 200.8% with an internal rate of return of 69%. The recommendation is economically and technically feasible.

Table 4.5: Financial Analysis Summary

Parameter	Unit	Value
Discounted Payback Period	Years	1.04
Net Present Value (NPV)	USD	38,953.35
Internal Rate of Return (IRR)	%	69%
Return on Investment (ROI)	%	200.8%
Profitability Index (PI)	PI	3.01

4.4.2. Other Energy Conservation Measures

The other identified energy conservation measures included;

a) **Use of Energy Efficient Air Conditioners**: Most of the air conditioners installed at the facility are conventional high wall split units that use R22 refrigerant and are not energy efficient. The compressor of these air conditioners runs at a constant speed without regulation thus consuming more energy regardless of whether the set cooling temperature has been achieved. Replacement of the conventional air conditioners with variable refrigerant flow (VRF) technology which is more efficient as the compressor speed is adjusted accordingly depending on the cooling load and with R410A refrigerant will ensure energy savings.

b) **Insulation of refrigerant pipes**: The insulation of most of the refrigerant pipes is worn out hence increasing inefficiencies in the cooling process. Uninsulated refrigerant pipes allow infiltration of heat into the refrigerant thus rising its temperature. The temperature difference between the refrigerant and the room being cooled will be small hence less heat will be drawn from that particular room making the cooling take long thus more electrical energy consumed.

c) **Installation of Occupancy sensors**: It was observed that most of the washroom lights are left ON throughout the day including when not occupied. This leads to a lot of energy wastage thus raising the energy consumption and costs. The facility should install occupancy sensors to automatically manage the lights in the washrooms where they will only be switched on when the washroom is occupied. This will help reduce the energy consumed due to the lighting of the washrooms with no occupants.

d) **Creating awareness through stickers**: Behavioral change is essential in the conservation of energy since some of the wastages can be avoided through the creation of awareness.

Installation of sticks with messages such as “switch off the light” is a good reminder to occupants of a particular room to turn the lights off when they are not needed. This applies to other electrical loads such as air conditioners and computers when leaving the office since they still consume electricity while in sleep mode.

4.5 Design Solar PV System

4.5.1 System Architecture

The schematic of the designed system is shown in Figure 4.12. The hybrid system will comprise two energy sources that is; solar PV and a diesel generator acting as a backup. The DC power from the PV modules is converted to AC by a PV dedicated converter (grid-tied inverter). A converter is incorporated into the system for charging and discharging the Li-ion batteries. The multi-string PV configuration is the most suited for the proposed system. The hybrid system employs a serial operation where the directly generated electricity from the solar PV is prioritized to serve the electrical loads. Excess electricity is channeled for battery charging. In the evening and at night when the sunlight is not enough for electricity generation, the battery storage meets the load demand. On depletion of the battery storage to its depth of discharge, the diesel generator kicks in to supply the electrical load demand.

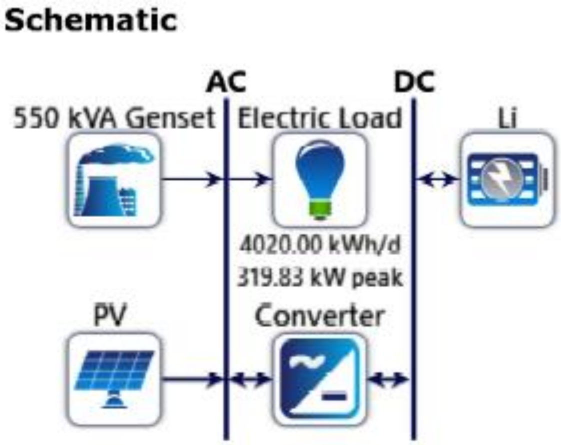
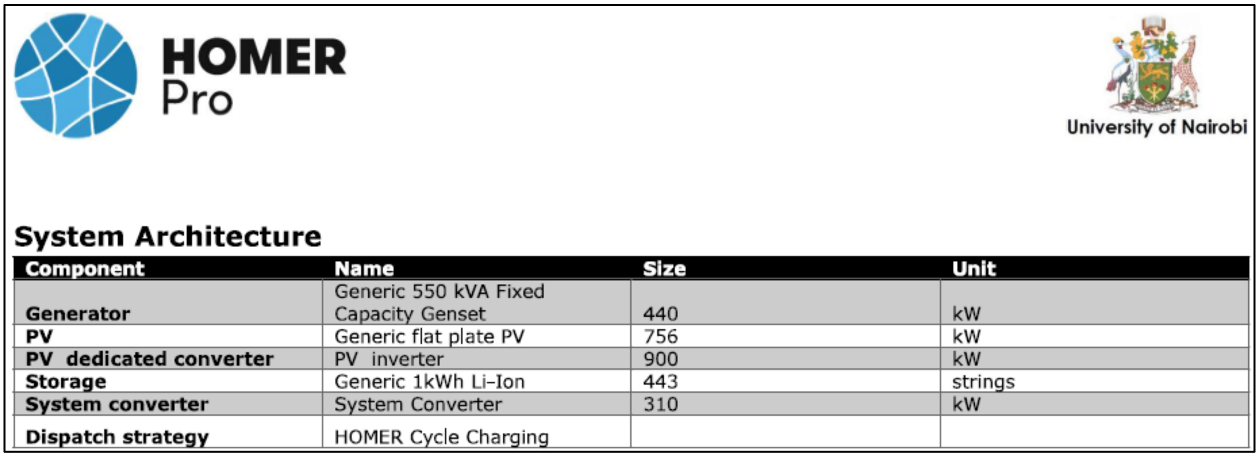


Figure 4.12: Schematic

The simulated PV system size is 756kWp with a PV dedicated converter of the same size and a 2500kWh battery storage capacity. The system incorporates a 310kW converter for battery storage charging and discharging. The cycling charging dispatch strategy is applied in this design meaning the battery storage can be charged by the diesel generator.



HOMER Pro

University of Nairobi

System Architecture

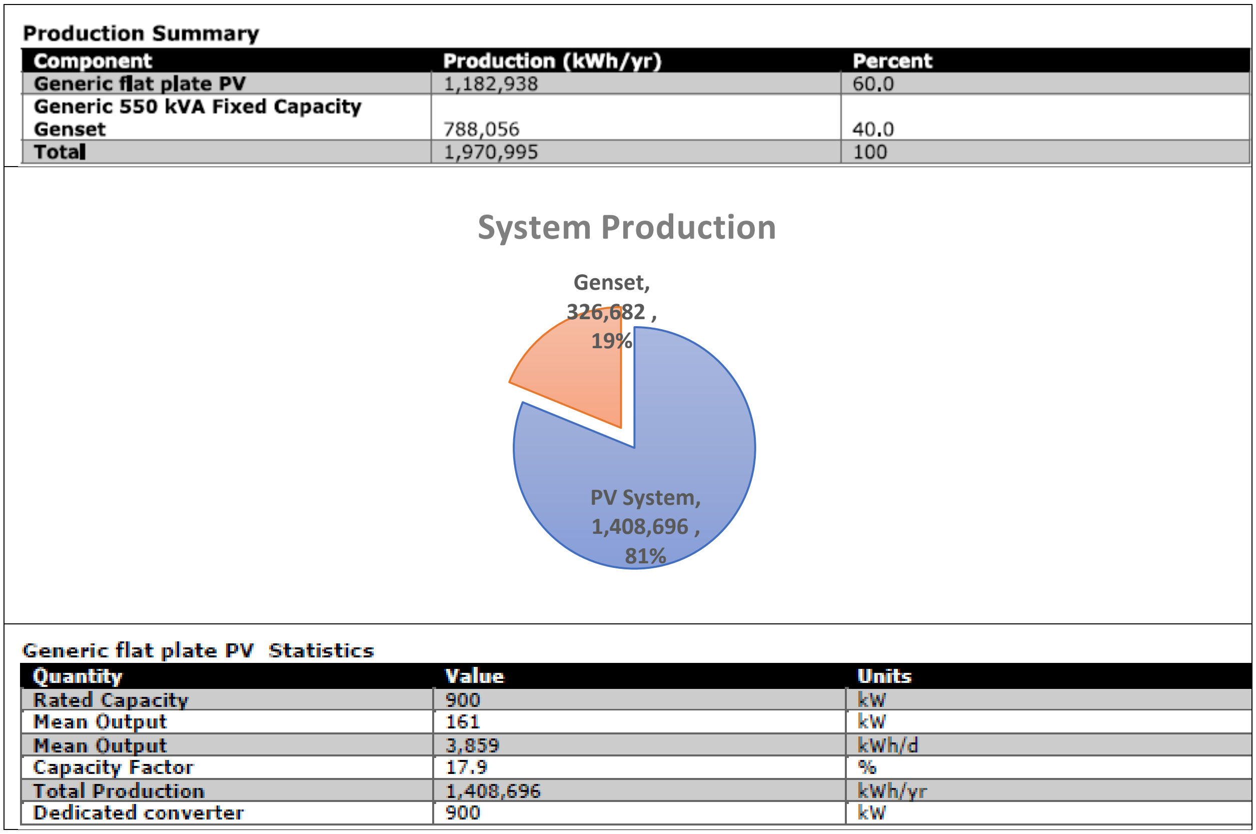
Component	Name	Size	Unit
Generator	Generic 550 kVA Fixed Capacity Genset	440	kW
PV	Generic flat plate PV	756	kW
PV dedicated converter	PV inverter	900	kW
Storage	Generic 1kWh Li-Ion	443	strings
System converter	System Converter	310	kW
Dispatch strategy	HOMER Cycle Charging		

Figure 4.13: PV System Summary

4.5.2 Electrical Summary

4.5.2.1 Electrical Production

Figure 4.14 shows the system production summary. The solar PV system contributes to 60% renewable energy penetration with diesel Genset contributing to 40%. The system will be able to sufficiently supply the electrical load at the facility projected to be 1,467,300 kWh/yr.

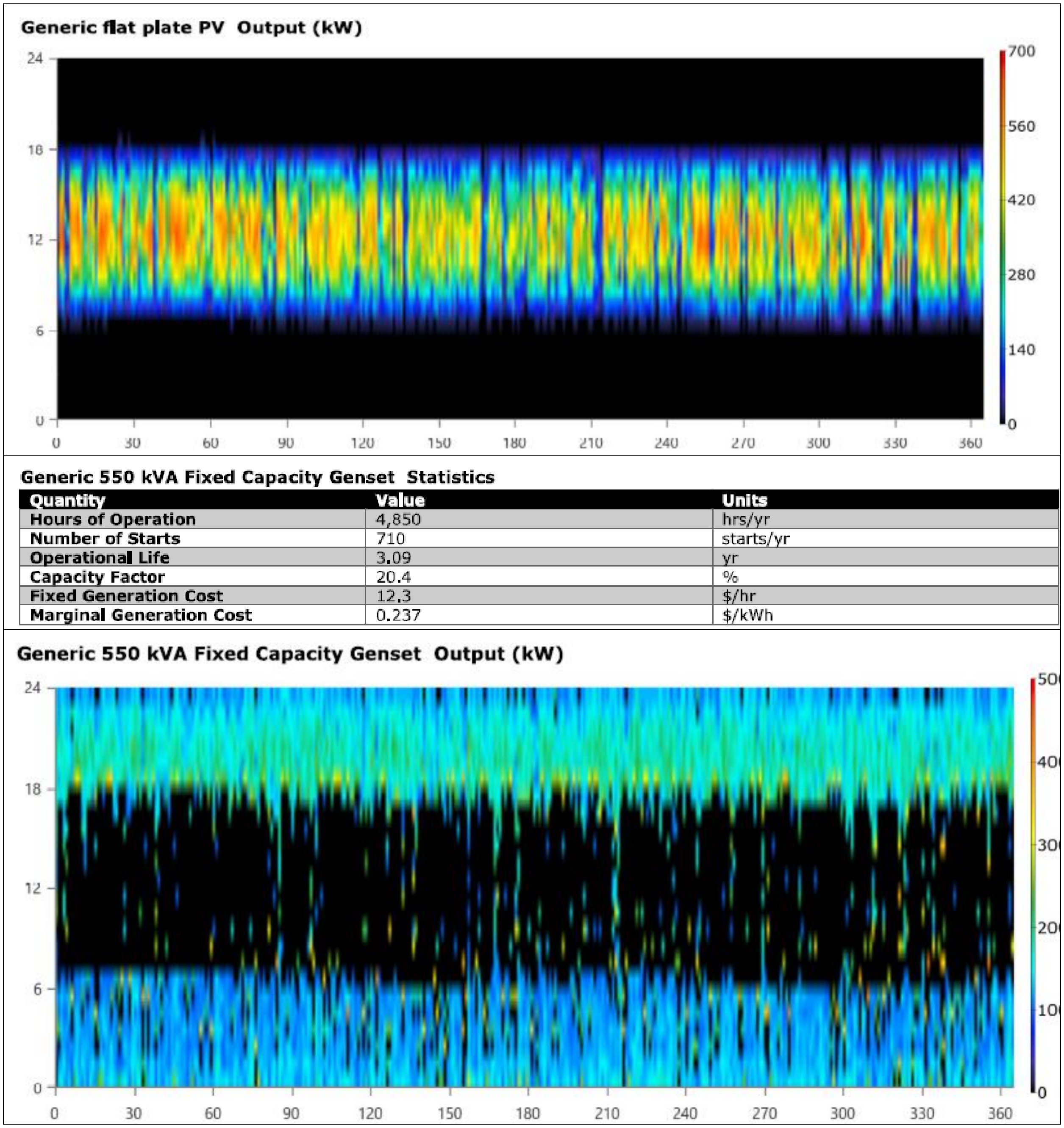


Production Summary

Component	Production (kWh/yr)	Percent
Generic flat plate PV	1,182,938	60.0
Generic 550 kVA Fixed Capacity Genset	788,056	40.0
Total	1,970,995	100

Generic flat plate PV Statistics

Quantity	Value	Units
Rated Capacity	900	kW
Mean Output	161	kW
Mean Output	3,859	kWh/d
Capacity Factor	17.9	%
Total Production	1,408,696	kWh/yr
Dedicated converter	900	kW



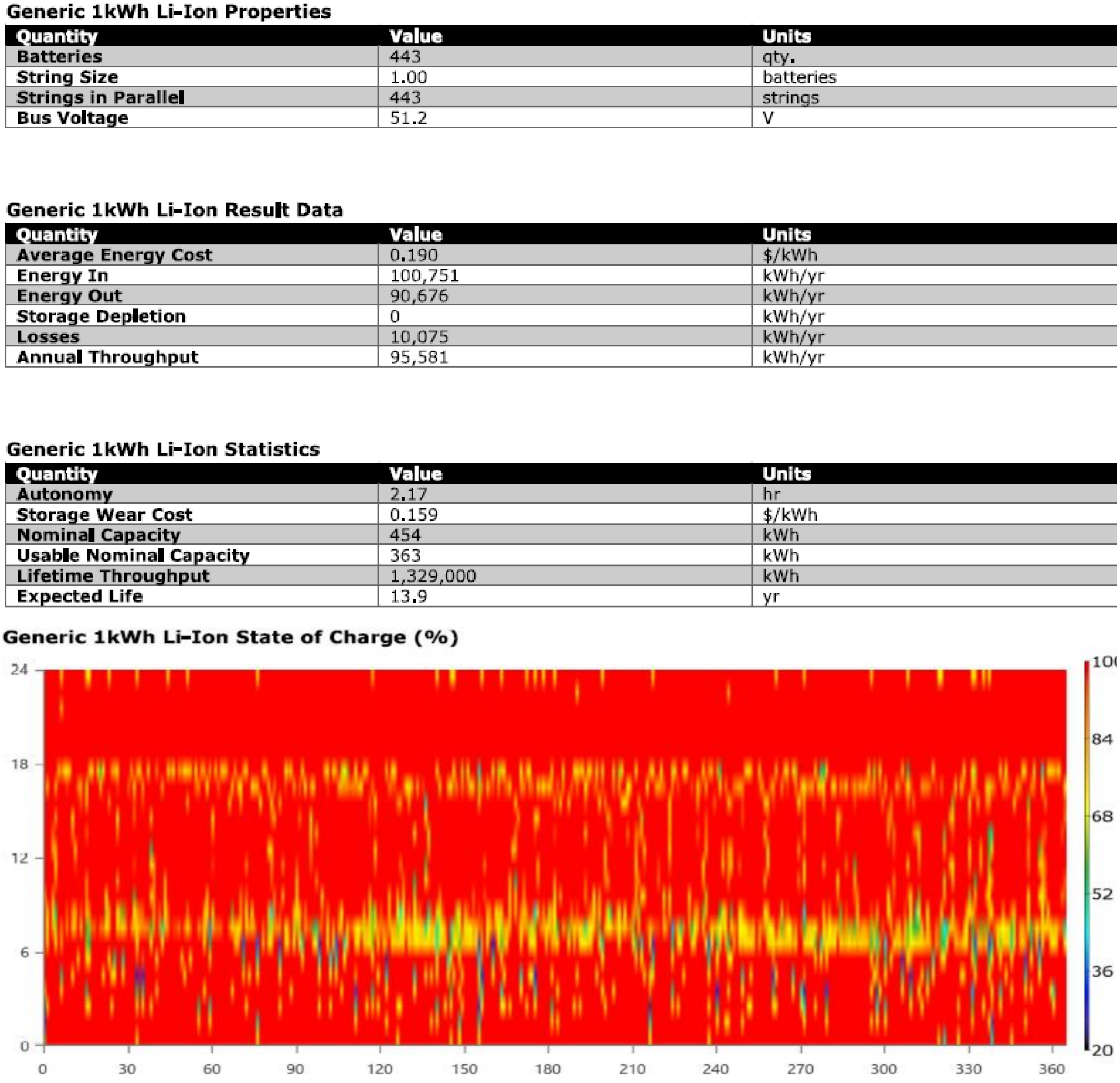
Generic 550 kVA Fixed Capacity Genset Statistics

Quantity	Value	Units
Hours of Operation	4,850	hrs/yr
Number of Starts	710	starts/yr
Operational Life	3.09	yr
Capacity Factor	20.4	%
Fixed Generation Cost	12.3	$/hr
Marginal Generation Cost	0.237	$/kWh

Figure 4.14: System Production Summary

4.5.2.2 Electrical Storage

System storage comprising Li-ion batteries with a 443kWh will support the system with 2.17 hours of autonomy.



Generic 1kWh Li-Ion Properties

Quantity	Value	Units
Batteries	443	qty.
String Size	1.00	batteries
Strings in Parallel	443	strings
Bus Voltage	51.2	V

Generic 1kWh Li-Ion Result Data

Quantity	Value	Units
Average Energy Cost	0.190	$/kWh
Energy In	100,751	kWh/yr
Energy Out	90,676	kWh/yr
Storage Depletion	0	kWh/yr
Losses	10,075	kWh/yr
Annual Throughput	95,581	kWh/yr

Generic 1kWh Li-Ion Statistics

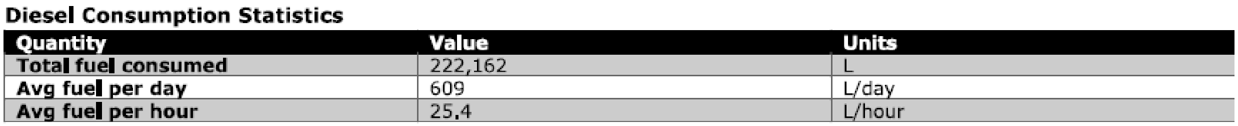
Quantity	Value	Units
Autonomy	2.17	hr
Storage Wear Cost	0.159	$/kWh
Nominal Capacity	454	kWh
Usable Nominal Capacity	363	kWh
Lifetime Throughput	1,329,000	kWh
Expected Life	13.9	yr

Generic 1kWh Li-Ion State of Charge (%)

Figure 4.15: Battery Storage Properties and Capacity

4.5.3 Diesel Consumption

The projected diesel consumption will be **222,162 L** annually representing a **46%** reduction when compared to the simulated base system that solely depends on diesel generators for electricity production.



Diesel Consumption Statistics

Quantity	Value	Units
Total fuel consumed	222,162	L
Avg fuel per day	609	L/day
Avg fuel per hour	25.4	L/hour

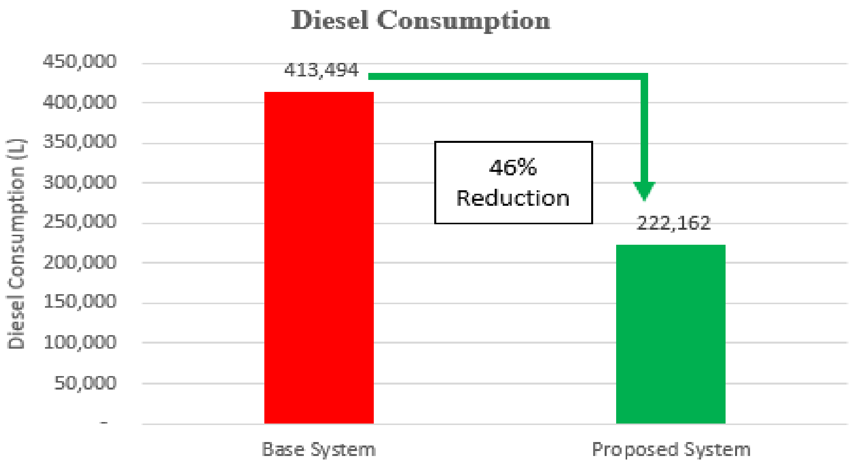
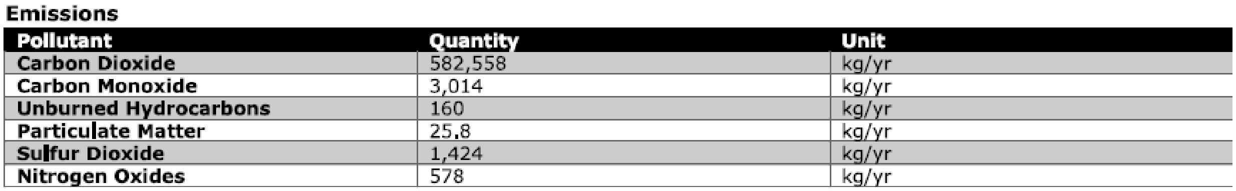


Figure 4.16: Diesel Consumption

4.5.4 Carbon Emissions

The average carbon emissions of the proposed system are projected at **582,558 kg/yr.** which translates to a **46%** reduction in the simulated base system emissions. The base system has a diesel consumption of 222,162 L annually which translates to 2.62 kgs CO_2 per litre of diesel consumed. This is within the range of 2.4 - 2.8 kgs CO_2 as indicated by research on diesel generator emissions.



Emissions

Pollutant	Quantity	Unit
Carbon Dioxide	582,558	kg/yr
Carbon Monoxide	3,014	kg/yr
Unburned Hydrocarbons	160	kg/yr
Particulate Matter	25.8	kg/yr
Sulfur Dioxide	1,424	kg/yr
Nitrogen Oxides	578	kg/yr

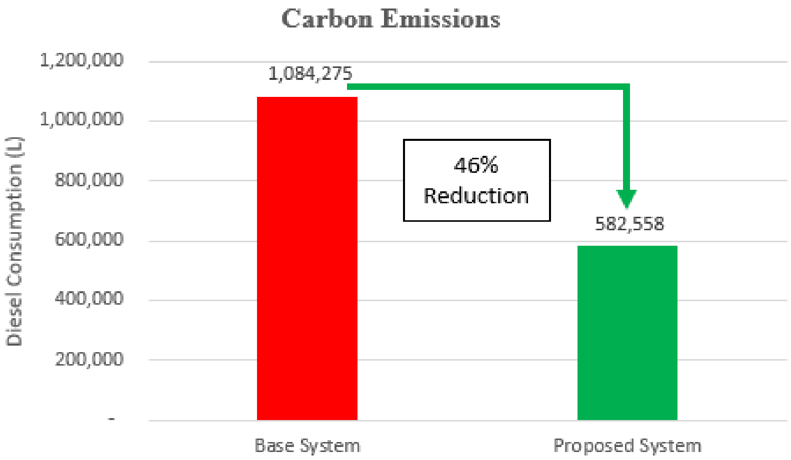


Figure 4.17: Greenhouse gas emissions

4.5.5 Solar PV System Emissions

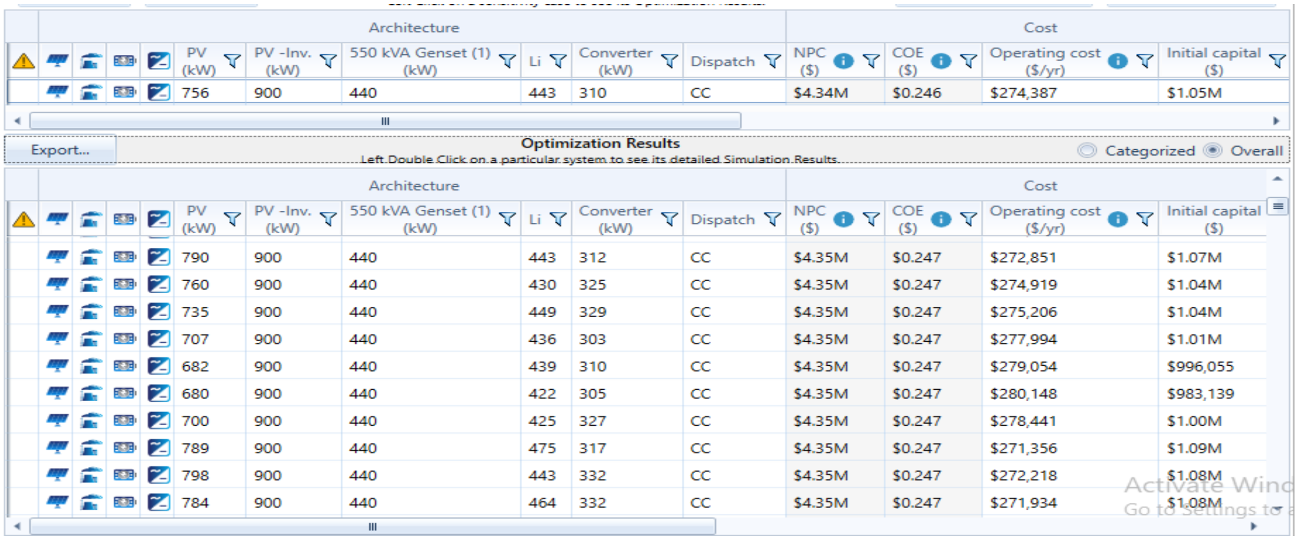
The solar PV system emissions were calculated as 49.9 g CO_2-eq/kWh. The annual generation from the solar PV system was simulated as 1,408,696 kWh/yr as indicated in the system production summary in Figure 4.14 above. Therefore, the calculated CO_2 equivalent (CO_2-eq) emissions are 70,293.9304 kgs annually as calculated in Eq. (4.1)

$$1{,}408{,}696\, x\, \frac{49.9}{1{,}000} = 70{,}293.9304\ kgs\ CO_2eq \qquad (\,4.1\,)$$

4.5.5 System Economics

4.5.5.1 Net Present Costs (NPC)

Several solutions were simulated by the software with the most feasible system determined based on the Net Present Cost (NPC). The lowest and most preferred system had an NPC of $4.43M as shown in Figure 4.18.



Architecture						Cost			
PV (kW)	PV -Inv. (kW)	550 kVA Genset (1) (kW)	Li	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)
756	900	440	443	310	CC	$4.34M	$0.246	$274,387	$1.05M

Export...

Optimization Results

Left Double Click on a particular system to see its detailed Simulation Results.

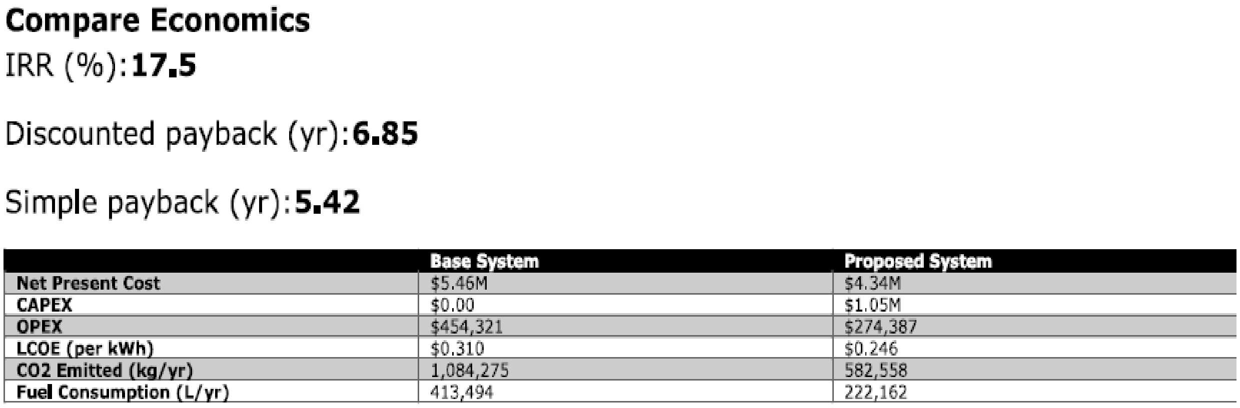
○ Categorized ● Overall

Architecture						Cost			
PV (kW)	PV -Inv. (kW)	550 kVA Genset (1) (kW)	Li	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)
790	900	440	443	312	CC	$4.35M	$0.247	$272,851	$1.07M
760	900	440	430	325	CC	$4.35M	$0.247	$274,919	$1.04M
735	900	440	449	329	CC	$4.35M	$0.247	$275,206	$1.04M
707	900	440	436	303	CC	$4.35M	$0.247	$277,994	$1.01M
682	900	440	439	310	CC	$4.35M	$0.247	$279,054	$996,055
680	900	440	422	305	CC	$4.35M	$0.247	$280,148	$983,139
700	900	440	425	327	CC	$4.35M	$0.247	$278,441	$1.00M
789	900	440	475	317	CC	$4.35M	$0.247	$271,356	$1.09M
798	900	440	443	332	CC	$4.35M	$0.247	$272,218	$1.08M
784	900	440	464	332	CC	$4.35M	$0.247	$271,934	$1.08M

Figure 4.18: System Net Present Costs

4.5.5.2 Payback Period

Figure 4.19 shows the economic comparisons of the base and proposed systems. The simple payback is 5.42 years while the discounted payback is at 6.85 years. A system lifetime of 25 years justifies the economics since the investment will be accrued within a shorter period.



Compare Economics

IRR (%):**17.5**

Discounted payback (yr):**6.85**

Simple payback (yr):**5.42**

	Base System	Proposed System
Net Present Cost	$5.46M	$4.34M
CAPEX	$0.00	$1.05M
OPEX	$454,321	$274,387
LCOE (per kWh)	$0.310	$0.246
CO2 Emitted (kg/yr)	1,084,275	582,558
Fuel Consumption (L/yr)	413,494	222,162

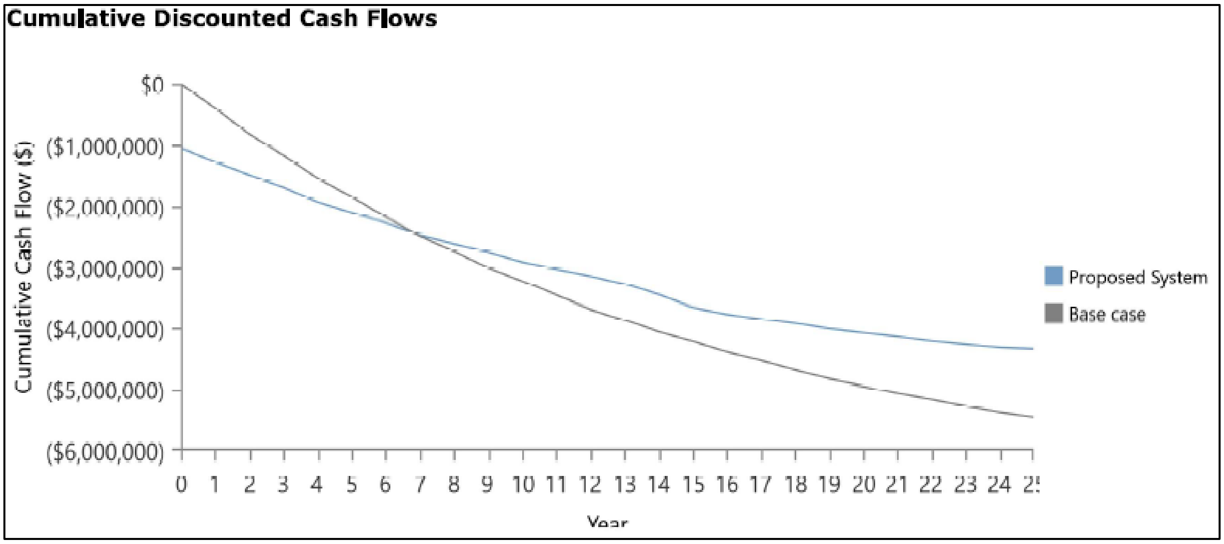


Figure 4.19: System Economics

4.5.5.3 LCOE

The simulated Levelized cost of electricity (LCOE) drops from $0.310 in the base system to $0.246 in the proposed system representing a 21% reduction as depicted in Figure 4.20.

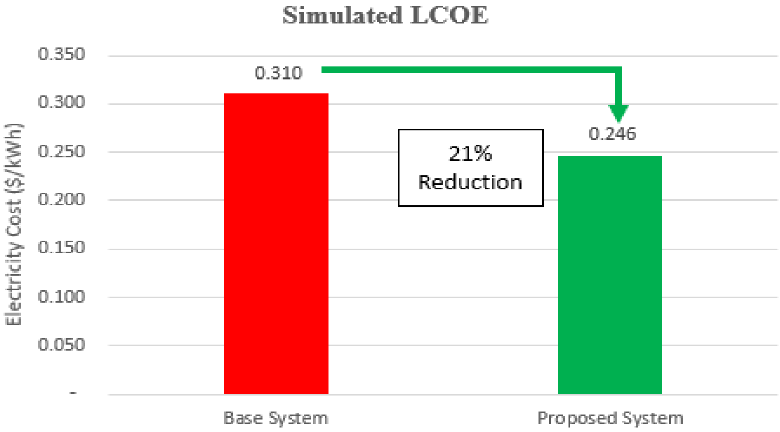
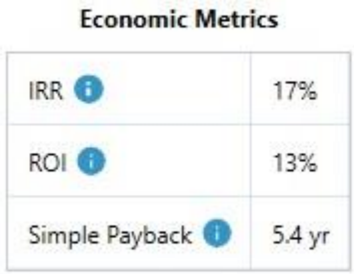


Figure 4.20: Simulated LCOE

4.5.5.4 IRR and ROI

The system has a positive internal rate of return of 17.5%. The return on investment is 13% representing gained returns as shown in Figure 4.21. The total returns of the system supersede the total costs over the entire lifetime of the system.



Economic Metrics

IRR	17%
ROI	13%
Simple Payback	5.4 yr

Figure 4.21: Economic Metrics

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Electricity generation by use of diesel generators is rampant in remote areas that are isolated from the grid. Primarily depending on diesel for electricity generation has its fair share of downsides including high production costs due to high and fluctuating fuel prices and operation and maintenance costs. Additionally, there is the risk of environmental pollution, global warming, acid rain, and climatic change due to the emission of greenhouse gases into the atmosphere. Greenhouse gases emitted from diesel generators include Carbon dioxide, Nitrogen oxides, and Sulphur oxides. Diesel generators emit between 2.4 – 2.8 kgs of CO_2 for every litre of fuel consumed which is dependent on the fuel properties. Higher diesel consumption will therefore ensure increased production of the emissions.

A Solar PV system mainly encompasses solar modules, inverters/converters, and battery storage. The solar cells are the most essential part of the modules as they ensure the generation of power from sunlight through the photovoltaic effect. The most commonly used solar cells currently are silicon-based cells including monocrystalline, polycrystalline, and amorphous. DC power from the solar modules is converted to AC power by the inverters since most of the electrical equipment demand an AC power input. Modern inverters ensure that the solar modules are producing maximum power at any given time by making them operate at their MPPT point. Generated power from the solar modules is stored in batteries for use during periods when the solar radiation is low or at night when there is no sun at all. Different types of batteries have been developed with the most commonly used being Lead-acid and Lithium-Ion. A solar PV system would either be grid-connected or standalone (independent from the grid). Different researches have been carried out on hybrid electrical access systems across the world. However, these are site-specific since the parameters of sites vary per location including but not limited. the solar insolation and temperature

The design of the solar-diesel-storage hybrid system was done using the HOMER Pro software chosen due to its robustness which includes functions such as design, optimization, simulation, and sensitivity analysis including its availability and low cost. The preliminary stage in the design involved the collection of data from the site both qualitative and quantitative. Quantitative data involved analysis of diesel consumption and costs over two years, inventory of electrical loads, and measurement of the main incomer power for 14 days. The qualitative data was focused on observation of the operations at the site mainly to identify the potential behavioral change that could have a huge impact on the reduction of possible energy waste. Other data collection tools included clamp meters to measure line currents and data extraction software such as PEL software and Data view software. Analysis of the collected data was primarily done with the Excel spreadsheet before the system design and optimization by HOMER. Various economic parameters were also factored in the design including but not limited to SPB, NPV, IRR, ROI, LCOE, and discounted payback period.

Generational electrical power from conventional sources such as fossil fuels is not only expensive but also costly to the environment as a whole due to GHG emissions. Analysis of the cost of production and carbon emissions from the base system and the proposed system shows a huge contrast in favor of the hybrid renewable energy system. This was after HOMER software simulation of 1,158 solutions out of which 868 were feasible with the best PV system proposed as 756 kWp including a battery storage capacity of 443 kWh backed up by one of the 550 kVA generators already installed at the facility. The simple and discounted payback periods are 5.42 years and 6.85 years respectively which is low considering the system’s expected lifetime of 25 years. The Levelized Cost of electricity brings out the high cost of generation while using the diesel generators alone at $0.31/kWh compared to $0.246/kWh in the hybrid renewable energy system depicting a 21% reduction. The carbon emissions subsequently incur a 46% reduction from 1,084,275 kg/yr to 582,558 kg/yr. The feasibility of the renewable energy hybrid system is further enhanced by an IRR and ROI of 17.5% and 13% respectively indicating that the project will accrue returns making it a worthy investment.

5.2 Recommendation

Further study is recommended on the optimization and reconfiguration of the electrical distribution system including evaluation of load balancing. The electrical distribution should be optimized such that it matches the demand in terms of the size of cables used, and the protection circuit among others. This study did not go into detail about checking if the right cable size is used to supply the given loads at the site. This is vital to avoid overheating of cables which introduces power losses and may cause thermal insulation breakdown leading to shorting of the conductors. Being a three-phase power distribution system, a load balancing study is recommended to ensure that the load is equally distributed between line 1 (red), line 2 (yellow), and line 3 (blue). An unbalanced load could lead to overheating of one phase more than the others leading to thermal insulation damage hence the importance of carrying out this study.

Moreover, a post-implementation study is necessary to understand the impact of the suggested energy conservation measures and establish the associated behavioral change. The qualitative study at the facility identified various behavioral changes that could be encouraged to save on their possible associated energy wastage. Some of this included; leaving the lights on in the offices and washrooms unnecessarily when there was no occupant. The installation of occupancy sensors primarily in the washrooms was identified and suggested as a viable remedy to this. However, there was still behavioral change required in the offices which could be enforced through the use of awareness stickers as a way of reminder. A future study is therefore vital on the impact of the associated behavioral change by the staff in terms of energy conservation.

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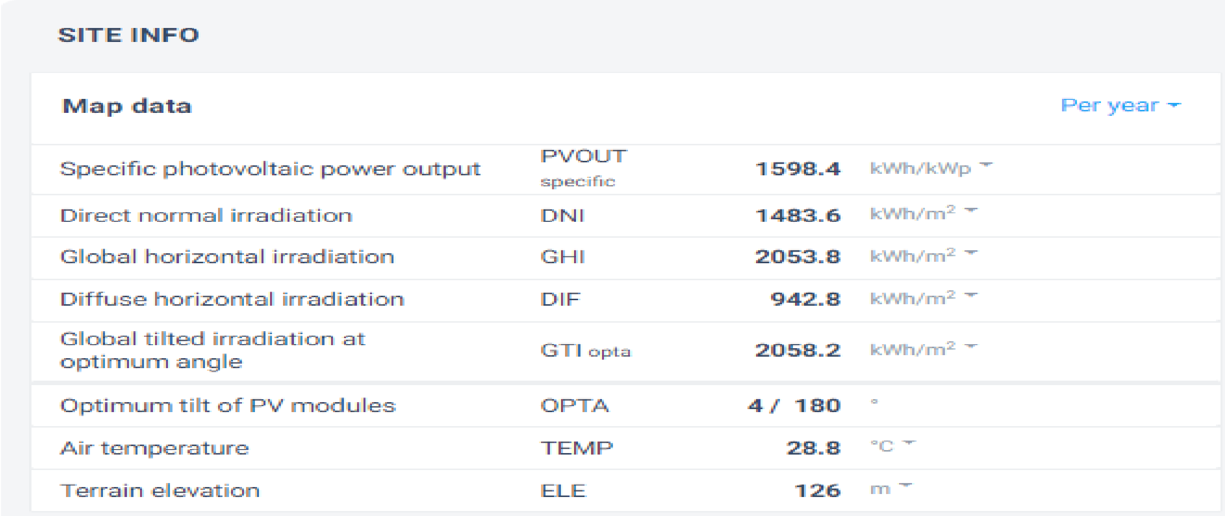
APPENDICES

Appendix A: Weather Data

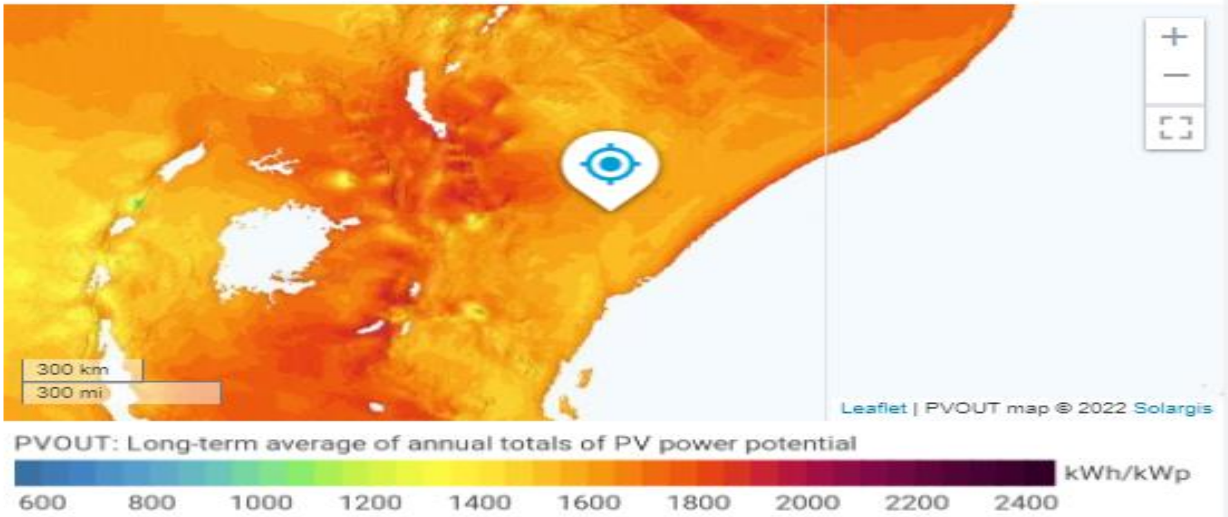


SITE INFO

Map data Per year

Specific photovoltaic power output	PVOUT specific	1598.4	kWh/kWp
Direct normal irradiation	DNI	1483.6	kWh/m²
Global horizontal irradiation	GHI	2053.8	kWh/m²
Diffuse horizontal irradiation	DIF	942.8	kWh/m²
Global tilted irradiation at optimum angle	GTI opta	2058.2	kWh/m²
Optimum tilt of PV modules	OPTA	4 / 180	°
Air temperature	TEMP	28.8	°C
Terrain elevation	ELE	126	m

PVOUT map



PVOUT: Long-term average of annual totals of PV power potential

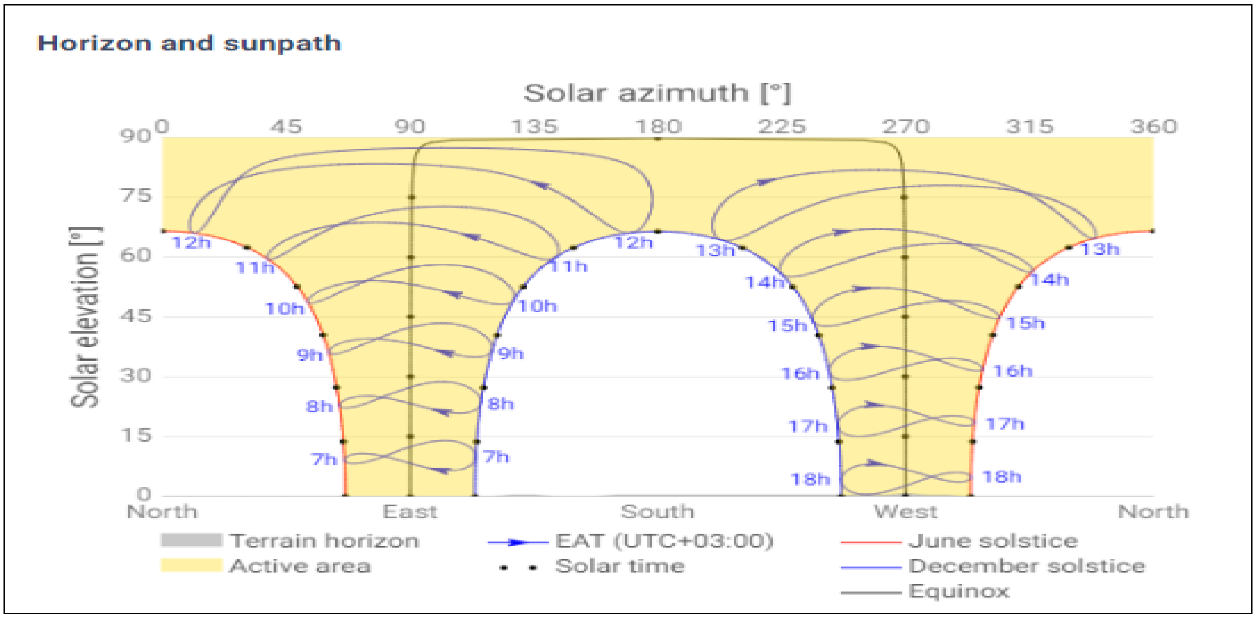


Figure 6.1: Site Weather Data. Adapted from [36]

Appendix A-1: Installed Diesel Generators Specifications

Table 6.1: Installed Generators Technical Specifications

Parameter	Unit	Generator 1	Generator 2
Manufacturer	Co.	Caterpillar (NI) Ltd	Caterpillar (NI) Ltd
Model No.	No.	P550-3	P550-4
Serial No.	No.	FGWPES27CPCA02435	FGWPES27CPCA02436
Rated Power	kVA	550	550
Rated Current	A	765	765
Rated Voltage	V	415/240	415/240
Rated Frequency	Hz	50	50
Phases	No.	3	3
Rated Power Factor (PF)	Cos ϕ	0.8	0.8
Year of Manufacture	Year	2019	2019
Running Hours	Hrs	8457	8434

Appendix A-2: Baseline Diesel Consumption

Table 6.2: Facility Baseline Diesel Consumption

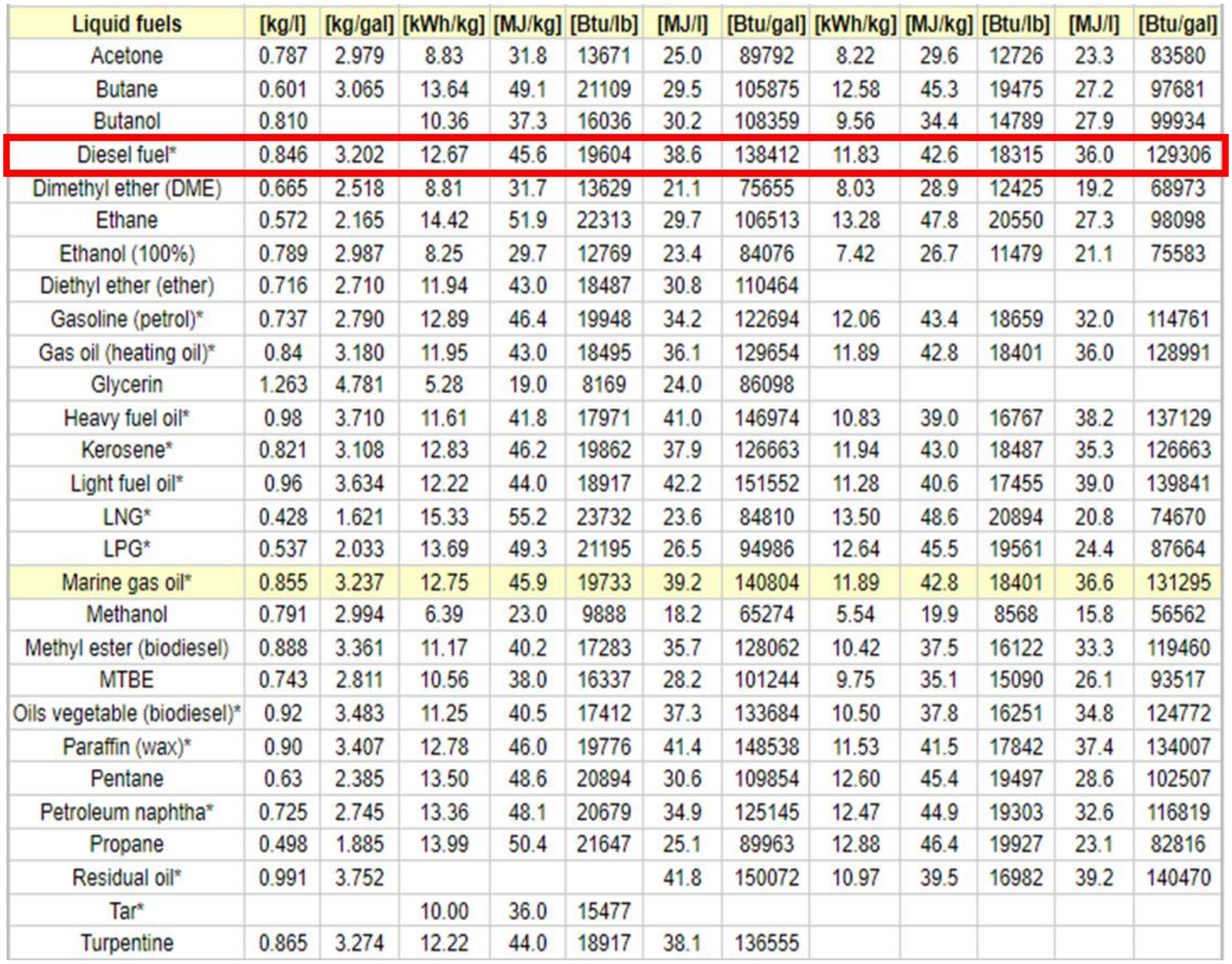
Month	Days	Diesel Consumption	Cost	Total Cost	Primary Energy	Electrical Energy	Daily Energy	Unit Cost
		L	USD/L	USD	kWh	kWh	kWh/Day	USD/kWh
Jan-20	31	41,664.00	0.97	40,414.08	496,079.36	111,617.86	**3,600.58**	0.362
Feb-20	28	38,976.00	0.97	37,806.72	464,074.24	104,416.70	**3,729.17**	0.362
Mar-20	31	41,664.00	0.97	40,414.08	496,079.36	111,617.86	**3,600.58**	0.362
Apr-20	30	43,200.00	0.97	41,904.00	514,368.00	115,732.80	**3,857.76**	0.362
May-20	31	42,460.00	0.97	41,186.20	505,557.07	113,750.34	**3,669.37**	0.362
Jun-20	30	41,194.00	0.97	39,958.18	490,483.23	110,358.73	**3,678.62**	0.362
Jul-20	31	41,760.00	0.97	40,507.20	497,222.40	111,875.04	**3,608.87**	0.362
Aug-20	31	40,510.00	0.97	39,294.70	482,339.07	108,526.29	**3,500.85**	0.362
Sep-20	30	40,510.00	0.97	39,294.70	482,339.07	108,526.29	**3,617.54**	0.362
Oct-20	31	43,270.00	0.97	41,971.90	515,201.47	115,920.33	**3,739.37**	0.362
Nov-20	30	40,510.00	0.97	39,294.70	482,339.07	108,526.29	**3,617.54**	0.362
Dec-20	31	40,510.00	0.97	39,294.70	482,339.07	108,526.29	**3,500.85**	0.362
Jan-21	31	44,640.00	0.97	43,300.80	531,513.60	119,590.56	**3,857.76**	0.362
Feb-21	28	39,341.00	0.97	38,160.77	468,420.17	105,394.54	**3,764.09**	0.362
Mar-21	31	44,765.00	0.97	43,422.05	533,001.93	119,925.44	**3,868.56**	0.362
Apr-21	30	42,815.00	0.97	41,530.55	509,783.93	114,701.39	**3,823.38**	0.362
May-21	31	43,560.00	0.97	42,253.20	518,654.40	116,697.24	**3,764.43**	0.362
Jun-21	30	43,560.00	0.97	42,253.20	518,654.40	116,697.24	**3,889.91**	0.362
Jul-21	31	43,293.00	0.97	41,994.21	515,475.32	115,981.95	**3,741.35**	0.362
Aug-21	31	44,344.00	0.97	43,013.68	527,989.23	118,797.58	**3,832.18**	0.362
Sep-21	30	43,196.00	0.97	41,900.12	514,320.37	115,722.08	**3,857.40**	0.362
Oct-21	31	44,437.00	0.97	43,103.89	529,096.55	119,046.72	**3,840.22**	0.362
Nov-21	30	43,455.00	0.97	42,151.35	517,404.20	116,415.95	**3,880.53**	0.362
Dec-21	31	44,619.00	0.97	43,280.43	531,263.56	119,534.30	**3,855.95**	0.362
TOTAL		**1,018,253.00**		**987,705.41**	**12,123,999.05**	**2,727,899.79**		
Average		**42,427.21**	**0.97**	**41,154.39**	**505,166.63**	**113,662.49**	**3,737.37**	**0.362**

Appendix A-3: Lighting Inventory Summary

Table 6.3: Lighting Inventory Summary

Type of Lighting	Unit Wattage (W)	Choke (W)	Total Fixtures	Total Tubes/Bulbs	Total Lamps Wattage	Lighting Load (kW)	Daily Energy Consumption (kWh)
Single 4ft. Fluorescent Tube (T8)	36	10	488	488	22,448	22.448	155.664
14 W Compact Fluorescent Lamp	14	0	457	457	6,398	6.398	36.666
Single 2ft. Fluorescent Tube (T8)	18	10	75	75	2,100	2.1	15.484
7 W LED Bulb	7	0	13	13	91	0.091	0.707
20 W Compact Fluorescent Lamp	20	0	6	6	120	0.12	0.12
4Way 2ft. x 2ft. Fluorescent Tube (T8)	18	10	10	19	532	0.532	3.556
11 W LED Downlights	11	0	20	20	220	0.22	1.012
50 W LED Floodlight	50	0	2	2	100	0.1	1.2
40 W Incandescent Lamp	40	0	51	51	2,040	2.04	16.76
9 W LED Bulb	9	0	1	1	9	0.009	0.045
100 W LED Floodlight	100	0	1	1	100	0.1	2.4
18 W Compact Fluorescent Tube	18	0	179	179	3,222	3.222	38.664
TOTAL			**1303**	**1312**	**37,380**	**37.38**	**272.278**

Appendix A-4: Diesel Fuel Properties



Liquid fuels	[kg/l]	[kg/gal]	[kWh/kg]	[MJ/kg]	[Btu/lb]	[MJ/l]	[Btu/gal]	[kWh/kg]	[MJ/kg]	[Btu/lb]	[MJ/l]	[Btu/gal]
Acetone	0.787	2.979	8.83	31.8	13671	25.0	89792	8.22	29.6	12726	23.3	83580
Butane	0.601	3.065	13.64	49.1	21109	29.5	105875	12.58	45.3	19475	27.2	97681
Butanol	0.810		10.36	37.3	16036	30.2	108359	9.56	34.4	14789	27.9	99934
Diesel fuel*	0.846	3.202	12.67	45.6	19604	38.6	138412	11.83	42.6	18315	36.0	129306
Dimethyl ether (DME)	0.665	2.518	8.81	31.7	13629	21.1	75655	8.03	28.9	12425	19.2	68973
Ethane	0.572	2.165	14.42	51.9	22313	29.7	106513	13.28	47.8	20550	27.3	98098
Ethanol (100%)	0.789	2.987	8.25	29.7	12769	23.4	84076	7.42	26.7	11479	21.1	75583
Diethyl ether (ether)	0.716	2.710	11.94	43.0	18487	30.8	110464					
Gasoline (petrol)*	0.737	2.790	12.89	46.4	19948	34.2	122694	12.06	43.4	18659	32.0	114761
Gas oil (heating oil)*	0.84	3.180	11.95	43.0	18495	36.1	129654	11.89	42.8	18401	36.0	128991
Glycerin	1.263	4.781	5.28	19.0	8169	24.0	86098					
Heavy fuel oil*	0.98	3.710	11.61	41.8	17971	41.0	146974	10.83	39.0	16767	38.2	137129
Kerosene*	0.821	3.108	12.83	46.2	19862	37.9	126663	11.94	43.0	18487	35.3	126663
Light fuel oil*	0.96	3.634	12.22	44.0	18917	42.2	151552	11.28	40.6	17455	39.0	139841
LNG*	0.428	1.621	15.33	55.2	23732	23.6	84810	13.50	48.6	20894	20.8	74670
LPG*	0.537	2.033	13.69	49.3	21195	26.5	94986	12.64	45.5	19561	24.4	87664
Marine gas oil*	0.855	3.237	12.75	45.9	19733	39.2	140804	11.89	42.8	18401	36.6	131295
Methanol	0.791	2.994	6.39	23.0	9888	18.2	65274	5.54	19.9	8568	15.8	56562
Methyl ester (biodiesel)	0.888	3.361	11.17	40.2	17283	35.7	128062	10.42	37.5	16122	33.3	119460
MTBE	0.743	2.811	10.56	38.0	16337	28.2	101244	9.75	35.1	15090	26.1	93517
Oils vegetable (biodiesel)*	0.92	3.483	11.25	40.5	17412	37.3	133684	10.50	37.8	16251	34.8	124772
Paraffin (wax)*	0.90	3.407	12.78	46.0	19776	41.4	148538	11.53	41.5	17842	37.4	134007
Pentane	0.63	2.385	13.50	48.6	20894	30.6	109854	12.60	45.4	19497	28.6	102507
Petroleum naphtha*	0.725	2.745	13.36	48.1	20679	34.9	125145	12.47	44.9	19303	32.6	116819
Propane	0.498	1.885	13.99	50.4	21647	25.1	89963	12.88	46.4	19927	23.1	82816
Residual oil*	0.991	3.752				41.8	150072	10.97	39.5	16982	39.2	140470
Tar*			10.00	36.0	15477							
Turpentine	0.865	3.274	12.22	44.0	18917	38.1	136555					

Figure 6.2: Diesel Fuel Properties. Adapted from [37]

Appendix B

Appendix B.1: PEL 103 Error Analysis

Table 6.4: PEL 103 Specifications and Accuracy

Measurement	Measurement range	Accuracy
PEL 103 POWER ANALYSER		
Frequency (f)	[42.5 Hz to 69 Hz]	± 0.1% Hz
Phase to neutral voltage (V)	[10 V ; 1000 V]	± 0.2% ± 0.2 V
Phase to phase voltage (U)	[17 V ; 1700 V]	± 0.2% ± 0.4 V
Current (I) without current sensor	[0.2% Inom ; 120% Inom]	± 0.2% ± 0.02% Inom
Active Power (P)	PF= [0.5 inductive ; 0.8 capacitive]	± 0.7% ± 0.0007% Pnom
	V= [100 V ; 1000 V]	
	I= [5% Inom ; 120% Inom]	
Reactive Power (Q)	Sin ϕ = [0.5 inductive ; 0.5 capacitive]	± 1% ± 0.015% Qnom
	V = [100 V ; 1000 V]	
	I = [5% Inom ; 120% Inom]	
Apparent Power (S)	V = [100 V ; 1000 V]	± 0.5% ± 0.005% Snom
	I = [5% Inom ; 120% Inom]	
Total Harmonic Distortions (THD)	PF = 1	± 1%
	V = [100 V ; 1000 V]	
	I = [5% Inom ; 120% Inom]	

Appendix C

Appendix C1: Implemented ECMs

	
Energy Star-rated A/C	*LED Security Light*
	
Energy Star-rated Printer	*Energy Star-rated Deep Freezer*

Figure 6.3: Implemented Energy Conservation Measures

Appendix C2: Sample Energy Star Ratings

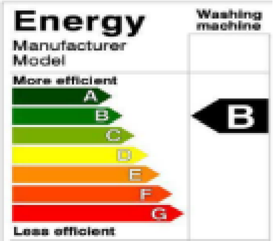
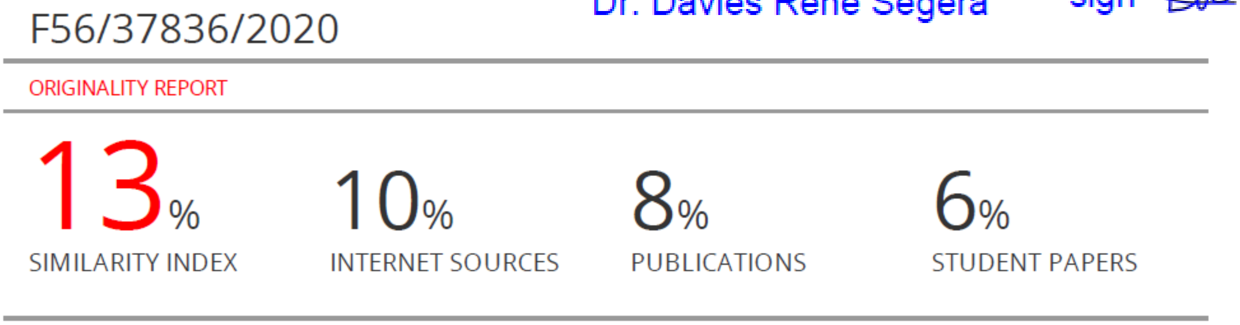
		

Figure 6.4: Sample Energy Star Ratings

Appendix D: Turnitin Originality Report

Prof Cyrus Wekesa Wabuge sign

Dr. Davies Rene Segera sign



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