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DEVELOPING A CASE STUDY FOR EFFICIENT UTILIZATION OF SOLAR PV SYSTEMS IN SOMALIA

M.Sc. Thesis by

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DEVELOPING A CASE STUDY FOR EFFICIENT UTILIZATION OF SOLAR PV SYSTEMS IN SOMALIA

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by

Abdullahi Abdisalam Hassan

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M.Sc. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"DEVELOPING A CASE STUDY FOR EFFICIENT UTILIZATION OF SOLAR PV SYSTEMS IN SOMALIA"** completed by **ABDULLAHI ABDISALAM HASSAN** under the supervision of **PROF. DR. BÜLENT YEŞİLATA** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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2023, 13 April **Abdullahi Abdisalam Hassan**

DEVELOPING A CASE STUDY FOR EFFICIENT UTILIZATION OF SOLAR PV SYSTEMS in SOMALIA

ABSTRACT

This thesis explores the potential of photovoltaic systems as a solution to Somalia's power problems, such as lack of access and high costs. The study looks at a rural area called Jazeera, 15km away from Mogadishu, which faces power shortages. The results show that grid extension and microgrid systems are not cost-effective, but solar home systems are suitable solutions for homes that fall into three categories according to power consumption. The thesis also analyzed Safari Hotel, located at latitude (2.033) and longitude (45.3044), where electricity bills are high, the design and investigation of this project is carried out by using a mathematical approach and Photovoltaic Geographical Information System (PVGIS) for getting all necessary data and calculating monthly and annual PV generation in this project. The result showed that hybrid and grid-connected solar systems could reduce costs by at least fifty percent. 126 solar panels, 72 batteries, and 4 inverters would be required for a hybrid solar PV system; the estimated capital cost for this system is $83,800, and this system has an estimated payback period of 2.5 years, while the grid-connected solar system in this study used two different feed-in-tariff models: a grid-tied PV system that uses the gross metering billing method would require 189 solar panels and 5 grid-tied inverters; this system has the annual capability of producing 175223.24 kWh; the estimated capital cost for this system is $33,490 with a 1-year payback period; while another one that uses the net metering billing method would require 126 solar panels and 4 grid-tied inverters, this system has the annual capability of producing 116815 kWh; the estimated capital cost for this system is $25,000 with a 9-month payback period. Through the use of the designs and analyses in this thesis, there is a chance of eliminating at least 93452.456 kg per year of carbon dioxide that would have been emitted from a diesel generator producing the same amount of electricity. This also provides an opportunity to save $33,292 per year that would have been paid to electric utility companies. This thesis concludes that solar energy is the best solution for Somalia's electricity challenges.

Keywords: Solar energy, photovoltaic system, renewable energy, electricity.

SOLAR'DA GÜNEŞ FV SİSTEMLERİNİN ETKİN KULLANIMINA YÖNELİK BİR VAKA ÇALIŞMASI GELİŞTİRİLMESİ

ÖZ

Bu tez, fotovoltaik sistemlerin, sınırlı erişim ve yüksek maliyetler de dahil olmak üzere, Somali'nin güç sorunlarını ele alma potansiyelini araştırıyor. Çalışma, Mogadişu'ya 15 km uzaklıkta bulunan ve sık sık elektrik kesintilerinden muzdarip olan kırsal Cezire bölgesine odaklanıyor. Bulgular, şebekeyi genişletmenin veya mini şebeke sistemlerini uygulamanın uygun maliyetli çözümler olmadığını, ancak güneş enerjili ev sistemlerinin güç tüketimine göre üç kategoriye ayrılan evler için pratik olduğunu gösteriyor. Ayrıca çalışmada enerji faturalarının yüksek olduğu enlem (2.033) ve boylamda (45.3044) yer alan Safari Oteli de incelenmektedir. Araştırma, aylık ve yıllık PV üretimi için gerekli tüm verileri ve hesaplamaları içerir. Sonuçlar, hibrit ve şebekeye bağlı güneş sistemlerinin maliyetleri en az yüzde elli oranında azaltabileceğini gösteriyor. Örneğin, bir hibrit güneş enerjisi sistemi, tahmini sermaye maliyeti 83.800 $ ve geri ödeme süresi 2,5 yıl olan 126 güneş paneli, 72 pil ve 4 invertör gerektirir. Çalışma ayrıca şebekeye bağlı güneş enerjisi sistemleri için önemli maliyet tasarrufu sağlayabilecek ve karbondioksit emisyonlarını azaltabilecek iki farklı tarife garantisi modelini araştırıyor. Bu tezde sunulan tasarım ve analiz kullanılarak, benzer miktarda elektrik üreten bir dizel jeneratör tarafından üretilecek yılda 93452.456 kg'a kadar karbondioksiti ortadan kaldırmak mümkündür. Ek olarak, güneş enerjisi çözümlerinin uygulanması, kamu hizmeti şirketlerine ödenecek yılda 33.292 $ tasarruf sağlayabilir. Sonuç olarak bu tez, güneş enerjisinin Somali'nin elektrik sorunlarına en etkili çözüm olduğu sonucuna varıyor.

Anahtar Kelimeler: Güneş enerjisi, fotovoltaik sistem, elektrik, yenilenebilir enerji

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NOMENCLATURE

Acronyms

RES	Renewable Energy Sources
PV	Photo Voltaic
NASA	National Aeronautics and Space Administration
SSE	Surface and Solar Energy
PVGIS	Photovoltaic Geographical Information System
MPP	Maximum Power Point
GHG	Green House Gas
CSP	Concentrated solar power
IEA	International Energy Agency
TES	Total Energy Saving per day
DOD	Depth Of Discharge
AC	Alternating Current
DC	Direct Current
PSH	Peak Sun Hours
MW	Mega Watt
SOC	State of Charge
PR	Performance Ratio
Pbp	Payback period
kWh	Kilowatt hour

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CHAPTER 1

INTRODUCTION

The preliminary objective of this section is to explain the background and motivation behind this thesis. Problem statement, objectives, scope of the thesis

1.1 Background

Since the breakdown of Somalia's central government in 1991, post-crisis and instability have dominated Somalia's tabloids for decades, the calm and dynamism brought about by the growth of private enterprises have continued to maintain normal life in Somalia while electrical services continued to be one aspect of the private enterprise in Somalia. Meanwhile, most energy firms generate power using diesel genset, which impacts and creates critical issues relating to excessive electricity prices renewable energy solves many problems related to fossil fuel sources. They also exist naturally and can be used to replace fossil fuels to generate electricity. Renewable energy, often known as clean energy, is generated by natural sources such as wind, sun, biomass, hydropower, and waves. Renewable energy sources are limitless, and the energy generated from them emits no greenhouse gases [1]. Solar photovoltaic technology is one of the fastest growing renewable energy resources that generate electric power on the globe. Its greatest advantages are that it is available anywhere in the world, clean, zero emissions, and low maintenance requirements; the application of photovoltaic systems extends from rural areas to urban areas. Usually, PV systems are classified according to their functional and operational requirements, component configurations, and the way the equipment is connected to various power devices.

1.2 Problem statement

- Electricity prices in Somalia are much higher compared to neighboring Kenya and Ethiopia. Rising electricity prices have been detrimental to commercial

investment, which was part of the reason why companies are cutting production and considering moving to neighboring countries, where production costs are cheaper, will the use of solar system reduce higher electric charges?

- Electricity in rural areas of Somalia is almost non-existent, how can the rural areas benefit from solar energy sources and what is the appropriate source and system for these areas?

1.3 Objectives

The aim of this thesis is to establish the following points,

- To encourage deployment and use of renewable energy sources in Somalia.
- To encourage and demonstrate to both local and international investing enterprises in Somalia that utilizing solar PV systems can reduce high electricity payments.

1.4 Scope of the work

This thesis focuses on developing a case study on the efficient use of solar PV systems in Somalia. Somalia confronts two major challenges: a lack of access to the power transmission network and excessive electricity prices, to get a solution for these two problems, firstly, a review of completed solar PV projects in Somalia will be carried out, and associated solar PV publications overview Somalia's geography, climate and energy consumption, solar PV importance to Somalia in comparison to alternative sources of energy, after that some examples to promote both local and foreign investment energy companies in Somalia are illustrated using the results of this thesis, which strongly concludes that utilization of solar PV system will reduce electricity costs and also minimize electricity shortages in Somalia.

CHAPTER 2

BACKGROUND WORK

2.1 Literature review of earlier works

It is essential to investigate literature sources on solar energy. As this thesis is one of the few papers on solar energy in Somalia, some solar PV systems projects have been mentioned and some research papers similar to this thesis have been reviewed:

The biggest electricity company in Somali, BECO, announced in 2020 that it had completed the installation of a new station to generate electricity from solar energy. It has the ability to generate 8 MW from this power plant and it operates only 4 hours per day. The aim of this project was to reduce the company's dependence on Diesel generators to produce electricity. This project also positively impacted many people living in Mogadishu as it reduced the electricity tariffs price per kilowatt-hour from $0.49 to $0.36 [3].



Figure 2.1 8 MW Beco solar power [3]

A microgrid hybrid electrification project established by Somalia Stability Fund (SSF) and carried out via SolarGen was kicked off in War-Sheikh in 2018. This project had a

production capacity of 33 kW. The goal was to offer affordable electricity to more than 200 houses in War-Sheikh by using solar energy. Prior to this project, the War-Sheikh community faced a shortage of electricity. After this undertaking was finished and began producing power in November 2018. The residents of War-Sheikh had access to electricity every day [4].



Figure 2.2 33 kW Solar power at War-shiekh [4]

Ceaser Migisha [5] presented a report on-site power generation opportunities and challenges with rooftop solar photovoltaic system for Uganda. Two building blocks tied with utility were taken as a case study, as daily blackouts in 2010 were approximately 8 hours. A standby generator that consumes diesel approximately 4,800 liters per year was used. The annual primary energy consumption was 191,127.5 kWh, excluding the power generated from standby diesel generators, which is 100,000 kWh per year, mathematical, simulation approaches and economic viability reviews have been applied to direct applicable energy efficiency which resulted in a significant energy saving of 90,404.5 kWh per year being realized. Evaluation of the PV power generation on the roof resulted in an annual output of approximately 124,328.75 kWh with approximately 8 years of payback period.

N. Jenkins [6] provided a paper on the approximate photovoltaic structure for small-scale and distant resistors. In his paper, he questions the technical components of using

photovoltaic structures for low-energy substances where connectivity from a large energy distribution network is in appropriate. The generation of various additives of the photovoltaic device is mentioned and the overall layout of the device is measured Characteristic programs of photovoltaic structures explained.

AlSalaymeh et Al. [7] researched the possibility of using a stand-alone solar PV system in Amman's residences also aimed to perform an economic analysis of the system while payback method for grid tied solar system was approximately three years which indicates a clear sign that utilizing on grid solar system is more suitable than utilizing standalone PV system in Jordan, as installation of a standalone system requires a higher initial investment than an on-grid system. An additional study by AlSalaymeh et Al.[7] used PV arrays to meet the energy requirements of the University of Jordan with an expected area of 15000m2 with 15MW power capacity . The results show that the proposed photovoltaic system achieved an internal rate of return (IRR) of 32% within a payback period of three years.

AL-Hasan et al. [8] studied the improvement of power load patterns in Kuwait utilizing on-grid PV systems, while the solar PV system and the power grid can both meet the power load demand, during the evaluation process it was found that both maximum incident solar radiation and peak load was equivalent in Kuwait which confirm the role of utilizing solar PV plants for minimizing demand of electric load, also considerable reduction in the peak load can be reached vie using on grid photovoltaic system

Akinyele [9] performed a techno-economic analysis of solar micro grid systems in three Nigerian locales, by using the worst-case scenario for residential consumption of energy. The investigation examined system losses, battery charge status, and the possibility of increasing load. The results showed that systems with 61, 76, and 68 kW could meet the needs of customers with an annual load of 63,500 kW/ h. The system incorporated a diesel generator, and assessments revealed that the starting cost was greater than that of PV micro-grid systems.

Various software applications have been deployed to calculate and simulate energy applications, especially in the renewable energy industry. PV Geographical Information System (PVGIS), Renewable energy technology screen (Retscrean), Hybrid Optimization Model for Electric renewable (HOMER) and PVsyst are widely used for PV system power generation simulation and design.

Khresat [10] assessed the feasibility of a 5 MW on-grid solar PV power station as a source of electricity in Jordan. RET Screen program was used to calculate plant yearly power output, specific yield, and economic indicators.

Harder and Gibson [11] investigated the possibilities of a 10MW solar power facility in Abu Dhabi using RetScreen modelling software to anticipate energy output, economic viability, and greenhouse gas (GHG) reducing emissions. In a life cycle cost study, the benefits of lowering greenhouse gas and air pollution emissions by replacing natural gas with PV power generation were assessed, with a net present value of USD 47 million.

Prasath and Boruah [12] used PVsyst software to simulate the energy efficiency of a university rooftop PV system. The results show that the solar power system will generate 590 MWh per year and reduce carbon emissions by 42 tons. The payload required by the Bikaner School of Engineering in India was designed and simulated using PVsyst software. In addition, PVsyst is used to analyze system performance ratio (PR) and losses.

Kumar, M.,Kumar, N.,Rejoice, P.R., Mathew, M. [13] implemented PVsyst software program to study the general performance and feasibility of installing a 100 kW photovoltaic device at the university institute. The simulation results indicated that the PV device produces 166 MWh per year, with an overall performance ratio of 80%.

Yaqoub Al-Khasawneh, Waid Omar, and Habis Al-Zoubi [14] discussed the viability of using a grid-connected photovoltaic system to power the hotel in Amman. Annual estimated actual energy consumption was 444 MWh, by utilizing both PVGIS and PVsyst software noticed that 912 solar panels spread among twelve converters, with area

of 1757.3 m² will be required for designing system which can generate 541 MWh per year with 82.8% of performance ratio, result achieved in the paper shows that payback period of the system will be approximately four years

Belmahdi and Bouardi [15] investigated by using PVsyst software using PVsyst Software of the prominent region in northern Morocco to install a 1 MWh PV system. The evaluation among locations was carried out based on the loss of the system, energy generation capacity of the system and performance ratio of the system.

Aminu Dankaka Adam, GokhanApaydin [16] published a paper on grid-connected photovoltaic systems as a tool for reducing greenhouse gas emissions in Turkey. Their paper shows how a 500 kWp photovoltaic (PV) power generation system contributes significantly to reducing greenhouse gas emissions and the potential impact of introducing carbon emission reduction costs into solar PV power. All solar radiation data needed for the design was sourced from RETScreen. The results show emissions reductions of up to hundreds of tons of carbon dioxide and that the cost of reducing carbon dioxide emissions has a positive impact on the system's cumulative cash flow.

Hussein et al. [17] assessed the possibility of a grid-connected solar PV system in Bangladesh using NASA SSE solar irradiance data, the GeoSpatial toolbox, and HOMER optimization software. In addition, the economic viability of a solar photovoltaic system as a source of power generation was assessed for 14 popular locations in Bangladesh using RETScreen modeling software and the proposed 1 MW grid-connected solar PV system. The study found favorable circumstances for the construction of the planned solar photovoltaic system for all of the sites studied in Bangladesh.

Christian Kwaku Amuzuvi [18] published an article on the design of a photovoltaic system as an alternative electrical energy source to power the lighting circuits of buildings in Ghana. The aim of the paper is to make comparison between solar PV systems and existing generators which have capacity. 60KVA, system analysis and design was performed by using PVSYST software and calculations were performed

taking into account the tilt and direction of the PV generator and its economics. The results discovered that the required battery capacity is 17850 Ah, the required solar capacity is 12.53 kW and 132 kW inverter size will be required for performance analysis. Can save a lot of lifelong energy, enhance reliability, and has a significant effect on the environment.

Salih et al [19] investigated the concept of an urgent energy system to provide power to a refugee camp on the Sudan-Chad borderline. The system was modeled and optimized using HOMER software. The electrical load at the camp was calculated and compared to the various configurations of the proposed energy systems. According to the evaluation results, solar PV panels, a high density polyethylene biogas, and a mini wind turbine system might supply enough power to the camp.

Ibrahim et al [20] carried out research for the design and optimization of a photovoltaic system adapted to an existing diesel grid system to power the city of Eldein in south-western Sudan. A total of four HOMER simulation results are optimally hybridized with a 2000kW PV, a 5000kW diesel generator, two batteries (each with a nominal capacity of 1000 kWh), and a 2000 kW power converter. It has been shown to provide better technical economic performance among all the cases investigated

Kebede [21] researched a 5MW feasibility study on-grid system solar PV plants at 35 different sites across Ethiopia. Technical analyses and financial performance of the system was done by using HOMER, which established that the average annually energy yield that can be generated at various locations is up to 8674 MWh, simulation results showed that while such projects are economically viable, as it is not very attractive to private investors, the study guided that more government support is needed for such investments.

Samykano and Sudhakar, Nallapaneni M. [22] presented a techno-economic study of a 1 MW grid-connected solar PV plant in Malaysia by using PVGIS and PV watts software. Their paper proposes a 1 MW solar PV power plant for UMP's rural and suburban campuses on the east coast of Pahang. The result of the study found that the

annual proposed plant can generate electricity around 1390 MWh, with a GHG emission reduction of 818.71 tCO2 also found that this system can contribute in meeting five percent of total energy needs of the campus. The technical performance achieved by PVGIS is very similar to the PV Watt results.

Oyetunde A, Oludamilare B.A., Kehinde A. and Abraham O.A. [24] used PVGIS software to develop technical study of on-grid and off-grid solar systems for residential usage in the Nigerian metropolis of Ogbomoso. The results in the paper showed that the estimated load of the off-grid system is 9.57 kWh per day, while the on-grid system is 4006 kWh per year, also showed that an array size of 3.5 kW and 86 kWh battery capacity are required to power the load for off-grid system, It was also found that eight 250W rated PV modules are sufficient to power the load on the grid system, On the other hand, the performance of both systems was about 71% for the on-grid system and about 75% for the off-grid method.

Youssef K., Hüseyin G., and A.S.F. Qand [25] conducted PVGIS simulations to assess the usability of solar systems with various technologies and solar tracking in Baghdad. They also found that owing to its high sun irradiation, Baghdad will be appropriate for deploying PV systems in the future. This report provides important information regarding building PV systems in Iraq to address the country's power issue and minimize the usage of fossil fuels.

2.2 Review of Photovoltaic Geographic Information System (PVGIS)

PVGIS has been the primary tool for obtaining basic geographic data required in a solar system, also it is free online which makes calculation and simulation of both off-grid and on-grid solar system anywhere in the world [26], meanwhile Google Maps are displayed on the left side of the simulator, making it very easy to select sites needed to simulate. The figure beneath indicates the beginning web page of PVGIS online application.

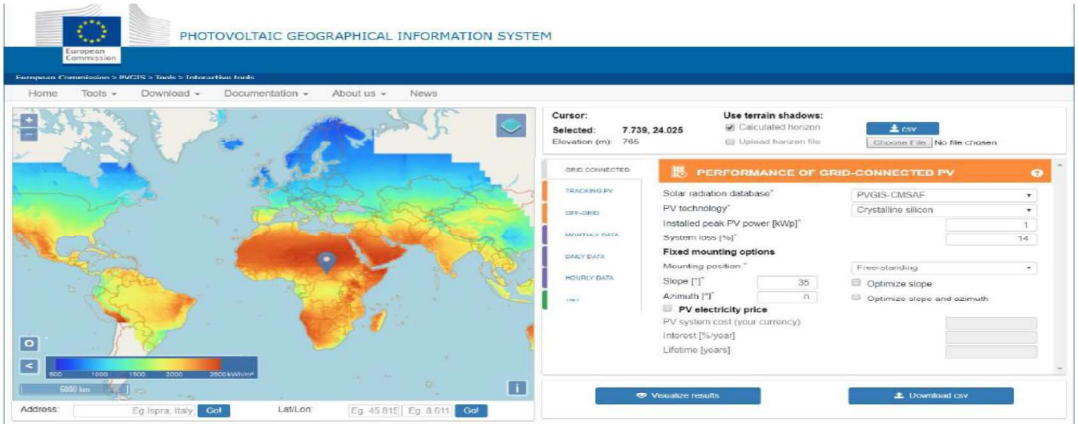


Figure 2.3 Start page of PVGIS [26]

PVGIS computes monthly as well as annual PV output in kWh, as well as monthly and annual solar radiation in kWh/m^2. In general, the PVGIS simulator offers the following essential features that can assist in gaining access to the required data.

a) Menu: It includes a drop-down menu of on-grid, tracking PV, off-grid, monthly information, daily information, hourly data, and typical meteorological year.

b) PV technology: An icon that indicates which sort of photovoltaic panel technology is being utilized for simulation.

c) Installed PV peak power: A symbol for inputting the maximum output of a pre-specified PV module at a fixed solar radiation of 1000 W/m^2 and a temp of 25 ° C.

d) Capacity of the battery

e) Percentage of system losses

f) Symbols for selecting the panel's mounting situation, open ground or building incorporated.

g) The last icon allows users to select whether to display a result or download comma-separated values

PVGIS was selected for this thesis because it is a free online application with forecasting relative accuracy to estimate produced energy by solar PV systems. As Somalia is a developing country, some financial parameters such as interest rates, debt rates and tax

rates are not used while most other applications require financial parameters to illustrate the result of estimating energy produced by a solar PV system. PVGIS illustrates the result without detailing the financial parameters of the system, as the main two points that need to use software for this thesis are to calculate monthly and annual PV generation in kWh of the system and solar radiation in kWh / m2 available in the site, while PVGIS can calculate them.

2.3 Overview of Somalia's geography, climate and energy consumption

As the thesis is concerned about developing study on the professional use of solar power system in Somalia, we need an overview of geography, climate and energy situation in Somalia

2.3.1 Geography and climate of Somalia

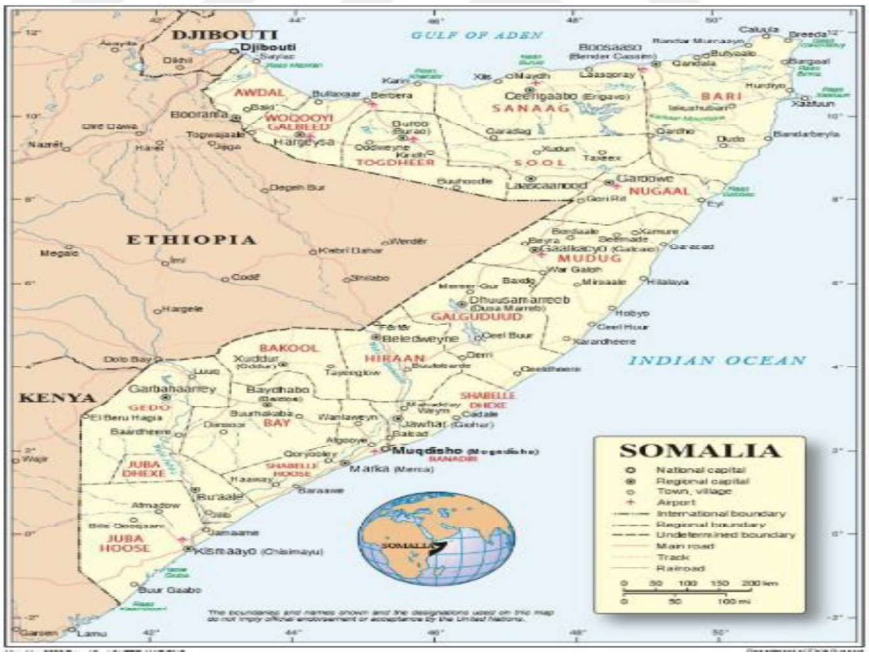


Figure 2.4 Somalia's map [27]

Somalia is a coastal country sited in East Africa in the Horn of Africa, which includes Ethiopia and Djibouti. Somalia lies between 11.55N and 1.39S and about 40E and 51E [16]. Its northern and mid-western territories are adjacent to Djibouti and Ethiopia. Kenya is on the south-western border and the Gulf of Eden is in northern Somalia. The Indian Ocean forms its eastern border. Somalia has the longest shoreline on the African continent with a coastline extending 3,333 km [27] and it has a total area of 637,657 square kilometers of which constitutes land [27], the country is divided into 18 different regions with population approximately 17 Million [16], the capital city Mogadishu has the highest population in Somali, the northern part of Somalia is a mountainous region, and in many places the height is 900 to 2,000 meters above sea level [27]. At an elevation of less than 180 meters above the sea level, the southern and central parts are essentially flat plateaus [27].The Shabelle and the Juba are the only perennial rivers in the country, but 90% of their flows begin in neighboring Ethiopia and flow southward in the direction of the Indian Ocean. Shabelle did not reach the sea until during heavy rains.

The climate of Somalia is mainly desert climate. Depending on the region, the climate is hot all year round with seasonal monsoon winds. Somalia has an irregular rainfall pattern with repeated droughts. In Somalia, there are 2 rainfall seasons -named Gu and Dayr- and 2 dry seasons -named Jiilaal and Hagaa-. Gu's rain falls from April through June, brings new meadows and briefly transforming the desert into a flowering paradise. The majority of the land is covered with lush flora, particularly on the central grazing plateau, where grass is abundant. The Hagaa drought (July/September) and Dayr rains (October/November) follow the Gu season. The next season is Jiilaal from December to March, which is the most challenging for ranchers and their herds [28]. In general, precipitation occurs in the form of local downpours and is very varied. Except where the altitude is high and along the Indian Ocean coast, the daily average highest temperature in the Somalia is between 30 and 40 °C. The daily average highest temperature varies from 20 ° C to over 30 ° C [28]. Extreme maximum temperature, recorded from below freezing in the highlands to above 45 ° C in the Gulf of Aden coastal plain from December to July. In the north, relative humidity ranges from around 40% in the

afternoon to 85% in the afternoon. It differs slightly based on the time of day and season. It varies slightly depending on the night and season. In December in the cold season February fog often reduces visibility in the highlands. Temperatures in the south are not so extreme, ranging from about 20 ° C to 40 ° C [28]. The hottest months are from February to April. Coastal measurements are usually 5-10 degrees lower than inland ones [28]. Relative humidity in coastal areas is usually about 70 percent even in the dry season [28].

2.3.2 Situation of energy in Somalia

The situation of energy in Somalia is developing gradually, with the growth of private enterprises maintaining normal life and electrical services being one aspect of private enterprise. Somalia is one of the countries with the lowest energy consumption in sub-Saharan Africa [29].

In Somalia, only certain homes and businesses have access to electricity, and the availability of power varies substantially by location and kind of habitation. The cost of consuming power in Somalia closely relates to the price of crude oil, Mogadishu has the lowest electricity cost per kilowatt hour at $0.3, which is significantly more costly than neighboring Kenya and Ethiopia.

On the other hand, people in Somalia who live in rural areas face energy shortages that affect their normal lives. While they use firewood as a main source of energy as it provides unhealthy and substandard lighting without additional energy services. This puts a lot of pressure on forest resources and contributes to desertification and the destruction of pastures and farmlands. The method of providing power to rural and remote locations is known as rural electrification. There are three approaches used for rural electrification: grid extension, micro-grid system and solar home systems [30].

The term "grid extension" describes a network expansion from the electric power grid to the rural and less developed areas through the construction of medium-voltage transmission lines and the installation of low-voltage distribution networks. Poles,

transformers, and transmission lines are the principal elements needed to extend the grid system. Steel poles and concrete poles are both often used in Somalia, however since the sea is to the east of the selected rural are in this study, the air there is too salty and corrosive for steel poles to survive. A typical good grade spun concrete pole has a minimum lifespan of 50 years [31] and it costs ranges between $600 to $1,000 [32].

A micro-grid is a rural power distribution system that employs both conventional and renewable local generation units; the system can only supply a limited number of users, which includes both houses and businesses that require power for productive purposes. Micro-grids are an intriguing and important step between independent and large-scale grid-based electricity systems, the system's scale, which has local control and can range from one to several hundred kW [33].

Solar home systems are small plants with built-in energy storage that supply electricity to specific homes or buildings. Solar home systems, also known as stand-alone photovoltaic systems, will be covered in the next sections.

2.3.2.1 Potential of Renewable Energy in Somalia

Renewable energy is one approach to addressing the country's energy shortages challenges, especially in the rural areas. According to the African Development Bank, the country has the highest potential of any African country for onshore wind energy, the vast coastline, which attracts offshore winds, is favorable for wind power. Wind speed measurements vary from a minimum of 3 m/s to a maximum of 11.4 m/s [29]. As for solar energy, there are several prospective to utilize the abundant solar energy resources and in fact, it has already been tapped. The most common applications include lighting, cooking, pumping and heating in public and private buildings. Somalia receives a daily amount of solar radiation ranging from 5 to 7 kWh/m^2 , which makes one of the countries which receives highest solar irradiation in the world [29].

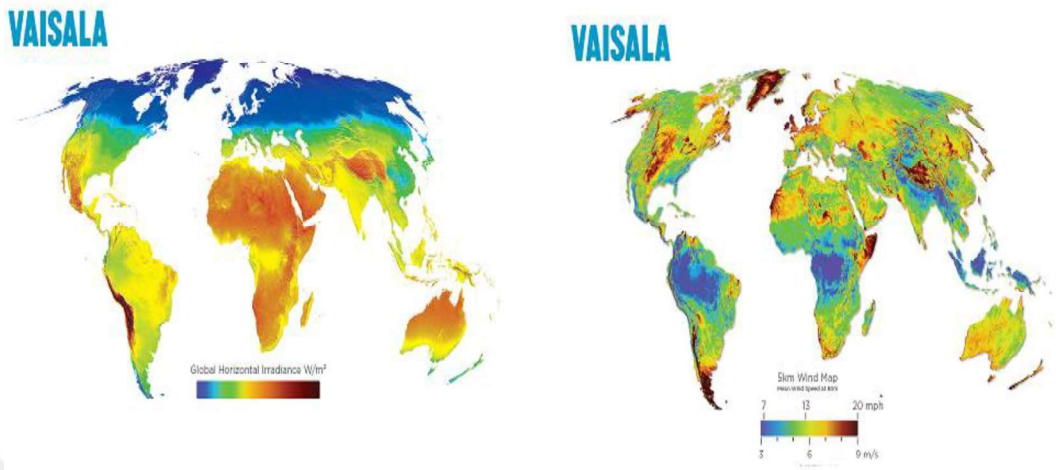
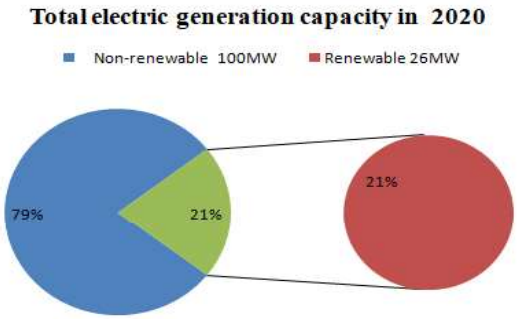


Figure 2.5 Global mean solar irradiance and wind speed [34]

According to the International Renewable Energy Agency (IRENA), the total electric production capacity in 2020 was 126MW, as most energy companies rely on diesel generators to generate electricity, so 100MW was from nonrenewable energy While 26 MW, which was 21% of total electricity production capacity in 2020, was generated from renewable energy, this was a step forward in reducing the electricity tariff price per kilowatt-hour by utilizing abundant renewable energy sources.

Table 2.1 Total generated electric capacity in 2020

Capacity in 2020	Power (MW)	Percentage
Non-Renewable energy	100 MW	79%
Renewable energy	26 MW	21%
Total	126 MW	100%



22MW of the total capacity of renewable energy was generated from solar and rest 4MW was generated from wind.

Table 2.2 Status of renewable energy in Somalia

Renewable energy capacity by 2020	Power (MW)	Percentage
Solar Energy	22 MW	85%
Hydropower	0 MW	0%
Bio-energy	0 MW	0%
Geothermal energy	0 MW	0%
Wind Energy	4 MW	15%
Total	26 MW	100%

2.4 Solar energy need in comparison to other renewable energy resources in Somalia

Different forms of renewable resources, like geothermal and hydroelectric, all have geographic limitations, while wind and solar possess less geographic limitation than other renewable energy sources. As we know the major problem statement of this thesis is about high electricity prices in urban areas and electric shortages in rural areas in Somalia. Some of the ways in which solar energy is better suited than wind energy; is that solar energy produces more predictable energy than wind energy, large-scale energy production is possible by using the solar farms, unlike wind turbines solar panels can be installed on the roof of a house or office, solar panels are more practical in suburban or

urban areas, utilizing solar power is much easier than wind energy, wind turbines are noisy, but solar operates completely quietly, and it allows for a faster installation with a minimum number of wires, solar requires less supervision and less maintenance solar energy is less susceptible to damage from lightning and strong wind [35].

2.5 Review of photovoltaic system related terminology used in this thesis

Photovoltaic systems are typically categorized based on functional and operational requirements, element configuration, and how equipment is connected to various energy sources and electrical loads. The major classifications of photovoltaic systems are grid connected systems and standalone systems, photovoltaic structures can be designed to provide DC and/or AC energy services, they can be connected or independent of the utility grid, and they can be connected to various energy sources and energy storage systems.

2.5.1 Stand-alone system (off-grid)

A photovoltaic system that is not connected to the grid is known as an off-grid PV system. This is the most commonly used as it provides power without a power supply. Therefore, the off-grid system is suitable in remote locations in countries where they have little or no access to electricity. Off-grid systems are those that can maintain a residence without the need of a network or other infrastructure. As the load's demands may differ from the output of the solar panels, the electrical power supplied by the solar photovoltaic panels inside the off-grid system must be saved or stored. Battery banks are also frequently used for this purpose. The major elements needed for using stand-alone PV system are solar panels that convert solar energy into electricity, battery banks used to store the energy, charge controllers used to protect the system, and an inverter is used to convert DC into AC. The following section describes and focuses on the remaining components of an off-grid PV system.

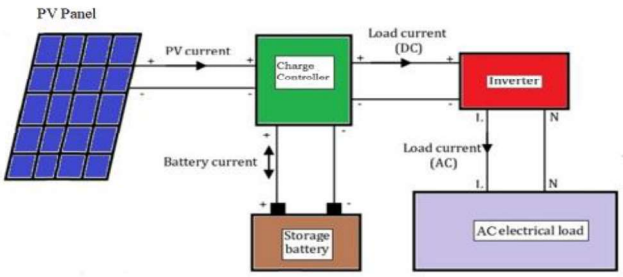


Figure 2.6 Stand-alone PV system

a) Battery

A battery is the essential element in a stand-alone PV system. It is made up of modules that contain cells; these cells facilitate chemical reactions depending on the state of charge of the battery which enables the battery to charge or discharge, respectively. The main purpose of batteries in off-grid PV systems is to store energy during sunny hours and power loads when sunlight is not available.

Lithium-ion (Li-ion) batteries and Lead-acid batteries are the two main types that are suitable for use with solar photovoltaic systems. Lithium-ion (Li-ion) batteries are the most recent technology on the market commonly found in high-end electronic equipment. They have a longer lifetime most products come with a minimum 10 year warranty [36], this longer life relates to lithium-ion batteries having a higher depth of discharge, and as a result of which more of the energy stored in the battery can be used before recharging, Lithium ion batteries are not commonly used in home solar PV-applications in Africa due to their high cost, relative to their size and weight [36]. Additionally, lead acid batteries have been in more frequent use for a much longer time than lithium-ion batteries, they have been used to store energy since the 1800s; lead acid batteries have a low depth of discharge which means they have a shorter lifetime-between five and 10 years [36]. Lead acid batteries are the most inexpensive energy storage option, making them the most cost effective. They are also reliable because of

the fact that the technology has been around for years, they may be effortlessly disposed of and recycled. Lead acid batteries technology may be found in different voltage ranges, i.e. 2V, 6V and 12V



Figure 2.7 Lithium-ion (li-ion) batteries and Lead-acid batteries

The following points describe some of the variables used to describe the present condition of a battery [37].

- SOC represents the (State Of Charge) of the battery as a percentage of maximum capacity. It is associated with the remaining quantity of electricity available in the battery. The value of SOC varies from 0% to 100%. When SOC is 100%, it means that the battery is fully charged, whilst when SOC is 50%, it means that the battery is half-full. SOC of a dead battery is 0%. To extend battery life the SOC should not exceed 50%, therefore, it is necessary to charge the battery when the SOC reaches 50%.

Table 2.3 State of charge 12volt Standard Batteries

Percentage of charge	Battery voltage
100%	12.7
85%	12.52
70%	12.36
55%	12.24
40%	12.12
25%	12
10%	11.94
0%	11.9

- Depth of Discharge (DOD) describes the percentage of battery capacity that has been discharged expressed as a percentage of maximum capacity.
  A discharge of at least 80 % DOD is referred to as a deep discharge.
- The terminal voltage is the voltage among the battery terminals with load applied. The terminal voltage changes depending on the SOC and charge / discharge current.
- The open circuit voltage is the voltage between the battery terminals when no load is applied. The open circuit voltage depends on the state of charge of the battery and increases with the state of charge.

b) Charge controller

The charge controller is a vital component in stand-alone PV systems, as we know it is very vital to charge and discharge the battery at the correct voltage and current to ensure a long battery life. A charge controller is an electronic machine which controls the current flowing from a solar array to a battery bank, when the produced PV power exceeds the load, extra power is sent to the battery. If the battery is charged full and the PV generator is still connected to the battery, the battery may be overcharged and it may cause some problems. The charge controller plays an important role here by disconnecting the PV generator from the battery, when the load exceeds the energy generated by the solar panel; the charge controller protects the battery and disconnects it from the load to prevent over-discharge. It also prevents power from flowing back into the solar panel overnight.



Figure 2.8 PWM and MPPT [38]

A solar charge controller is available in unique technology, Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT), both technologies are extensively used within the stand-alone PV system and are both great alternatives for correctly

charging the battery. The PWM controller is, in essence, a transfer that connects a solar array to the battery. The result is that the voltage of the array could be pulled right all the way down to close to that of the battery. The MPPT controller, which is more sophisticated, will alter and modify its input voltage to harvest the most energy from the solar array, after which it will remodel this energy to deliver the various voltage requirements of the battery plus load. Thus, it basically decouples the array and battery voltages. An MPPT charge controller has a greater price and is relatively more efficient than a PWM charge controller [38].

c) Inverter

The Inverter, also known as power conditioning unit is the heart of the stand-alone PV system. Most applications typically use AC power, where as the PV module and battery bank are power source of DC current. The inverter does the job of converting DC power to AC power in a PV system.



Figure 2.9 Off grid inverter

2.5.2 Grid-connected solar PV system

Grid-connected PV system, also known as a "grid-tied", or “on-grid" solar system, a grid-connected photovoltaic system is one which generates energy using solar photovoltaic panels and provides it to electric utilities. A grid-connected PV system is one that produces energy using a solar photovoltaic harvester and distributes it to an electric utility. They are not intended to be a replacement for grid electricity, unlike standalone PV systems. Grid-connected PV systems are commonly situated in metropolitan locations, where grid connection is commonly accessible. The electricity generated by the PV array is supplied back to the grid rather than stored in the battery.

As a result, the utility functions act as a kind of reserve medium, and electricity may be imported out from the utility when needed in the building. One of the fundamental benefits of on-grid PV system is its ease of use, cheap operating and maintenance expenses, and lower electricity bills. Additionally, the PV system, the electrical grid, or a combination of the two may power the property. This means that, depending on the owner's requirements, the system might be small or large. Excess power generated by the PV system is sent into the grid, and system owners are often compensated for the exported electricity. At the end of 2019, global grid-connected solar capacity was at 580.1 GW, along with 3.4 GW of off-grid PV capacity [39].

We may infer that grid-tied PV systems are more advantageous than other systems since the need for energy is increasing every day, and this demand cannot be met by traditional power plants. Grid-connected PV systems are more dependable than other types of PV systems, since the absence of a battery minimizes the initial investment, in this thesis a grid-connected configuration will be used. The period of time when the Solar PV system can supply the grid, from morning to afternoon, may be met if the generated solar energy is integrated into the conventional grid. The utility will keep supplying power for the balance of the time because there is no battery backup. Grid-tied

systems have shown to be advantageous in natural catastrophes, by supplying emergency power when utility power has been disrupted.

.The PV array, inverter, and metering system are the three essential components of a grid-connected PV system [37].

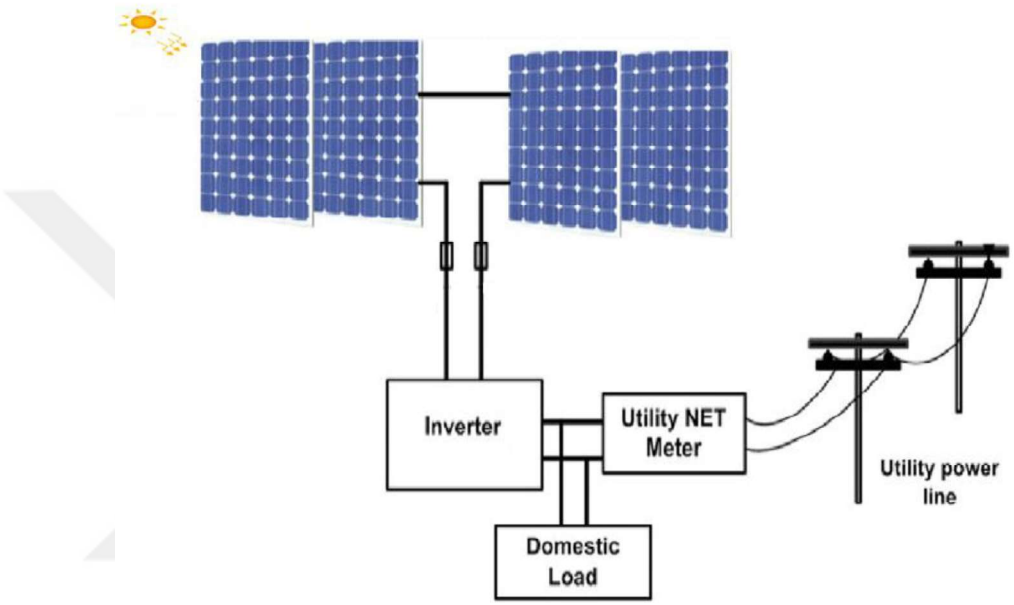


Figure 2.10 System component of grid-tied PV system

a) Inverter

Inverters are a critical component of every solar power system. While they are regarded as the heart of any solar project, it is a device that converts direct current (DC) power generated by a solar panel to alternating current (AC) electricity; in order to function properly and achieve peak performance. Some inverters offer extra services and capabilities like data monitoring and sophisticated utility controls. Due to this, inverter technologies have significantly improved. To reduce the cost curve of this product, inverter producers are continually pushing themselves to provide a greater

value inverter at a cheaper price. String inverters, Central inverters and Micro-inverters are some types of inverters that are mentioned in this thesis.

1) String inverters

In general, solar panels are installed in rows, one after the other on a string. In other words, if we have 25 panels, we will put them in 5 rows, with 5 panels in each row. As a result, we may link many string inverters to a single string inverter. Resultantly, string inverters are suited for systems in which the solar arrays are not oriented numerous directions and are placed in a fixed direction. String inverters are frequently observed in commercial and residential settings. With the use of this technology consumers may now have smaller string inverters with a better power efficiency. They are becoming more well-known and considered as the best option for tiny installations that do not exceed 1MW. Nowadays, the term "power optimizer" is used when referring to string inverters. This method has a better ability than string inverters to reduce the negative effects of shadow. Subsequently, a number of manufacturers are now simplifying the installation of solar panels by including power optimizers.

2) Central inverters

The features of central inverters are assumed to be similar to those of string inverters, with the exception that they are substantially larger and can accept more strings during panel installation. In this situation, modules of strings are not directly connected to the inverters. They are instead attached to a combiner box, which delivers direct current electricity to the central inverters, where it is converted to alternating current power. Central inverters can be utilized in large, high-productivity systems, the utilization of a central inverter will make monitoring of the system easier by reducing number of inverters and control panels. However, the performance of the whole system can be deeply reduced, because of connecting a large number of solar module strings to a central inverter. Therefore, if any error occurs at any solar module string will cause to stop the operation of the remain solar panel strings; on the other hand, a central inverter due to the weight and generated heat may require an additional concrete foundation to

place the inverter, central inverters are designed to be more suitable when working in harsh weather conditions.

3) Micro-inverters

Micro-inverters are mostly regarded to be an excellent choice for both residential and business usage. Since micro-inverters may also be installed on each individual panel, they are comparable to power optimizers. Micro-inverters, as opposed to optimizers, perform this conversion at the solar panel level, in other words. As a result, since the conversion is performed at the panel level, it won't affect the other panels if one performs worse than the others, and no risk will be signaled. Micro-inverters are known to be efficient and are perfect for installations with panels facing a variety of orientations; nevertheless, they are more expensive than string inverters.

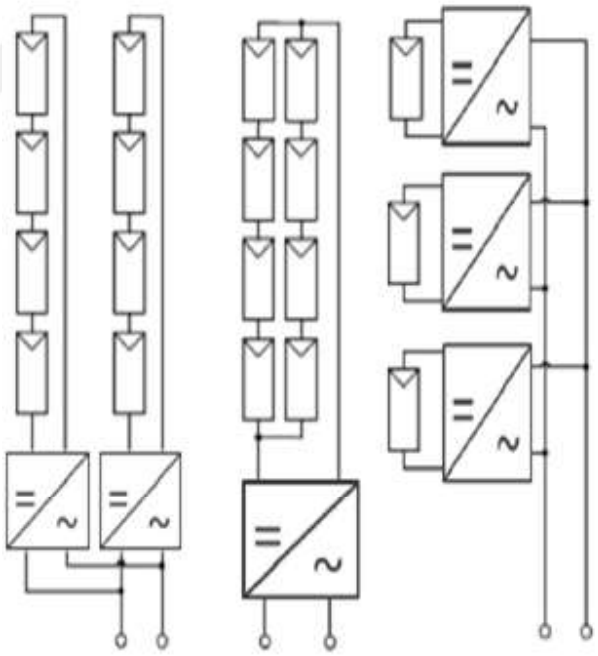


Figure 2.11 String inverters, Central inverters and Micro-inverters

We can conclude the comparison chart of String inverters, Central inverters and Micro-inverters in table below

Table 2.4 Comparison chart of the three main types of solar inverter

Point of view	**Central inverter**	**String inverter**	**Micro-string inverter**
Cost	Lowest	Lower	Expensive
Warranty	≥ 5 years	≥ 10 years	≥ 20 years
Connection	The PV arrays are connected in parallel to one central inverter	The PV strings are connected to separate inverters	Each PV module has an inverter integrated on it
Efficiency	Medium	High	Very high
Effect of error	Any error occurs at solar module string will cause to stop the operation of the remain solar panel strings	Does not affect the general operation of the whole system	Any error occurs in one micro-inverter will cause only one panel goes down, rather than the whole system
Scalability	More costly and complex	More costly and complex	Easier to expand the system
Monitoring	Easiest	Easier	Hard
Suitability	Suitable for commercial uses	Suitable for medium small scale	Suitable for use in homes
Maintenance	Very hard	Hard	Moderate

b) Solar energy utility meters

A key technique for grid-connected solar PV systems is metering, and the energy meter put in standard metering by the power utility is a unidirectional meter, with the ability to monitor the energy consumed by a building. Installing a grid-tied Solar PV system with

a standard uni-directional meter will record both the exported and consumed electricity. This will result in higher energy bills. To monitor energy export and import, three types of metering systems are available [40].

1) Net meters display a household's net power consumption. A net meter does not show how much solar power is provided to the grid or how much power is received from it. It implies a distinction between the two, net use.
   The great thing is that if extra solar energy is generated than is being consumed, the net meter actually runs backwards [40].
2) Bidirectional meters which have three display screens are also an option. One is a test display with all of the lighting fixtures turned on. The second implies grid energy flowing in, while the third shows solar energy leaving the system [40].
3) A dual metering method employs separate meters that can't interact with one another; the original utility meter was maintained to keep track of how much electricity was drawn from power grid. A second meter records the amount of solar energy transmitted to the power grid. This is known as production meter [40].

C) Metering Policy for billing process used in grid-tied solar systems

In this section we will cover some metering policies that are applicable in a grid-tied solar system. Nowadays, net metering and gross metering are the primary billing schemes utilized in grid-tied solar systems.

1) A net metering system is one in which electricity exports are offset by imports. A utility energy meter will read the energy used as (IMPORT) and the excess solar energy that is supplied back to the utility grid as (EXPORT) using net-metering (EXPORT). By implementing a net metering policy for the billing process, customers are boosted to utilize solar photovoltaic panels to cover the power consumption of their homes and utilize the supply from the power grid as a backup. Customers also benefit from certain credits on their bills if they offset

some or all of the energy back to the grid. This involves the use of bi-directional energy meters, which can measure supply from both consumer to utility and utility to consumer. This strategy not only assists utilities in managing demands during peak hours, but it also allows users to indirectly contribute to the electricity system [41].

2) Gross metering compensates users for the entire amount of solar energy units produced and provided to the utility, under gross metering clients are unable utilize the electricity produced by the solar PV system directly, under gross metering instead, the electricity is provided directly to the utility via another circuit, and the utilized electricity is sent from the utility. Feed-in tariffs and end-user supply costs have generally been separated. Utilities are choosing gross metering at a lower price, which is not a good choice for most customers compared to net metering [41].

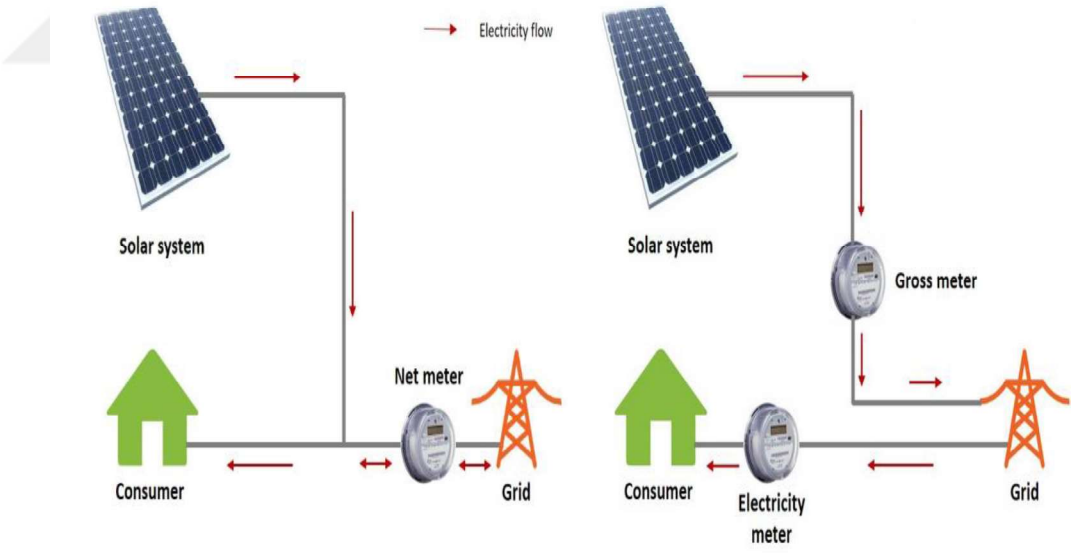


Figure 2.12 Net metering and Gross metering [41]

CHAPTER 3

METHODOLOGY

3.1 Utilization of Solar PV Systems in Somalia

The purpose of this thesis is to create a research study about the effective usage of solar Photovoltaic system in Somalia, the design and investigation of this project is carried out by using a mathematical approach and PVGIS for getting all necessary data and calculating monthly and annual PV generation in this project. Furthermore, estimating accurately the solar resources and calculating and analyzing the result, selection of the site, title angle of orientation are also important and contribute in optimizing the system for calculating the performances and so on. The first point of the problem statement of the thesis was whether using solar PV system as a renewable energy source can reduce higher electricity charges? The second point was electricity in rural areas of Somalia is almost non-existent. How can the rural areas benefit from solar energy sources and what is the appropriate system for these areas? In response to the first point, Safari hotel that pays $5000 per month in power costs is used as an example, a system reduces electric charges at least 50% by utilizing solar PV system will be designed, additionally, to respond to the second point of the thesis, data of a rural area called Jazeera 15 km from Mogadishu which faces electricity shortage was collected. By using a mathematical approach, how using solar energy can solve electricity shortages and which appropriate system for these areas will be pointed out.

3.2.1 Utilization of solar energy for reduction of high electricity charges in Somalia

Due to the location of Somalia, it receives high amounts of solar radiation all year round; because of this the country has huge potential for solar energy generation. Daily, on average the country receives solar irradiance of 5 to 7 kWh/m^2. This makes Somalia one of the top nations for daily solar irradiance. The country faces a challenge with

regards to connecting renewable energy systems to the grid, because of a lack of regulations and policies that allow prosumers to connect their systems to the utility grid. The utility companies are the ones that decide to approve or refuse for prosumers to make connections as a result of this situation.

In order to achieve the goal of the thesis, two systems will be designed; a hybrid PV system and a grid-connected solar PV system. The most practical way to reduce electricity costs is by using a grid-connected system. This system can be with or without a battery for storage. The preferred system for this thesis is a grid-tied system that does not have a battery as it has a cheaper capital cost. This system allows for solar energy to be fed back into the grid, and the solar energy generated will meet the demands from dawn to afternoon. Later on in the day the electricity from the grid provides for the system's demands.

At the moment, two billing schemes are mainly used in grid-tied solar systems; net metering and gross metering. With net metering the policy used encourages users to balance their energy requirements by using a PV solar system and the utility grid. Users can export excess electricity produced by the PV solar system to the utility grid, and import electricity from the utility grid when there is a deficit in the electricity from the PV system. On the contrary, gross metering users are reimbursed for the exported electricity that is fed into the utility grid. Under this policy the user cannot directly use any electricity produced by the PV solar system, rather the user gets all of their electricity from the utility grid.

Each system design will be different according to the metering policy implemented, and we will size and discuss them in separate sections. Prior to sizing the systems, the amount of solar radiation obtainable on the site is put into consideration and the PV panels that are suitable are selected.

a) Description of the Site

The site is a hotel called Safari hotel, it is located north of Aden Adde International Airport and is neighboring to Banadir Hospital. The exact coordinates of the site are (2.033) latitude and (45.3044) longitude. Monthly the hotel pays electricity bills that cost up to $5000. The aim of this thesis is to reduce the bill costs by 50%.

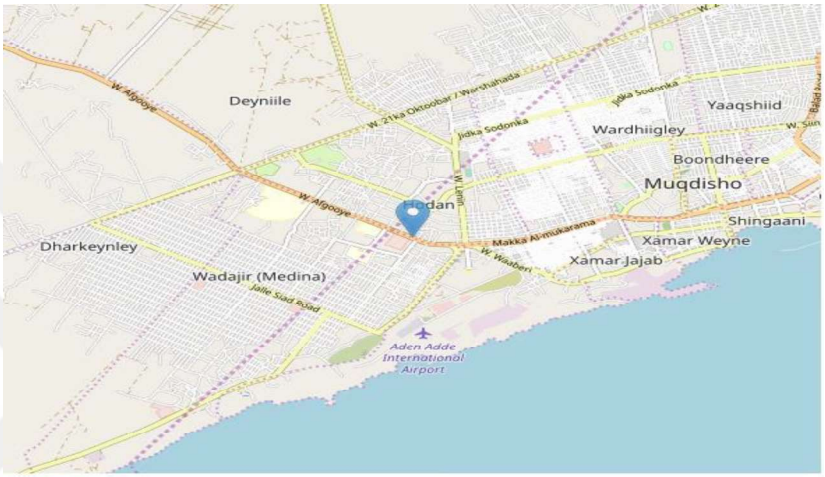


Figure 3.1 Location of Safari hotel

Information about the solar radiation in the area, we used the Photovoltaic Geographical Information System (PVGIS). This system provided the annual average daily solar irradiation of 6.43 kWh/m^2 at the site which is shown in Figure 3.2.2 the amount of solar radiation that a PV panel array receives is largely influenced by the longitude and latitude of the location. It is also notable that the highest amount of radiation received was in the month of March at 7.06 kWh/m^2 per day and the lowest being in July at 5.38 kWh/m^2 per day, with the average daily solar radiation being 6.4 kWh/m^2 according to the figures in Table 3.1.

Table 3.1 Solar radiations data from PVGIS

Location	**Monthly Solar Irradiation kWh/m2**		**Daily Solar Irradiation kWh/m²**
Latitude 2.033	January	216.21	6.97
Longitude 45.3044	February	206.27	6.87
	March	219.08	7.06
	April	195.5	6.51
	May	184.74	5.95
	June	163.18	5.43
	July	167.06	5.38
	August	184.92	5.96
	September	198.05	6.6
	October	206.03	6.64
	November	197.49	6.58
	December	210.117	6.77
	Annual	2348.647	76.72
Annual Average			6.4

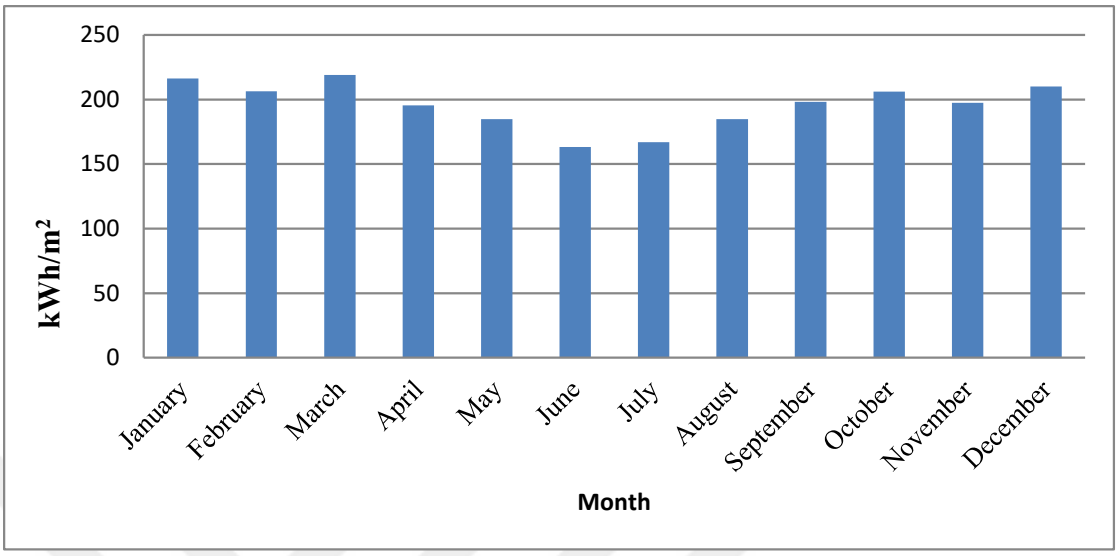


Figure 3.2 Monthly solar irradiation for safari hotel

b) Selection of PV modules

Three main criteria that are considered when choosing PV modules for grid-connected systems namely: cost, quality and panel lifespan. The PV systems that are being designed are purposed to function for several years, and the modules being considered are poly crystalline and mono crystalline. It is important that the modules selected have longevity and also at the same time because the modules are going to be purchased in large quantities, the cost is going to matter. In this thesis polycrystalline panels are going to be used as their cost is less than that of mono crystalline panels as well as having higher efficiency which leads to more optimal energy production. The orientation and inclination of the solar panels play a major role in how efficient the panels will produce electricity. To get high electricity output the panels should be placed facing towards the sun. In this case because the latitude is relatively low, the best angle to tilt the panels would be and angle almost equal to the latitude angle of the site, facing either north or south.

Table 3.1 Information of the PV module characteristic [42]

Mechanical Characteristics		**Electrical Characteristics**	
Solar cell type	Poly-Crystalline Cell	Power	460W
Number of cells	96	Max voltage rating (Vmp)	49.7V
Dimensions (mm)L*W*D	1956*1310*40	Operating current (Imp)	9.26A
Weight (kg)	26	Open circuit voltage(Voc)	61.2V
Warranty	25years	Short circuit current (Isc)	9.64A

c) System design

The system that is being designed is required to help save $2500 per month. The first step in the design process is to factor in the peak sunshine hours at the site.
The peak sunshine hours are the amount of time it takes for solar radiation to accumulate during peak solar conditions. It is important to know the peak sunshine hours when determining the sizing of the system for the hotel's needs.

Peak hours can be used to indicate the average hours of peak sunshine available at the site, during which the PV arrays are absorbing more than1 kW/m2. After the peak sunshine hours have been found, and then the system can be sized accordingly

$$\text{Psh} = \frac{\text{kWh}/\text{m}^2}{1\text{kW}/\text{m}^2} \tag{3.1}$$

$$\text{Psh} = \frac{6.4\text{kWh}/\text{m}^2}{1\text{kW}/\text{m}^2} = 6 \text{ hours}$$

1) PV sizing

To achieve a monthly cost of $2500, the minimum cost of power in Mogadishu which is $0.300/kWh must be taken into account. Under the assumption that the hotel operators and the utility company decide upon using the net metering policy, the daily energy output needed to get the total energy savings per day can be calculated by dividing the monthly electricity tariff savings by the product of the lowest price of electricity per kWh and the number of days in a month. As reflected in the following

$$\text{Total energy saved per day} = \frac{\text{saved electric tariffs}}{\text{price per kWh} \times \text{number of days in a month}} \quad (3.2)$$

$$\text{Total energy saved per day} = \frac{2500}{(0.3 \times 30)} = 278 \text{ kWh}$$

0.8 was chosen for the system's efficiency since the peak solar hours are 6 hours and the panels we chose each had a power capacity of up to 460 watt.

$$\text{Number of panels required} = \frac{278 \text{ kWh}}{6 \text{ h} \times 0.8 \times 460 \text{ W}} = 126 \text{ solar panels} \quad (3.3a)$$

If a gross metering policy is used, it may not be optimal as a solution because the feed-in rates and the costs associated with providing electricity to the end consumer are usually not the same. In this situation, the calculations for finding the daily energy output needed for achieving the targeted savings would still involve dividing the

$$\text{Total energy saved per day} = \frac{2500}{(0.2 \times 30)} = 417 \text{ kWh} \quad (3.2a)$$

monthly savings by the product of the lowest price of electricity per kWh and the number of days in a month.

$$\text{Number of panels required} = \frac{417\ \text{kWh}}{(6\text{h} \times 0.8 \times 460\text{W})} = 189\ \text{solar panels} \qquad (3.3b)$$

Since the peak power for both systems is the same, the PV size for the hybrid system is the same as the PV size for the system that uses net metering billing. To achieve the goal, which is reducing electricity costs by at least 50%, the required panels for the hybrid system are 126 panels. Each has a capacity of 460 watts.

2) Inverter sizing

When converting direct current (DC) produced by the PV system to alternating current (AC), an inverter is necessary. The inverter should be able to handle the system's peak power requirements. In order to do so, the inverter should be designed to operate at about the PV system's maximum capacity. This is done by finding the point at which the solar module's voltage and current values result in the highest output. It is preferred to select a true sinusoidal inverter, when selecting an inverter for a grid connected PV system. Moreover, the inverter must have a higher maximum output capacity than is required in order to meet the safety requirements. Table below shows inverter specification which we selected in this system

Table 3.3 Inverter Specification [43]

DC input		**AC input**	
Maximum DC Input Power	21000Watt	Power	20kW
Maximum DC Voltage	850V DC	Frequency	50Hz/60Hz
Maximum DC Input Current	60A	Power	20kW
MPPT Tracking Voltage Range	200-820V	Phase	3 phase4line(3L +N+PE)
Input Terminal	MC4	Maximum Current	30A

To establish the number of inverters necessary, we must first identify peak power. There are two different maximum power generated from the solar panels: one for system utilizing net metering and one for system use gross metering.

$$\text{Maximum generated solar power} = \text{no panels} \times \text{panel wattage} \tag{3.4}$$

$$\text{Maximum generated solar power} = 126 \times 460 = 58\ \text{kW}$$

$$\text{Maximum generated solar power} = 189 \times 460 = 87\ \text{kW}$$

As a result, the maximum generated solar power towards the net metering scheme under this system is 58kW. The required size of inverters can then be determined by multiplication 1.3 for a safety aspect and dividing the inverter's rated AC power.

$$\text{no. of inverters} = \frac{1.3 \times \text{maximum generated solar power}}{\text{inverter rated AC power}} \quad (3.5)$$

$$\text{no. of inverters} = \frac{1.3 \times 58\ \text{kW}}{20\ \text{kW}} = 4$$

While the maximum generated solar power towards the gross metering scheme under this system is 87kW, by sizing the inverter for the gross metering scheme, 1.15 was chosen as a safety factor in order to ensure that the system's overall cost would not be high.

$$\text{no. of inverters} = \frac{1.15 \times 87\ \text{kW}}{20\ \text{kW}} = 5$$

Since peak power is the same for both systems, the hybrid system inverter size will be calculated in the same manner that it was calculated for the system that uses the net-metering billing method, but a different inverter is used, while the system is hybrid the required inverters for the hybrid system are 4 hybrid inverters. Each has an output capacity 20kW.

3) Battery sizing

As previously stated, the battery is an essential component of hybrid PV system, because the utility companies may refuse to have excess power generated by the system being exported into the grid. Therefore, the excess power generated by the PV system is directed and stored in the battery bank.

Table 3.4 Battery specification [44]

Cell Per Unit	1
Voltage Per Unit	2
Nominal Capacity	3000Ah
Weight	214kg
Normal Operating Temperature	25°C±5°C

Various factors are taken into account when sizing a battery bank for a PV system; the number of days that the battery can supply loads without getting support from other sources and this value was found as 1 for autonomy days; the depth of charge which is the percentage of the battery charge that can be used before recharging which is 80%; also the nominal capacity, efficiency and the voltage of the battery are taken of importance.

$$\text{No. of batteries} = \frac{\text{energy storage required} \times \text{Autonomy days}}{\mu \times \text{DOD} \times \text{Nominal capacity} \times \text{Battery voltage}} \tag{3.6}$$

$$\text{No. of batteries} = \frac{278\ \text{kWh} \times 1}{0.8 \times 0.8 \times 3000\text{Ah} \times 2\text{V}} = 72$$

The batteries should be connected in series and parallel to meet the desired battery voltage of the inverter, which is 48V so each of the 24 batteries will be connected in series, and after that, they will be connected in parallel. Batteries will be connected 3 parallel *24 series. To make sure that the batteries are protected we selected MPPT charge control.

Table 3.5 Charge controller specification [45]

Battery Voltage	48V
Rated Charge Current	200A
Maximum DC PV Voltage	450 V
Start-up Voltage	120V
Weight	13.7kg

4) Combination for PV array

In order to avoid overloading the inverter, the solar panels are arranged in parallel, where their amperage is combined but the voltage remains constant. As combinations of parallel and series connections are used the desired amperage and voltage can be achieved. In net metering policy

$$\text{Minimum series of panels per string} = \frac{\text{Minimum inverter MPPT voltage}}{\text{Rated volatage of pv panel}} \quad (3.7)$$

$$\text{Minimum series of panels per string} = \frac{200}{49.7} = 4$$

It has been determined that 4 modules for each string is the minimum needed, while a maximum number of modules for each string must be established, as shown below.

$$\text{Maximum series of panels per string} = \frac{\text{Maximum. inverter MPPT voltage}}{\text{open circuit voltage}} \quad (3.8)$$

$$\text{Maximum series of panels per string} = \frac{820}{61.2} = 13$$

This implies the maximum number of modules that are supposed to be able to connect in series per string is 13, according to the ideal design, the number of series modules will range between 4 and 13 modules.

While calculating the maximum number of parallel strings, it is crucial to take the short circuit and maximum power point currents into account.
The number of strings per inverter could be calculated as follows.

$$\text{maximum number of strings per inverter} = \frac{\text{maximum DC input current}}{\text{short circuit of the panel}} \tag{3.9}$$

$$\text{maximum number of strings per inverter} = \frac{60}{9.64} = 6$$

This implies that the input of the inverter join up to 6 parallel strings in total. The boundaries of the solar system can be quickly found using manual calculations, however, the precision and predictability of the results can vary. Therefore the closest combination within the demands will be selected. According to previous calculations, 126 panels were split between four inverters, with two inverters connected to 33 panels each and the rest connected to 30 panels each. Inverters 1and 2 will each have three parallel strings, with each string consisting of 11 panels, concurrently Inverters 3 and 4 will have parallel three strings with each string having 10 panels. In total these are 126 panels which meets the required demand.

On the contrary, if the gross metering policy is applied a total of 189 modules assigned across five inverters. Inverter 1 will have five parallel strings and each string will be having 9 panels, the rest of the four inverters will be having four parallel strings with 9 panels. This sums up to 189 panels, which meets the required demand. The minimum number of modules per string is found to be 3 modules per charge controller.

$$\text{Minimum panels in series per controller} = \frac{\text{start up voltage of charge controller}}{\text{Rated voltage of PV Panel}} \tag{3.10}$$

$$\text{Minimum panels in series per controller} = \frac{120\text{V}}{49.7\text{V}} = 3$$

Now it is important to find the maximum possible number of modules per charge controller as follows

$$\text{Maximum panels in series per controller} = \frac{\text{Maximum voltage of chargecontroller}}{\text{open circuit voltage}} \tag{3.11}$$

$$\text{Maximum panels in series per controller} = \frac{450}{61.2} = 7$$

This implies that the maximum number of modules that are supposed to be able to connect in series per charge controller is 7. According to the ideal design, the number of series modules will range between 3 and 7 modules. While calculating the maximum number of parallel strings, it is crucial to take the short circuit and rated charge controller currents into account.

The number of strings per charge controller could be calculated as follows.

$$\text{Maximum panels in strings per controller} = \frac{\text{Rated charge controller current}}{\text{short circuit of the panel}} \tag{3.12}$$

$$\text{Maximum panels in strings per controller} = \frac{200}{9.64} = 20$$

Based on the maximum number of modules that can be connected in parallel strings per charge controller, which is 20, we need to identify the closest combination of panels that meet our requirements. In the previous section, we found that the total number of modules for our solar system is 126. We need to use five charge controllers to meet this requirement. Four of the charge controllers will each be connected to 24 panels, while the other charge controller will be connected to 30 panels. Charge controllers 1, 2, 3, and 4 will have six parallel strings, each with four panels. While charge controller 5 will

have six parallel strings, each with five panels. The total number of panels adds up to 126 which are enough to meet the requirements.

4) Cable sizing

The choice of wiring affects the functionality and the safety of the PV solar system. It is important to ensure that the cables do not hinder the operation of any component in the system. The cables must be appropriately sized to avoid voltage drops and wire losses, in a grid-tied system. Cables that are too small can result in fire hazards and significant losses in the system. Two types of solar system cables, DC cables, and AC cables, are used, with DC cables being placed on the DC side of the system and AC cables on the AC side of the system respectively. Depending on the solar array configuration, string cables and array cables may be used. The most commonly used DC cable diameters are 2.5mm, 4mm, 6mm, and 10mm. In this thesis, a maximum wire voltage drop of 5% (Vdmax) has been used, which is the highest allowable loss as per international regulations.

The following formulae [46] can be used to determine the physical size of the wire.

$$S = (0.3LI_m)/\Delta V \qquad d = \sqrt{(4S/\pi)} \tag{3.13}$$

While S is required cross-sectional area of the copper in sq.mm, L is length of the wire in meters I_m is the maximum current in Ampere, ΔV is allowable voltage drop and d is diameter of wire in mm

$$\text{Maximum current of the system} = \text{safety factor} \times \text{no. of string} \times \text{ISC} \quad (3.13a)$$

$$I_m = 1.25 \times 5 \times 9.64 = 60 \text{ A}$$

We took 5 as number of strings because it was the highest string number available in the system, as a precaution against having cables that are undersized which can lead to fire hazards.

$$S = (0.3 \times 10 \times 60)/5 = 36 \text{ mm} \quad d = \sqrt{((4 \times 36)/\pi)} = 6 \text{ mm} \quad (3.13b)$$

The cables that connect the individual PV modules or strings are routed to the combiner box, which is typically located on the supporting structure. These cables can be single-conductor pigtails with pre-wired connections on the PV modules. A combiner box typically includes a safety fuse or breaker for each string. Since this design involves three or more strings, string over-current protection is required to protect modules and conductors against excess current faults. Fuses are connected in series with each string to reduce safety issues and to isolate broken strings, allowing the remaining strings to continue producing energy.

Each string's protective fuse should have a rating of amperage, which could be calculated as follows:

$$\text{string fuse amper rating} = \text{safaty factor} \times \text{Isc} \tag{3.14}$$

$$\text{string fuse ampere rating} = 1.25 \times 9.64 = 12\ \text{A}$$

$$\text{Minimum voltage rating of fuse} \geq 1.25 \times \text{O.C voltage} \times \text{No. of panels in series} \tag{3.15}$$

As our design used different numbers of panels in the series, we took the highest number of panels in the series and it was 11 panels.

$$\text{Minimum voltage rating of fuse} \geq 1.25 \times 61.2 \times 11 = 840\ \text{V}$$

5) Required Land

In the designing of the system, we also take into consideration the amount of space and the condition of the land that the system is going to have its solar panels mounted on. Calculating the amount of space required for this system will be simple since we already know how many PV modules it requires. Multiplying the overall solar arrays number of panels by the area of each one, we must first establish the ideal minimum distance between the rows in order to minimize shadows between the solar panels. To avoid unwanted shadows between the solar panels, an approximation of the row spacing distance between panels may be calculated using the optimum tilt angle. The methods for calculating this distance value vary, but to prevent unwanted shadows from forming between the rows, one of the most common and fundamental techniques is to use an inter-row spacing that is three times the panel's height [46].

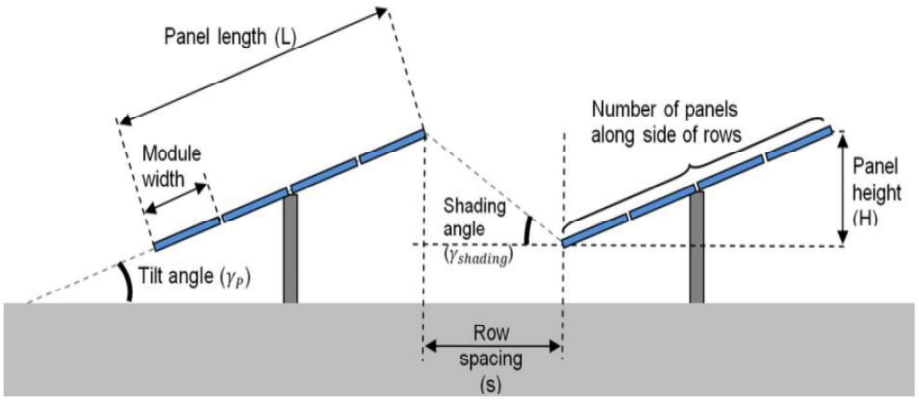


Figure 3.3 Row spacing between modules on a PV system [47]

$$D = 3 * H = 3 * L \cdot \sin(\beta) \tag{3.16}$$

Where L is the length of the module and β is the required inclination angle [46].

As we mentioned before the tilt angle was 5 degrees oriented due to south. Throughout this project each column comprises 3 panels hence module length would be three times the length of one panel which is equal to 3*2=6m

$$D = 3 * H = 3 * L \cdot \sin(\beta) = 3 * 6 * \sin(5) = 1.56m,$$

That implies the smallest space between rows is 1.5m. To eliminate undesired shadows among the rows of solar panels in this system, we chose a row spacing distance of 2m. We may calculate the system's necessary area based on the distance between the rows. We opted to use two different metering policies: net metering and gross metering. This was because we needed 126 PV panels for net metering and 189 PV panels for gross metering. Since the number of panels for gross metering is significantly higher, we chose to calculate the required system space based on this number. To determine the area required for the system, we first noted that each column has three panels, so 189 panels can be arranged in 63 columns (189/3=63). We then found that there are three

columns each with three panels, and each row contains twenty-one panels, resulting in a total of 3321=189 panels. Therefore, the required surface area for this system can be calculated as follows:

$$\text{Area} = \text{width} \times \text{length} \tag{3.17}$$

The length equals the total of solar panel length and the space between rows.

$$\text{Length} = (3\big((3 \times 2) + 2\big) = 24 \text{ m}$$

$$\text{width} = \text{no. rows} \times \text{width per panel}$$

$$\text{width} = 21 \times 1.5 = 31.5 \text{ m}$$

$$\text{Area} = 31.5 \times 24 = 756 \text{ sq. m}$$

In general, mild steel hollow sections are less expensive than aluminum. Due to that, mild steel hollow sections are the most common type used for solar mounting structures in Somalia. As a result, this system will need 95 of these sections (40*40 mm), 24 of these (75*75 mm), and 12 of these (50*50 mm).In this method, each mild steel hollow segment is six meters long.

d) Annual energy generation of the system

As the previous section mentioned system design, this section will illustrate the output of that design. The annual energy generation of the system was calculated using the system's monthly production of kWh. There are two types of energy output when calculating the system's energy output: expected energy output and actual energy output. The expected energy output, also known

as theoretical energy output, is determined by the system's peak power and the solar irradiation available at the site.

The theoretical energy produced each month can be computed mathematically using the formula below.

$$\text{Theor generated kWh per month} = \text{maximum power of the system} \times \text{monthly solar irradiation} \quad (3.18)$$

In this study, there are two separate peak power values: 57.96 kW for systems that utilize grid-tied solar PV systems by using the net metering billing method.

While 86.94 kW for a system that utilizes grid-tied solar PV systems by using the gross metering billing method. Tables and figures below depict the theoretical energy output (kWh) each month.

Table 3.6 Theoretical energy produced by the net metering billing method

Month	Monthly irradiation kWh/m^2	Peak power (kW)	Theoretical energy output (kWh)
JAN	216.2	57.96	12530.952
FEB	206.3	57.96	11957.148
MAR	219.1	57.96	12699.036
APR	195.5	57.96	11331.18
MAY	184.7	57.96	10705.212
JUN	163.2	57.96	9459.072
JUL	167.1	57.96	9685.116
AUG	184.9	57.96	10716.804
SEP	198.1	57.96	11481.876
OCT	206	57.96	11939.76
NOV	197.5	57.96	11447.1
DEC	210.2	57.96	12183.192
Annual			136136.448

Table 3.7 Theoretical energy produced by the gross metering billing method

Month	Monthly irradiation kWh/m^2	Peak power (kW)	Theoretical energy output (kWh)
JAN	216.2	86.94	18796.428
FEB	206.3	86.94	17935.722
MAR	219.1	86.94	19048.554
APR	195.5	86.94	16996.77
MAY	184.7	86.94	16057.818
JUN	163.2	86.94	14188.608
JUL	167.1	86.94	14527.674
AUG	184.9	86.94	16075.206
SEP	198.1	86.94	17222.814
OCT	206	86.94	17909.64
NOV	197.5	86.94	17170.65
DEC	210.2	86.94	18274.788
Annual			204204.672

While temperature loss, cabling and mismatch losses, conversion losses from DC to AC, and losses caused by dust and debris on panels all have an impact on the system's actual energy output, PVGIS was used to calculate the system's actual energy production per month. The figures below show the actual energy production (kWh) per month.

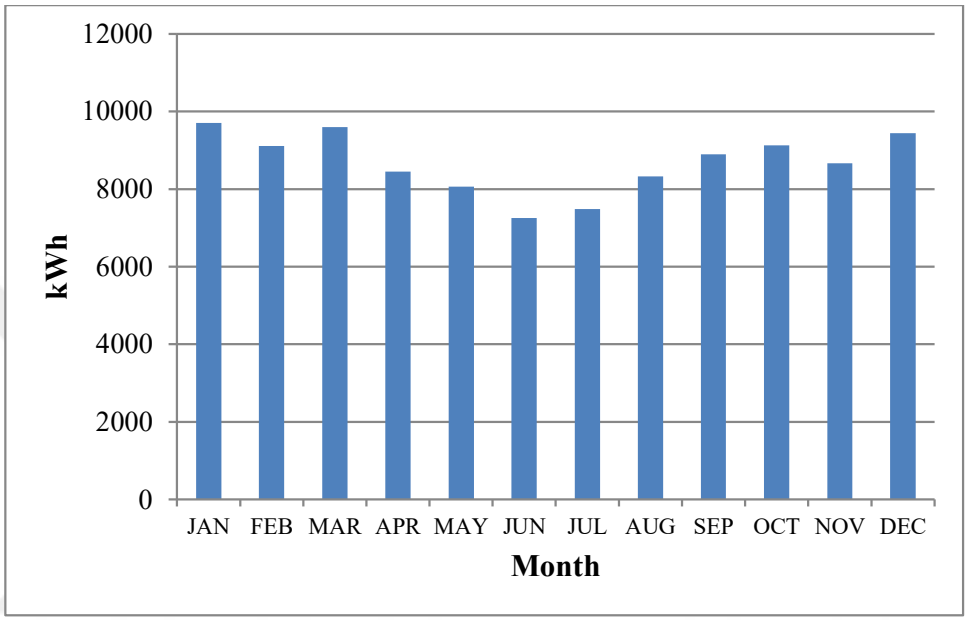


Figure 3.4 Actual energy produced by the net metering billing method

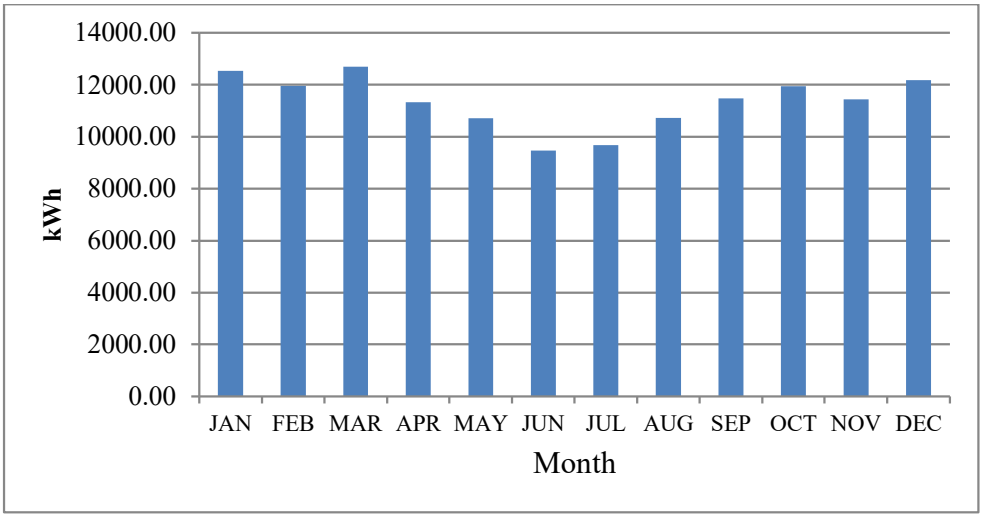


Figure 3.5 Actual energy produced by the gross metering billing method

To determine the quality ratio of a PV system, it is first necessary to calculate the system's performance ratio.

The performance ratio (PR) is a percentage-based measurement of a solar photovoltaic system's quality that indicates the ratio between the systems's actual and theoretical energy output [48]. As a consequence, after accounting for energy losses, it reflects the percentage of energy that is truly available at the site.

$$\text{Ratio of performance (PR)} = \frac{\text{System's actual energy output}}{\text{system's predicted energy output}} \tag{3.19}$$

This formula is used to calculate the system's monthly and annual performance ratios. The table below shows the performance ratio for each month for both systems

Table 3.8 Monthly performance ratio of system

Month	Performance ratio
JAN	77%
FEB	76%
MAR	76%
APR	75%
MAY	75%
JUN	77%
JUL	77%
AUG	78%
SEP	77%
OCT	76%
NOV	76%
DEC	77%

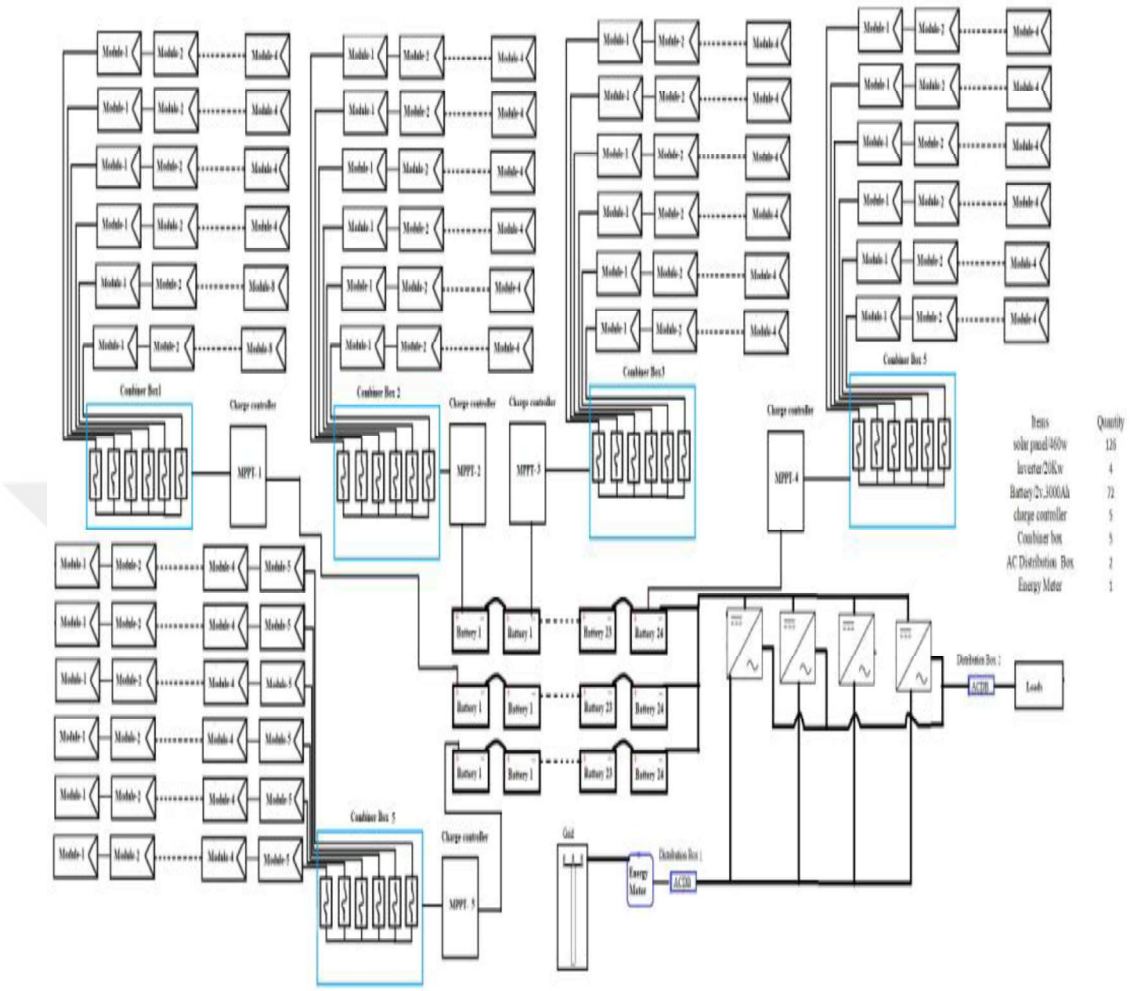


Figure 3.6 Single-line diagrams for system design of hybrid solar system

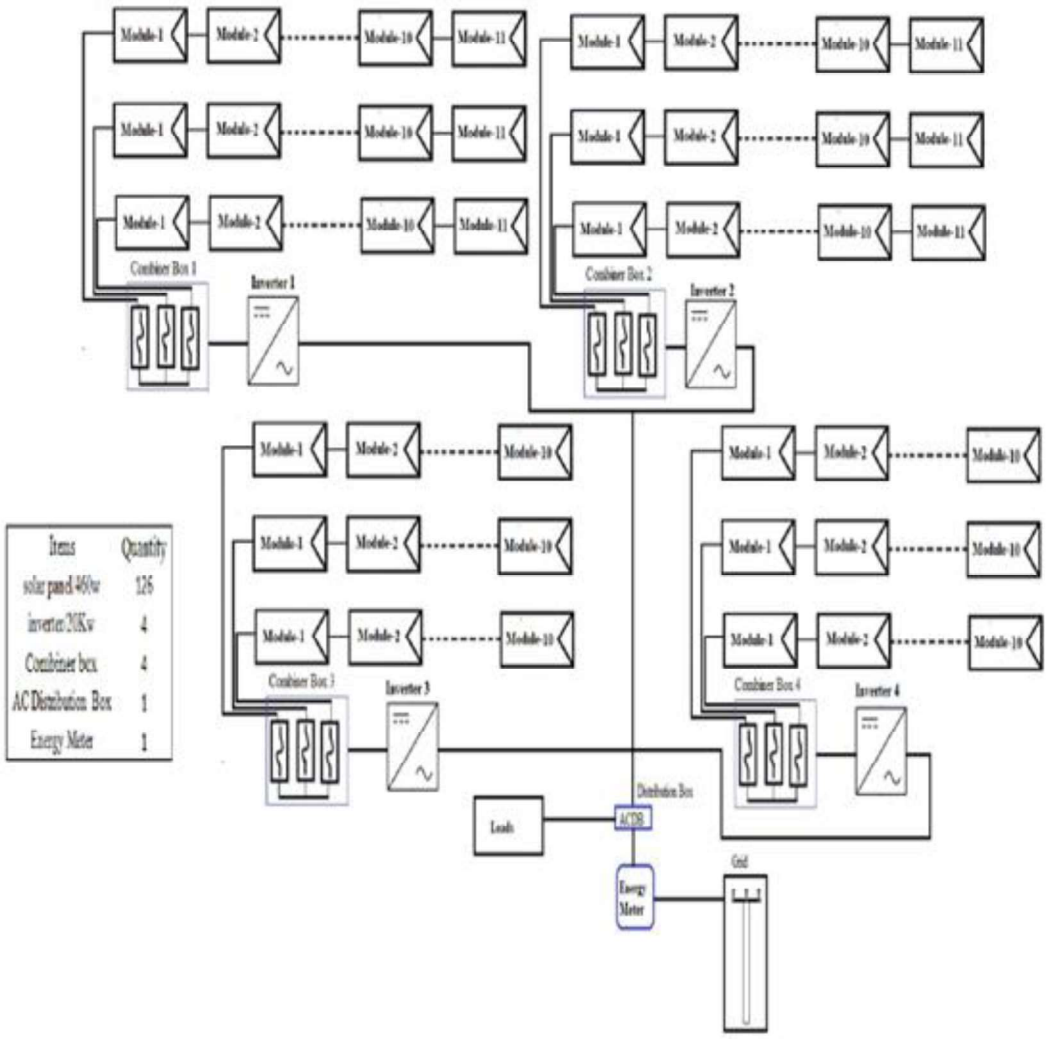


Figure 3.7 Single-line diagram for system design of net-metering solar system

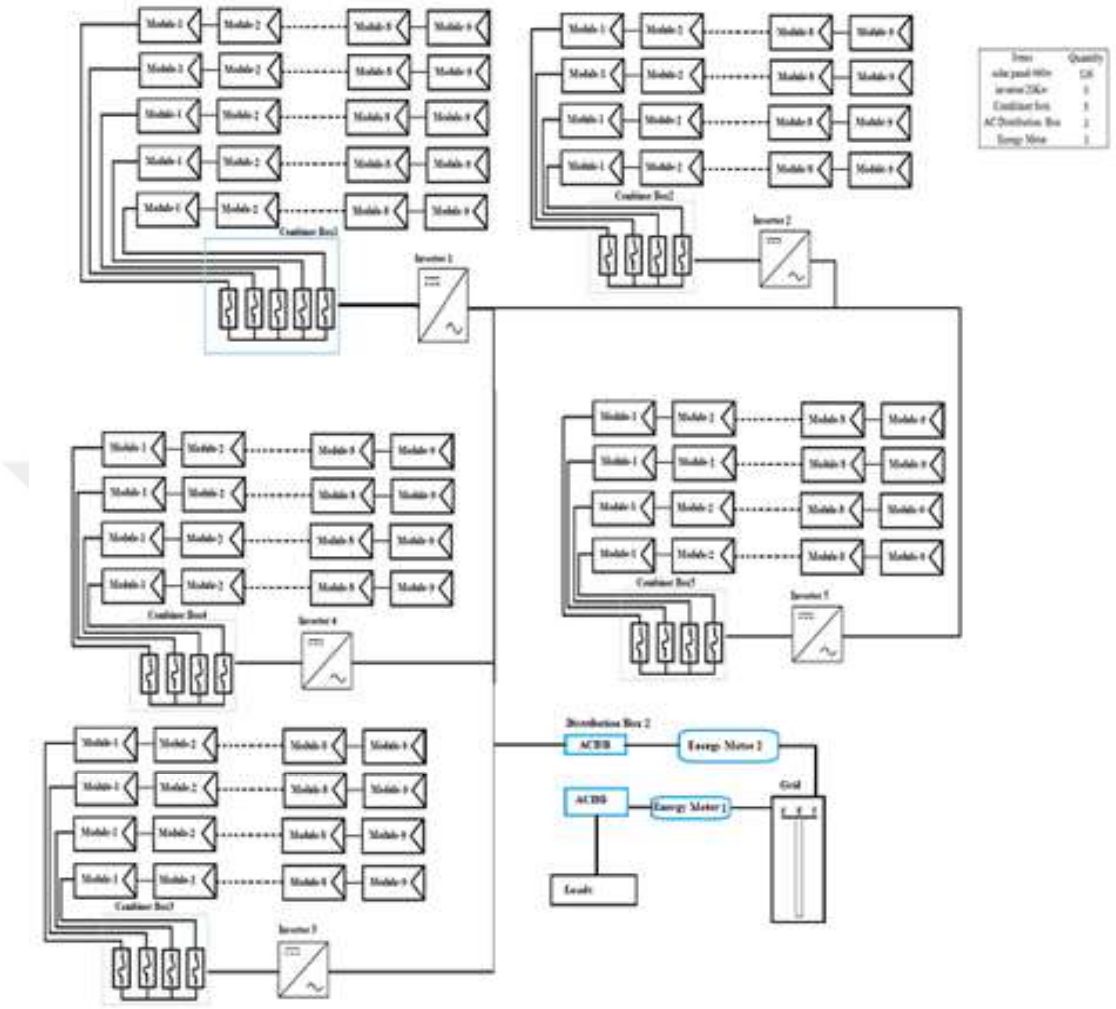


Figure 3.8 Single-line diagrams for system design of gross-metering solar system

3.2.2 Utilization of solar energy for elimination of electricity shortages in Somalia

The second part of the problem statement is concerning the lack of availability of electricity in the rural areas of Somalia, also how can the rural areas benefit from solar energy systems and what would be the most appropriate system for these areas. In this section we will discuss about the site that was chosen as the case study. The study looks at how much solar irradiation is available at the site, which will indicate which system is suitable.

a) Description of the site

JAZEERA is located in the southern part of Mogadishu, near ADEN ABDULLE AIRPORT, at (1.95) latitude and (45.18) longitude in the east the site lies the sea and rocky land.



Figure 3.11 Jazeera location

In this study, data about a rural area called Jazeera was collected. Jazeera is 15 kilometers from Mogadishu, and there are at least 400 houses that face electricity

shortages. According to the village chairman, the residents of that area receive electricity for 5 to 6 hours a day, especially in the evenings, and each household pays a minimum of $15 per month. Approximately 80% of these houses consume low power each day less than 2kW, 15% of these houses consume very low power less then 0.5kWper day and the rest 5% of these houses consume each day 5kW to 10kW. Grid extension, Micro-grid and solar home system are three approaches used for rural electrification. By using only a mathematical approach, this thesis will point out which system that is so appropriate for these areas.

Data about the solar radiation in this area was obtained from the Photovoltaic Geographical Information System (PVGIS). As seen in the figure 3.8, the average annual solar irradiation for that location is 6.41 kWh/m^2

Table 3.9 Jazeera solar irradiation data from PVGIS

Month	**Monthly radiation kWh/m^2**
JAN	216.78
FEB	207.63
MAR	221.59
APR	196.8
MAY	184.98
JUN	164.42
JUL	167.83
AUG	185.57
SEP	199.88
OCT	206.98
NOV	195.08
DEC	208.16

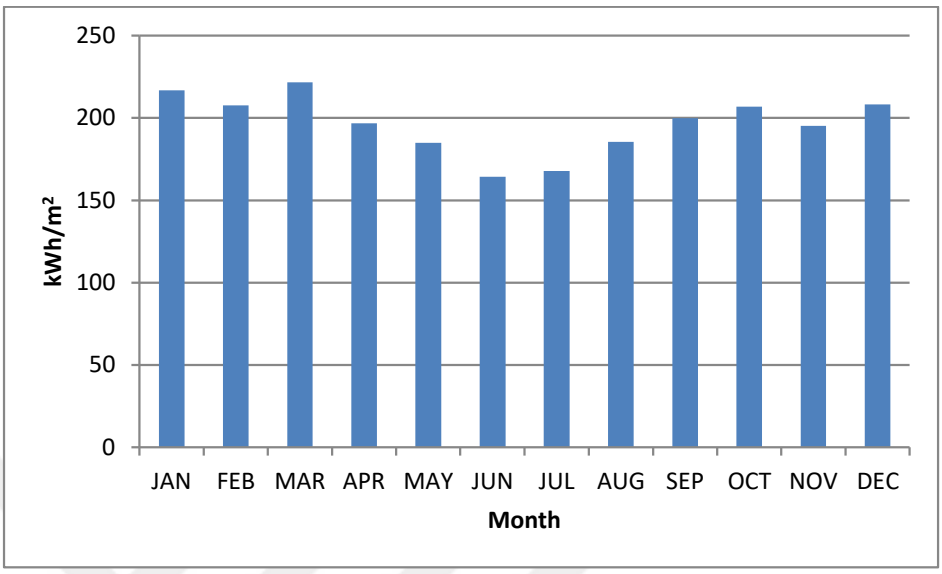


Figure 3.9 Jazeera solar insolation

The location's latitude and longitude are important factors in determining how much solar radiation a PV panel array receives throughout the year. The month of March has the maximum sun radiation while the month of July has the lowest. From the Table 3.7, the average daily solar irradiation in all of the year is 6. 4 kWh/m ^{2}

b) System design

There are three approaches used for rural electrification and this section will point out which system is more suitable for that area.

For the grid extension approach it is crucial to know how many concrete poles are needed in the system. This being because the concrete poles are going to be used to extend the PV system to the utility grid. The nearest power line to Jazeera is 12 kilometers away and the optimum distance between two concrete poles in Somalia is 50m. To find the number of required concrete poles, the following formula is used:

$$\text{number of required poles} = \frac{\text{Distancebetween the site and power lines}}{\text{Distance betwwen two poles}} \quad (3.20)$$

$$\text{number of required poles} = \frac{12\ \text{km}}{50\ \text{m}} = 240$$

Such a high number of concrete poles when using grid extension is not economically feasible because concrete poles cost around 600 dollars in Somalia, requiring $144000 without yet even factoring in the cost of the rest of the materials that will be needed. For the micro-grid system this system consists of solar panels, inverters and diesel generators. There are at least 400 houses which face electricity shortages, and approximately 80% of these houses consume low power each day less than 2kW, 15% of these houses consume each day very low power less then 0.5kW and the rest 5% of these houses consumes each day 5kW to 10kW.The total energy required for all these homes is found by using the following formula:

$$\begin{aligned}\text{Total electric load } &= (400\big((0.8 \times 2) + (0.15 \times 0.5) + (0.05 \times 10)\big) \\ &= 870\ \text{kWh}\end{aligned} \quad (3.21)$$

As the day contains 24 hours which means each hour will require 36.25kW

$$\text{number of solar panels} = \frac{36.5\text{kW}}{0.8 \times 450} = 100$$

Required diesel generator size will be multiplication of required load per hour and safety factor in this thesis 1.3 was taken as safety factor

$$\text{Diesel generator size} = 36.25\text{kW} \times 1.3 = 50\ \text{kW}$$

While the price of a 50 kW diesel generator in Somalia is $30000 and the price of a 450watt solar panel is $105, 100 solar panels will cost $10500. This means that employing micro-grid system is not economically feasible because of the needed cost for

only solar panels and generator is 40500$ while the costs of other parts such as inverters, cables, running cost such diesel, security, maintenance and so on remains. While the third approach was using solar home systems, as the power consumption for each household in Jazeera is not the same, classifying homes into three categories based on their consumption into A, B, and C is the best approach to determining which system is suited for each category.

Table 3.10 Different categories of consumption in Jazeera

Categories	Daily electric consumption
A	5to 10 kW
B	≤2 kW
C	<0.5 kW

For group C category homes use very low power so appropriate system, for group C is to use small solar home lighting kits such as 70W solar panel, integrated control box inside with controller, solar battery and with 2 USB outputs 5V, 3 LED bulb 3W/12V. For group B category homes use low power so appropriate system will be ((2*1000)/(0.8*6*460)= 1 panel of 460 watt and 1battery of 12V, 200Ah and so on. For group A, the appropriate system will be an off-grid solar system; utilizing this system will help access electricity day and night. Table below concludes different categories behalf consumption and which system is suitable for these categories.

Table3.12 Different categories of consumption in Jazeera with appropriate system

Categories	Electric consumption per day	Appropriate system
A	5 to10 kW	Off-grid solar system
B	≤2 kW	1 panel of 460wand 1 battery of 12V,200Ahand 1kW inverter
C	<0.5 kW	Small solar home lighting kits

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

After evaluating the numerous aspects in the preceding sections it is necessary to conduct an annual energy production and financial feasibility to determine the system's sustainability. Meanwhile, Environmental Analysis is essential to analyze the amount of CO2, saved as a result of utilizing this system.

4.2 Analysis of system yields

Figures 3.2 and 3.12 illustrate the solar irradiation levels at the study locations for each month from January to December. The monthly solar irradiation data was obtained using the PVGIS software tool for analysis. The annual average horizontal global solar irradiation was found to be 2348.7 kWh/m². As a result of the weather and climate conditions in Somalia, where the dry winter season runs from December to March and the rainy season peaks in June [44], the highest solar irradiation levels were observed from December to March, whereas the lowest levels were recorded in June.

By calculating the theoretical energy output of both the net metering and gross metering systems, which is dependent on the peak power and solar irradiation at the installation site. Tables 3.7 and 3.8 were created to estimate the theoretical energy yields of the two systems. As expected, March, which receives the highest solar irradiation during the year, demonstrated the highest theoretical energy output for both systems. Conversely, June had the lowest solar irradiation and therefore had the lowest theoretical energy output for both systems. The annual theoretical energy yields for the net metering and gross metering systems were calculated to be 136136.448kWh and 204204.672 kWh, respectively.

The actual monthly energy production of the two systems was determined using PVGIS. Figures 3.6 and 3.7 present the actual energy yields of the systems. In January, for instance, the net metering billing system generated 9705.6 kWh, whereas the estimated energy yield for that month was 12530.952 kWh. This implies that there was an energy loss of approximately 2825.35 kWh between the expected and actual energy yields. Such energy loss can be caused by factors such as module temperature, cabling, mismatch losses, and inversion losses from DC to AC. The net metering billing system had an annual actual energy yield of 104115.72 kWh, while the gross metering billing system had an annual actual energy yield of 156173.58 kWh.

The system's performance ratio was calculated monthly and annually; Table 3.9 shows the resulting values. The analysis reveals that the system achieved the highest performance ratio in August (78%), while the lowest ratios were observed in April and May (75%). Interestingly, April received more solar irradiation and had a higher energy yield compared to other months, indicating that the system's performance ratio is influenced by other factors beyond solar irradiation and energy production, such as temperature effects, wiring losses, inverter efficiency, and so on.



Figure 4.1 Average temperature in Mogadishu in celsius [49]

According to Figure 4.1, the month with the highest temperatures is April, with a temperature of 34°C. July is the coolest month of the year, with average temperatures of 30°C. While June has the lowest solar irradiation of the year, its performance ratio is

higher than that of April, May, October, November, and February due to its lower temperature. Using the performance ratio calculation, the overall performance ratio for both systems is 76%.

4.3 Environmental Analysis

As previously mentioned, Somalia's electricity production heavily relies on diesel generators, which emit carbon dioxide (CO_2) during operation. To determine the amount of CO2 emissions saved by implementing the proposed solar PV system, we need to calculate the emissions resulting from the fuel consumption of a diesel generator. According to previous studies [50], the CO_2 emission range of a diesel generator is between 2.4-2.8 kg CO_2/L, depending on both the engine and fuel characteristics. Additionally, the average specific fuel consumption of a diesel generator is estimated at 0.33 L/kWh [50], which translates to an estimated CO_2 emission of 0.8-0.93 kg CO_2/kWh. By multiplying this emission factor with the annual energy generation of the solar PV system, we can calculate the amount of CO_2 emissions saved by the system compared to using diesel generators. We can find the amount of carbon dioxide (CO_2) emission, saved by utilizing this system

$$\text{annual reductions in } CO_2 \text{ emissions} = 0.8 \times \text{Total yearly generated kWh of the system} \quad (4.1)$$

For net metering billing method and hybrid system

$$\text{annual reductions in } CO_2 \text{ emissions} = 0.8 \times 116815.57 = 93452.456 \text{ Kg}$$

For gross metering billing method

$$\text{annual reductions in } CO_2 \text{ emissions } = 0.8 \times 175223.24 = 140178.592 \text{ Kg}$$

This system has the potential to save at least 93452.456Kg of CO_2 per year compared to a diesel generator producing the same amount of energy.

4.4 Economic Analysis

The economic analysis of the system was undertaken to estimate the cost of project and expected profit. Calculating investment costs is crucial to the sustainability of any project, the credibility of this calculation, and hence the quality of the assessment. Cost analysis requires defining all investments. Tables below reflect the overall cost of this system's investment.

Table 4.1 Investment cost of grid tie solar system with net metering billing policy

Items	Quantity	Unit price	Total
Solar panel	126	$105.00	$13230.00
Inverter	4	$ 1875.00	$7500.00
*Others			$4270.00
Total			$25000.00

*others: cables, protection equipments, solar mounting structure and so on

Table 4.2 investment cost of grid tie solar system with gross metering billing system

Items	Quantity	Unit price	Total
Solar panel	189	$105.00	$19845.00
Inverter	5	$1875.00	$9375.00
*Others			$4270
Total			$33490.00

Table 4.3 Investment cost of hybrid solar system

Items	Quantity	Unit price	Total
Solar Panel	126	$105.00	$19845.00
Inverter	4	$3000.00	$9375.00
Battery	72	$650.00	$12000.00
Charge Controller	5	$1500.00	$46800.00
*Others			$4270.00
Total			$83800.00

Calculating investment expenses is critical to the viability of any project, the dependability of this estimate, and hence the quality of the evaluations. Defining the total investments is a prerequisite for the cost evaluation. as Somalia is still developing, some criteria like interest rates, taxes, inflation rates, and so on are not utilized As the primary goal of this project was to promote commercial investment companies in Somalia by demonstrating how using a solar PV system will reduce electric bills, In this thesis will compute a basic payback time on the basis of the lowest price per kWh in Somalia, which was 0.3$/kWh, and includes a 5% yearly maintenance fee.

This thesis will estimate how much the system will cost overall if it is taken by electrical utility providers.

$$\frac{\text{Total profit}}{\text{year}} = \left(\text{electricity consumed per year} \times {}^{\text{Price}}/_{\text{kWh}}\right) - \text{Annual maintenance rate} \quad . (4.2)$$

For net metering billing system

$$\text{Total profit} = (116815.57 \times 0.3) - 5\% = \frac{\$33292.4}{\text{year}}$$

For gross metering billing system

In this thesis used $0.20 per kilowatt-hour as the agreed-upon cost of supplying power to the grid

$$\text{Total profit} \ = (175223.24 \times 0.2) - 5\% = \frac{\$33292.4}{\text{year}}$$

The amount of time required to repay or complete the initial investment is referred to as the payback period (Pbp). The payback period is determined by the capital costs and the cash flow or total profit each year.

$$\text{Payback period(Pbp)} = \frac{\text{Capital costs}}{\text{Cash flow per year}} \tag{4.2}$$

For net metering billing system

$$\text{Payback period(Pbp)} = \frac{25000}{33293.4} = 0.75 \text{ year} = 9 \text{ months}$$

For gross metering billing system

$$\text{Payback period(Pbp)} = \frac{33490}{33293.4} = 1 \text{ year} = 12 \text{ months}$$

For hybrid solar system

$$\text{Payback period(Pbp)} = \frac{83800}{33293.4} = 2.5 \text{ year} = 30 \text{ months}$$

The Payback period for this system is one year for grid connected solar system and 2.5 years for hybrid solar system, by implementing this approach, there is a potential to save $33292/year that would otherwise be paid to the electricity utility providers.

CHAPTER 5

CONCLUSION

Within the scope of this thesis, a case study has been developed and the utilization of solar PV systems in Somalia has been conclusively researched and a reference model has been given, and since Somali suffers from two major problems, the first problem is related to lack of access to the broad-based electrification and second problem is related to high electricity costs. In this thesis, data was collected from a rural area known as Jazeera, located 15 km away from Mogadishu. There are at least 400 houses which face electricity shortages. As grid extension, microgrid system and solar-home systems are three approaches used for rural electrification, the results show that grid extension and micro-grid systems are not cost-effective as compared to solar home systems which are suitable solutions for homes. The paper analyzed a hotel in Mogadishu, where electricity bills are high, and showed that hybrid and grid-connected solar PV systems that could reduce costs by at least 50% within a year. The results presented in this thesis demonstrate that using solar energy is a viable solution to Somalia's electricity challenges, as this thesis is one of the few studies done on solar energy in Somalia. Using the results of this thesis might come in handy for local and foreign investment companies in Somalia, in terms of investment planning and in their engineering procurement and commissioning (EPC) of renewable projects. Finally, it has been identified that utilization of solar PV system will reduce electricity costs and also minimize electricity shortages in Somalia.