RESEARCH PROGRESS IN MECHANICAL AND MANUFACTURING ENGINEERING
e-ISSN: 2773-4765

RPMME

Vol. 5 No. 2 (2024) 238-251
https://publisher.uthm.edu.my/periodicals/index.php/rpmme

Analyzing the Economic Viability and Benefits of Solar Energy Implementation in Hargeisa, Somalia

Abdikarim Abdillahi Arab[1], Nur Syafiqah Adha Narrudin[1], Mohd Azahari Razali[1,2]*

[1] *Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400, Parit Raja, Batu Pahat, Johor, MALAYSIA*

[2] *Combustion Research Group (CRG), Faculty Of Mechanical And Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400, Parit Raja, Batu Pahat, Johor, MALAYSIA*

*Corresponding Author: azahari@uthm.edu.my
DOI: https://doi.org/10.30880/rpmme.2024.05.02.027

Article Info

Received: 21 May 2024
Accepted: 20 August 2024
Available online: 31 Dec 2024

Keywords

Solar Energy, Benefits, Economic Viability, HOMER software

Abstract

This study evaluates the economic and ecological viability of implementing solar energy systems in Hargeisa, Somalia, addressing the region's pressing energy challenges. Hargeisa's energy reliance on costly and environmentally harmful fossil fuels underscores the urgent need for sustainable alternatives. Solar energy, with its potential to reduce energy costs, create job opportunities, and mitigate carbon emissions, emerges as a transformative solution. Leveraging Hargeisa's geographical advantages, including high solar irradiance and extended sunshine durations, this research explores the feasibility and benefits of solar energy deployment. The study employs advanced modelling tools, including HOMER software, to optimize solar photovoltaic (PV) systems for local conditions, focusing on economic metrics such as net present cost, cost of energy, and operational efficiency. Findings indicate that, despite high upfront investments, solar energy systems are economically viable in the long term, offering significant environmental and financial benefits. Furthermore, this research emphasizes the importance of supportive policies, regulatory frameworks, and public-private partnerships in driving renewable energy adoption. By highlighting the critical role of solar energy in promoting energy independence, economic growth, and environmental sustainability, this study provides actionable insights for stakeholders and policymakers. The research concludes that solar energy represents a practical and scalable solution to Hargeisa's energy challenges, paving the way for a sustainable energy future in the region.

1. Introduction

Solar energy (SE) is the most important and popular renewable energy technology. Other renewable energy sources, such as wind, water, and bioenergy, are closely linked to solar energy. As science and technology advance, the potential for directly generating power and heat from solar energy continues to grow. However, the high cost of solar cells compared to traditional energy sources remains a key concern for scholars who question their prospects and widespread adoption. Renewable energy (RE) varies significantly across different geographic regions and nations. Notably, 2016 marked the largest annual increase in renewable energy capacity, with approximately 161 GW of new RE capacity installed. Solar photovoltaic (PV) accounted for 47% of this new capacity, making it the leading RE technology for electricity generation additions for the first time [1].

Foreign countries have been starting to assist African countries in developing their electricity industry. The African continent is such an unopened Pandora for renewable energy, solar energy included. Africa has abundant solar resources and high availability. However, Africa accounts for a tiny proportion (15MW) of the total installed capacity of 15 megawatts of solar photovoltaics worldwide. There are some solar module manufacturing plants in South Africa, but their production capacity is limited to 10 Megawatts. Solar energy is a sustainable resource and should have a promising African problem [2].

The energy situation in Somalia is heavily reliant on non-renewable resources, leading to challenges such as limited electricity access, high costs, and adverse environmental impacts. These issues are particularly acute in Hargeisa, highlighting the urgent need for sustainable energy solutions. Hargeisa's favourable geographical position offers plenty of sun irradiation, making it an excellent option for solar energy harvesting. This potential aligns with the region's pressing demand for alternative energy sources. Economically, adopting solar energy in Hargeisa could offer significant benefits. The reliance on costly energy sources heavily burdens consumers and businesses, stifling economic growth. Transitioning to solar energy has the potential to lower energy costs while creating job opportunities within the renewable energy sector [3]. Therefore, this study focuses on exploring solar energy utilisation in Hargeisa, emphasizing the importance of sustainable energy solutions in addressing the region's unique geographical and economic challenges.

This study examines the viability and effectiveness of solar photovoltaic technology in the context of Hargeisa's specific environmental conditions. Recent advancements in this technology offer promising alternatives for achieving sustainable energy solutions in the region. The implementation of solar energy in Hargeisa also presents significant ecological benefits, including reducing carbon emissions and conserving natural resources. Additionally, the study analyses Somalia's environmental policies related to renewable energy, emphasizing their role in promoting green energy initiatives [4]. By incorporating case studies from regions with similar geographic and economic conditions, the research provides valuable insights for devising actionable strategies tailored to Hargeisa. Finally, the study evaluates Somalia's policy and regulatory framework for renewable energy, focusing on government efforts to promote solar energy development. It also identifies challenges that must be addressed to successfully expand renewable energy in Hargeisa [5].

2. Literature Review

Somalia relies heavily on firewood and charcoal, which account for 80–90% of energy needs and are used by most of the population for cooking. This dependency on biomass is depleting the country's vegetation and contributing to environmental degradation [7]. Charcoal consumption, which is expected to reach 4 million tons per year, promotes deforestation, while illegal exports exacerbate the problem. The health consequences of traditional use of biomass can be minimized by using cleaner, more efficient fuels and equipment. Somalia's energy infrastructure is undeveloped, with hurdles to increasing electricity generation and transmission. In the 1980s, a project at Som Power sought to add 60 MW but was hampered by logistical problems. Energy demand has increased, with per capita consumption reaching 200 kg per year, owing to population expansion and consumer demand. In the late 1980s, Somalia's power generation was predominantly diesel-based, with a 177-183 megawatts capacity. Institutional shortcomings and limited donor participation have left the private sector to fill the void, particularly during war and isolation resulting in the rise of small independent power providers (IPP).

2.1 High Price of Electricity Tariffs

Mogadishu and Hargeisa exhibit higher levels of urban electrification than other Sub-Saharan African cities. However, businesses and individuals in these cities face the highest electricity bills globally, with varying pricing based on individual circumstances. The cost per kilowatt-hour may vary between $0.80 and $1.50. By contrast, neighbouring nations like Kenya and Ethiopia have far lower average prices, with rates as low as $0.15 per kWh and $0.06 per kWh, respectively. Power expenses in Somalia exhibit a substantial increase, accompanied by a significant decline in the country's earnings. In 2013, Somalia's per capita GDP was estimated to be US$133, far lower than Ethiopia's US$489 and Kenya's US$1,228. The variations in electricity pricing in Somalia are mostly attributed to the location, amenities, and fluctuating costs of energy sources. Customers residing in remote areas sometimes incur the highest costs for electricity. Fig. 1 presents the per capita gross domestic product (GDP) and average electricity expenses [8].

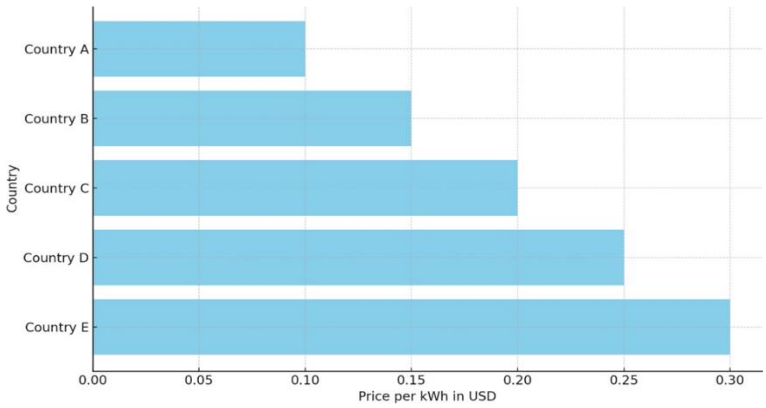

Fig.1 *Capita GDP And Average Electricity Tariffs [8]*

2.2 Energy Constraints on Socio-Economic Development

Fossil fuels remain the dominant energy source for the global economy and are expected to retain this role for the next two to three decades. However, the search for renewable energy sources is driven by concerns over sustainability, environmental impact, and the high cost of oil. The development of solid-state electronics, beginning with the creation of the transistor in 1948 and the thermistor in 1958, marked a turning point in energy consumption. This "Electronics Revolution" paved the way for subsequent technological advancement including the Information, Computer, Communication, Robot, and Internet Ages. These technological eras fueled a surge in energy demand as the global population grew and sought improved living conditions often with little regard for the environmental consequences of energy consumption. The long-neglected energy sector in Somalia has impeded economic growth and modernization. This neglect has left the population with limited access to electricity, a critical resource for daily life and economic activity. The sector has made little progress in innovation, technology, or infrastructure until recently, and legislative frameworks remain inadequate for ensuring energy security, affordability, and effective governance [9].

Energy is a cornerstone of socioeconomic development, with per capita consumption rising alongside economic growth. As economies expand, inanimate energy sources have gradually replaced human and animal labour in industry, agriculture, and households. However, Africa's limited access to electricity and vulnerability to climate change pose significant barriers to future economic and human development. Electricity is essential for alleviating poverty, promoting urbanization, and enabling industrialization and sustainable growth. Somalia's weak energy position, characterized by reliance on inefficient wood fuels and heavy dependence on imported petroleum, continues to constrain the nation's economic potential and resilience [10].

2.3 Energy Scenario in Somalia

Two of Somalia's major energy-related issues are chronic shortfalls and limited access to modern energy services. Long-running conflict, unpredictable regimes, and a lack of money have all impeded the development of a reliable and sustainable energy system. As a result, many people do not have access to electricity and modern cooking fuels, particularly in rural regions. The widespread reliance on traditional energy sources, such as firewood and charcoal, for cooking and lighting exacerbates environmental degradation and has detrimental effects on multiple aspects of life. The lack of electricity impacts education, healthcare, and economic productivity, further impeding progress. Additionally, gender inequalities are intensified as women and girls bear the burden of gathering firewood—a labour-intensive and time-consuming task that restricts their opportunities for education and income generation, perpetuating cycles of poverty and inequality [5].

2.3.1 Action-oriented scenario

Sustainable Development Goal (SDG) 7 focuses on ensuring universal access to affordable, reliable, sustainable, and modern energy, a fundamental objective for the energy sector. Achieving this goal also supports several other SDGs. The Energy Sector Assistance Implementation Plan (ESAIP) plays a key role in this effort. For example, it contributes to SDG 9 by promoting resilient infrastructure through reliable energy provision, and to SDG 15 by advocating for sustainable forest management, desertification mitigation, and biodiversity conservation. Additionally, expanding energy access helps reduce poverty (SDG 1) by enhancing productivity and incomes, and improves food security (SDG 2) by providing more dependable cooking fuels. While ESAIP has indirect benefits for education and women's health, such as advancing skills and promoting cleaner cooking energy, its primary impact lies in directly supporting these critical SDGs [7].

Effective energy sector administration requires well-crafted policies, including regulatory frameworks, pricing strategies, sectoral development plans, and improvements in energy efficiency. In urban contexts, particularly with the growing adoption of photovoltaic (PV) systems, planning tools are vital to address grid challenges and ensure smooth energy distribution. Somalia illustrates the complexities of energy-related issues, facing economic and environmental challenges. Its reliance on oil imports drains foreign reserves, while deforestation from firewood and charcoal consumption worsens environmental degradation. Energy availability is vital for Somalia's post-conflict economic recovery, yet a lack of robust energy strategies exacerbates regional disparities. Mogadishu's superior infrastructure attracts industrial activity, leaving other regions lagging [12].

Similar to other Somali cities, Hargeisa experiences frequent power outages that disrupt commercial and industrial activities. Integrating solar energy into its development strategies can reduce fossil fuel dependency, enhance energy security, and stimulate economic growth. However, challenges such as inadequate investment in equipment and a shortage of skilled personnel hinder efficient energy production. Collaboration among energy service providers (ESPs), guided by regulatory bodies, can significantly enhance the sector's efficiency, particularly in densely populated areas [13]. To attract financial backing, Somalia's government must establish a secure investment environment that instils confidence in energy businesses. As Somalia progresses in building democratic institutions and stabilizing politically, its energy infrastructure must evolve to meet rising demands driven by economic growth and the discovery of new energy resources in East Africa [14].

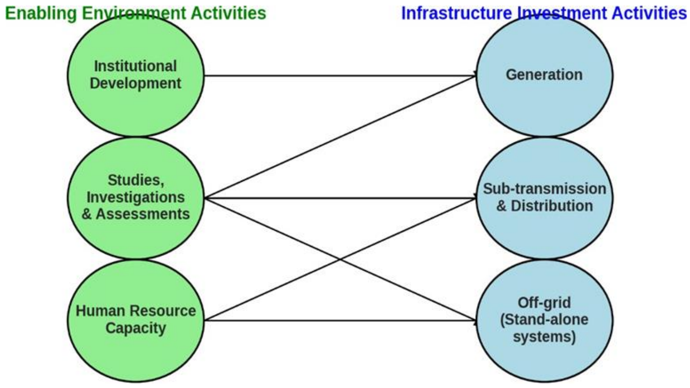

Fig. 2 *Structure of the Power Master Plan [14]*

2.4 Renewable Energy Status

2.4.1 Biomass

Biomass plays a central role in Somalia's energy framework, accounting for approximately 82% of the country's total energy consumption. Traditional biomass fuels such as firewood and charcoal are particularly prevalent among rural and low-income populations. Charcoal serves as a vital economic sector, providing income and fulfilling energy needs. About 97% of households in urban areas rely on charcoal as their primary energy source while rural households primarily depend on firewood. However, this heavy reliance on biomass has significant environmental consequences. The widespread use of charcoal and firewood depletes forest resources, accelerates soil erosion, and contributes to carbon dioxide (CO_2) emissions thereby degrading environmental quality. Energy consumption in Somalia is thus a major driver of environmental pollution, underscoring the urgent need for sustainable energy alternatives to mitigate these impacts [11].

2.4.2 Hydropower

The deployment of hydroelectricity has been seriously hampered by the security situation in this country. Currently, only 2.85 per cent of total electricity is generated from hydropower. The in-country potential for hydropower is estimated at between 100 and 120 MW, of which only 4 per cent has been exploited on the Juba River, and also a dam at Bardhere, in southern Somalia, has also been planned. Other challenges to the sector include the seasonality of the rivers [15].

2.4.3 Wind

Somalia's extensive coastline along the Indian Ocean presents significant potential for wind energy development. The country's geographic position generates consistent and strong wind patterns, particularly in the northern regions, making it an ideal location for wind energy production. However, this potential remains largely untapped due to challenges such as political instability, insufficient infrastructure, and limited funding for renewable energy technologies.

As global interest in sustainable energy grows, Somalia has an opportunity to capitalize on its wind resources. Developing wind energy would meet the country's energy demands and reduce reliance on fossil fuels, fostering environmental sustainability and economic growth. Advancing wind energy aligns with international efforts to combat climate change and promote eco-friendly energy solutions [18].

2.4.4 Geothermal

Somalia's location within the geologically active East African Rift System provides significant potential for geothermal energy development. The region's tectonic activity suggests the presence of geothermal resources beneath the Earth's crust. However, this potential remains largely untapped due to prolonged political instability, limited technical expertise, and inadequate financial resources. Harnessing geothermal energy could provide Somalia with a sustainable and reliable power supply, enhancing national energy security and driving economic growth. Furthermore, developing this clean energy source aligns with global environmental goals by reducing reliance on fossil fuels and mitigating the effects of climate change. While geothermal energy has yet to be fully utilized, it holds great promise for Somalia's future energy sector [19].

2.4.5 Solar

Somalia's strategic location and favourable climate offer immense potential for solar energy development. The country is well-suited for solar energy generation with high solar irradiance and year-round sunshine. However, the sector remains underdeveloped due to political instability, inadequate infrastructure, and limited investment in renewable energy. Despite these challenges, solar energy is increasingly recognized as a solution to Somalia's energy challenges. It has the potential to provide electricity to rural and remote areas with limited grid access, reduce dependence on imported fossil fuels, and improve energy security. Additionally, solar energy supports environmental sustainability and aligns with global renewable energy trends. By leveraging its solar resources, Somalia can drive economic growth, enhance energy access, and improve living standards for its population [20].

2.4.6 Renewable Energy Status in Somalia

The population of Somalia in 2013 was 6.17 million people. The total electricity produced in 2015 was 35 ktoe, with 97.1 per cent produced from fossil fuels. Final electricity consumption in 2015 was 28 ktoe. Table 1 shows the energy statistics of Somalia [15].

Table 1 *Somalia's' key indicators [15]*

Key indicators	Amount
Population (million)	6.17
GDP (billion 2005 USD)	3.12
CO2 emission (Mt of CO2)	0.89

Somalia's renewable energy sector is developing rapidly, with a focus on solar energy due to the country's abundant solar resources. Currently, Somalia's electrification rate is 35.3%, below the averages in East Africa and Sub-Saharan Africa. To address this gap, initiatives like the Somali Business Catalytic Fund (SBCF) are channelling private investments into solar energy projects. This has enabled businesses and households to access affordable and reliable solar energy, reducing reliance on costly generators and lowering electricity expenses.

Through lease-to-own financing for solar batteries and systems, the SBCF has been pivotal in expanding solar energy access, particularly for micro, small, and medium enterprises (MSMEs). This approach has been especially beneficial for women-led businesses, enabling them to acquire solar-powered equipment sustainably. Additionally, the World Bank's Somalia Electricity Access Project is funding solar home systems for households and businesses while exploring the feasibility of solar-powered hybrid mini-grids. These efforts collectively aim to enhance energy access, reduce costs, and promote economic growth in Somalia.

3. Methodology

3.1 Geographical Location and Site Description

Hargeisa, also known as Maroodi-Jeex, is a major city in northwestern Somalia, situated about 250 kilometres north of Ethiopia and 1,562 kilometres west of Mogadishu. The city is divided into six districts: Maxamuud Haybe, Gacan Libaax, Ahmed Dhagax, 26 Juun, Koodbuur, and Macalin Harun. It is recognized as a key hub for global commerce, particularly in indigenous grains, and is supported by initiatives such as the Somaliland Business Fund. Despite its economic significance, Hargeisa faces challenges from adverse weather conditions and ongoing crises, leading to prolonged humanitarian issues and population displacements. Historically, as an economic centre in southern Somalia, Hargeisa remains an important urban focal point, as highlighted in this study.

Fig. 3 *Map of Hargeisa, Somalia [22]*

3.2 Data Collection

This study utilized secondary data from the NASA Surface Meteorological and Solar Energy webpage to provide accurate long-term annual estimations for potential photovoltaic (PV) power generation. Reliable temporal resolution was crucial for optimizing power generation and minimizing costs. The analysis focused on residential electrical load consumption, using HOMER software to conduct techno-economic evaluations and simulate PV system performance based on electrical load profiles.

NASA's solar data, collected via satellites and spacecraft, supported site-specific analysis of solar energy potential. The implementation of this study involved selecting suitable locations, analysing energy demands, evaluating solar irradiance, and assessing available renewable resources. These assessments were tailored to the unique characteristics of each site to ensure effective optimization and cost efficiency.

3.2.1 Solar Radiation

Accurate assessment of solar energy usage requires understanding annual solar irradiance, seasonal variations, and related factors affecting energy input. Key parameters include daily sun radiation, clearness index, air temperature, and insolation values, which measure usable sunshine during the least productive solar month. In Hargeisa, Somalia, July has the lowest average solar energy at 6.36 kWh/m^2, while the region's annual average solar insolation is 6.10 kWh/m^2, with strong sunshine lasting approximately 6.10 hours daily.

Somalia benefits from abundant sunlight year-round, with horizontal solar energy averaging 6 to 10 kWh/m^2 daily and a yearly sunshine duration of 2,900 to 3,100 hours, making it one of the highest globally. This favourable environment has led to the growing adoption of solar energy in Somaliland among rural communities, businesses, and organizations. Average solar energy across Somalia reaches at least 210 watts/m^2, equivalent to 200 kilowatts/km^2, supporting sustainable solar PV systems.

Solar PV is particularly advantageous in Somalia compared to wind energy, as it involves simpler technical expertise, faster deployment, and lower maintenance costs. Solar PV performance depends on factors like light intensity, ambient and battery temperatures, load conditions, and PV module properties. Site-specific meteorological data, including solar radiation on tilted PV modules, must be analysed to optimize solar PV systems. With an average annual temperature of 27°C, Somalia's climate is well-suited for solar power, highlighting its potential to meet the region's energy needs efficiently and sustainably.

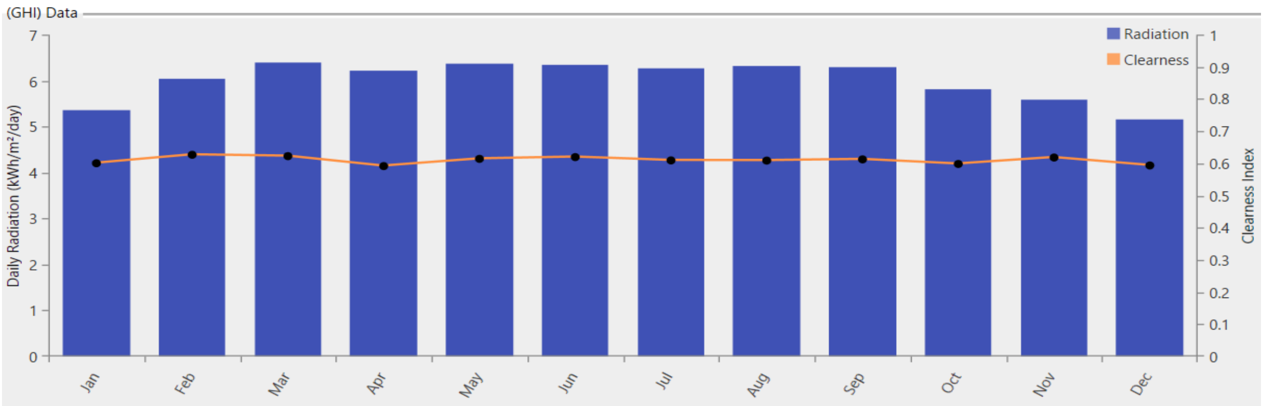

Fig.4 *Monthly global horizontal radiation data for Hargeisa*

3.2.2 Load Calculation

A research study in Hargeisa will monitor urban demographics by sampling 80 families. The energy consumption of middle-class households is assessed based on their use of "domestic appliances," such as portable refrigerators, laptops, and televisions, among other electricity-dependent devices like washing machines (as shown in Table 2). By analyzing a representative sample of 50 homes, the study will estimate load profiles by calculating the total energy consumption of their electrical systems, providing a clearer understanding of urban energy usage patterns.

Table 2 *The daily electric consumption of a common electronic consumer middle-class-size house in Hargeisa (Homer)*

Appliances	Quantity	Power (W)	Total Watt	Hours (H)	Total Energy Demand (KWh)
Lamps	6	15	90	8	0.72
Laptop	2	50	100	4	0.4
Washing machine	1	250	250	4.5	1.125
Mobile	6	15	90	4	0.36
Tv	1	80	80	8	0.64
Refrigerator	1	100	100	12	1.2
Flat iron	1	750	750	4	3
Microwave	1	1000	1000	5	5

3.2.3 Photovoltaic Array Sizing

DC inverters are turned into AC inverters. Stand-alone inverters are utilized to convert the DC voltage stored in a battery into AC, which is then used to power electrical equipment. The inverter's designated voltage must align with the battery's designated voltage. Consequently, when using a stand-alone system, the inverter must have the capacity to manage the total power in watts utilized at any given instant. The inverter needs to be robust since it functions as an independent unit. sufficient to accommodate the aggregate power consumption for a single instance. The inverter necessary for the PV system presented in this paper should generate alternating current (AC) voltages ranging from 208 to 240 volts at a frequency of 50 hertz. The selected inverter for the study is the Peimar SG340P solar inverter. The following formulas can be utilized to ascertain the optimal dimensions of an inverter, which can be employed to estimate the inverter capacity.

$$PV\ Module = \frac{Total\ Energy\ Demand}{Sustainable \times Efficiency} \quad (1)$$

3.3.3 Inverter Sizing

AC inverters play a crucial role in converting direct current (DC) power into alternating current (AC) power for household use. In solar-powered households, inverters transform DC energy stored in batteries into AC electricity compatible with standard outlets. To ensure efficient power delivery, the inverter's input current rating must exceed the combined wattage of all connected appliances. The inverter must manage the entire simultaneous power demand for completely autonomous systems. The inverter of a standalone photovoltaic system should generate an AC voltage between 220 and 240 volts at a frequency of 50 hertz. Equation 2 can be used to determine the required inverter capacity, ensuring optimal performance and reliability.

$$Inverter = \frac{Total\ rating\ (w) \times Concurrent\ Load\ Factor}{Inverter\ Peak\ Efficiency} \quad (2)$$

Table 3 *Parameters of Dynapower DPS - 250 (Homer)*

Technology	Sinusoidal wave
Nominal Voltage	480-576Vdc
Rated power	60KW
Relative Capacity	60%
Maximum AC	22.7A
Inverter peak efficiency	95

3.3.4 Selection of Charge Controller

In stand-alone photovoltaic (PV) systems, charge controllers are essential for maintaining batteries at optimal charge levels, preventing overcharging and the negative effects of array-induced battery loading. Lead-acid batteries, particularly sealed lead-acid types, are commonly used in both off-grid and grid-connected installations due to their reliability and suitability for PV systems. Key specifications for solar charge controllers include maximum amperage and voltage, which are determined by the solar panel current and the system configuration. Selecting an appropriate charge controller requires consideration of both solar panel and battery voltages. Equation (3) is used to calculate the required charge controller capacity, ensuring efficient and reliable system operation.

$$Charge\ Control = \frac{short\ circuit\ current}{No.of.string\ parallel} \quad (3)$$

Table 4 *MPPT charge controller parameters*

Technology	MPPT
Nominal Voltage System	24/48V
Rated current	60Amps
Maximum battery voltage	32V
Maximum Input voltage	100Vdc

3.2.1 Payback Period Calculation

The net profit refers to the financial gain obtained by the client or financier once the expenses related to the installation of a solar home system throughout the contract are subtracted. The return period represents the length of time it takes for the investor to recover their initial investment by selling the electricity produced by the photovoltaic (PV) system. The calculation of earnings generated from the sale and installation of a residential solar energy system is determined by employing Equation (4).

$$Net.Profil = Total\ Profit - Installation\ Cost \quad (4)$$

The return on investment, or ROI, is determined by dividing the total yearly profit rate by the initial investment cost. The payback period can be determined by utilizing equation (5).

$$Payback = \frac{Capita\ Cost}{yearly\ Profit} \quad (5)$$

3.2.2 Grid Solar Home System Calculation

In grid-connected solar home systems, each component is vital in ensuring reliability and efficiency. The Peimar SG340P series photovoltaic panels were chosen for their high efficiency and resilience to various weather conditions, delivering a combined output of up to 2 kW, forming the foundation for electricity generation. FB20-

100 batteries were selected for energy storage due to their ability to endure daily charging and discharging cycles without significant degradation. The batteries are connected in a string configuration to optimize space and support system scalability, allowing for future expansions to meet increased energy demands.

The system uses a Dyn250 converter with a 25 kW capacity to efficiently convert DC power from the PV panels into AC power, which is essential for powering household appliances and integrating with other electrical systems. The converter's capacity ensures a stable energy supply despite fluctuations in energy production, providing dependable power to end users. This configuration meets current energy requirements and offers a scalable framework for future improvements, such as adding more solar panels or increasing battery storage as energy needs grow and technology advances.

Table 5 *Solar Home System*

Component	Name	Qty	Size	Unit
PV	Peimar SG340P	1	2	kW
Storage	FB20-100 (battery)	8	1	string
Converter	Dyn250	1	25	kW

4. Result & Discussion

4.1.1 Solar Optimization

Fig. 5 shows various configurations of a solar home system that is connected to the grid. Each system includes photovoltaic (PV) panels, batteries, and inverters. It explores various system capacities as indicated by variations in the power of the inverter and solar panels and consistent battery storage in all situations. The effects of load following (LF) and Cycle Charging (CC), two distinct operating techniques, on system efficiency and economic feasibility are assessed. Moreover, the analysis focuses on economic variables such as net present cost (NPC), cost of energy (COE), operational and maintenance costs, and original investment costs. These metrics assess the financial implications of each system configuration, with lower NPC and COE indicating more cost-effectiveness. The table additionally emphasizes sustainability through the renewable percentage (100% in all cases), demonstrating the systems' entire reliance on renewable energy sources as well as their environmental benefits by displaying zero fossil fuel usage. Furthermore, this extensive comparison helps comprehend how different configurations and dispatch tactics affect the economic outcomes and the operational efficacy of solar systems. By studying these scenarios, stakeholders can discover the most successful configurations for certain applications, allowing for more informed decisions in the deployment of solar energy systems that balance cost, efficiency, and ecological impact.

	Architecture				Cost				System	
Scenario	Solar (kW)	Battery	Convert (kW)	Dispatch	NPC ($)	COE($)	Op & Co ($/yr.)	Initial cost($)	Ren frac (%)	Total fuel (L/yr.)
PV/Battery/Inverter	2161	75	91	LF	$245517.9	$0.08365	$5680.296	$172085.8	100	0
PV/Battery/Inverter	2173	75	101	CC	245734.1	0.084	5684.623	172246	100	0
PV/Battery/Inverter	2181	75	93	LF	245768.6	0.084	5684.034	172288.2	100	0
PV/Battery/Inverter	2163	75	89.359	LF	245525.4	0.084	5680.183	172094.8	100	0
PV/Battery/Inverter	2173	75	106.219	CC	245789.5	0.084	5686.192	172281.200	100	0
PV/Battery/Inverter	2186	75	88.370	LF	245796.6	0.084	5683.761	172319.700	100	0
PV/Battery/Inverter	2202	75	90.76	CC	246013.3	0.084	5687.071	172493.6	100	0
PV/Battery/Inverter	21869	75	88.37	LF	246061.2	0.084	5688.761	172519.7	100	0
PV/Battery/Inverter	2242	75	103.329	LF	246604.3	0.084	5696.956	172956.9	100	0
PV/Battery/Inverter	2010	76	134.5	CC	246956.5	0.084	5736.878	172793	100	0
PV/Battery/Inverter	2066	76	87.321	LF	247239.9	0.084	5734.082	173112.5	100	0
PV/Battery/Inverter	2313	75	91.658	CC	247374.3	0.084	5705.861	173611.	100	0
PV/Battery/Inverter	2079	76	99.126	LF	247501.7	0.084	5739.343	173306.3	100	0
PV/Battery/Inverter	2110	76	89.262	LF	247787.6	0.084	5741.866	173559.5	100	0
PV/Battery/Inverter	2323	75	146.05	CC	247941.3	0.084	5721.338	173978.5	100	0
PV/Battery/Inverter	2146	76	85.139	LF	248198	0.085	5746.911	173904.8	100	0
PV/Battery/Inverter	2166	76	88.587	LF	248473	0.085	5751.169	174124.7	100	0
PV/Battery/Inverter	2169	76	111.322	CC	248699.2	0.085	5757.491	174269.2	100	0
PV/Battery/Inverter	2174	76	151.65	LF	249359.3	0.085	5773.625	174720.6	100	0
PV/Battery/Inverter	2240	76	90.539	CC	249385.9	0.085	5763.963	174872.1	100	0

Fig.5 *Solar Optimization Results*

4.1.2 Consumption of Electrical Energy

The data provides valuable insights into the output and utilization of a solar energy system. According to Table 5, the system produces a total of 261,020 kWh annually, entirely from solar energy, showcasing the feasibility of standalone solar systems for sustainable energy solutions. This case study highlights the potential of solar power to meet energy demands independently, supporting discussions on reducing reliance on fossil fuels.

Table 6 *Production of Electrical Energy*

Component	Production(kWh/year)	Percent
Solar	261,020	100
Total	261,020	100

Table 6 analyzes energy consumption, showing that the AC primary load utilizes all 227,022 kWh of the generated energy annually. No energy is allocated to TDC Primary Load or Deferrable Load, indicating immediate consumption without storage or delayed use. This consumption pattern suggests that incorporating energy storage or load-shifting mechanisms could enhance system efficiency, particularly by managing peak demand and ensuring energy availability during periods of low solar generation.

Table 7 *Consumption of Electrical Energy*

Component	Production(kWh/year)	Percent
AC Primary Load	227,022	100
TDC Primary Load	0.00	0.00
Deferrable Load	0.00	0.00
Total	227,022	100

Fig. 6 serves as an analytical tool to evaluate the performance of a photovoltaic (PV) system by illustrating its monthly electricity output over a year, measured in megawatt-hours (MWh). This graphical representation highlights the system's ability to consistently convert solar radiation into electricity despite seasonal and weather variations. The data's consistency underscores the effectiveness of the system's design in maintaining stable energy production throughout the year. Such temporal stability is a key indicator of a well-engineered solar energy system capable of reliably meeting energy demands with minimal monthly fluctuations.

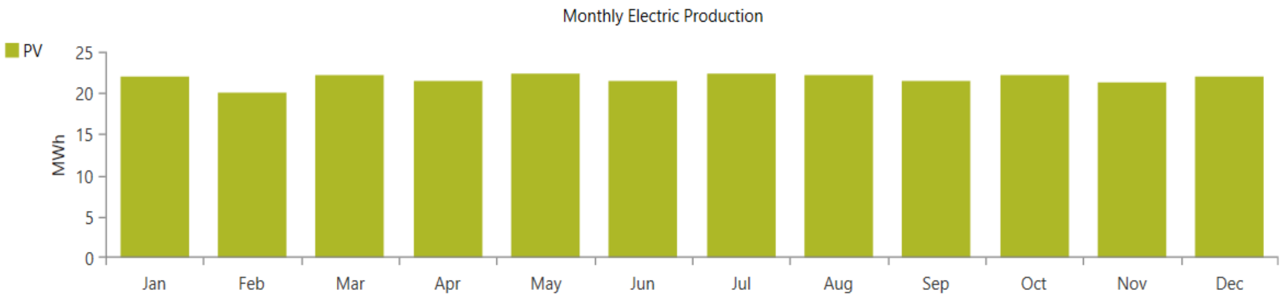

Fig.6 *Monthly Electric Production*

4.1.3 Solar Radiance

Figure 7 illustrates the daily variation of solar irradiance over 24 hours, a critical metric for assessing photovoltaic (PV) system performance. The horizontal axis represents time in hourly intervals, while the vertical axis displays solar irradiance levels in watts per square meter (W/m^2). This graph offers insights into the temporal dynamics of solar energy availability throughout the day.

The representation is a valuable tool for renewable energy studies, providing empirical data that informs the development of advanced mathematical models and algorithms. These models help predict solar irradiance patterns under various environmental conditions, such as weather changes or seasonal shifts in sunlight angles, aiding in the optimization and planning of solar energy systems.

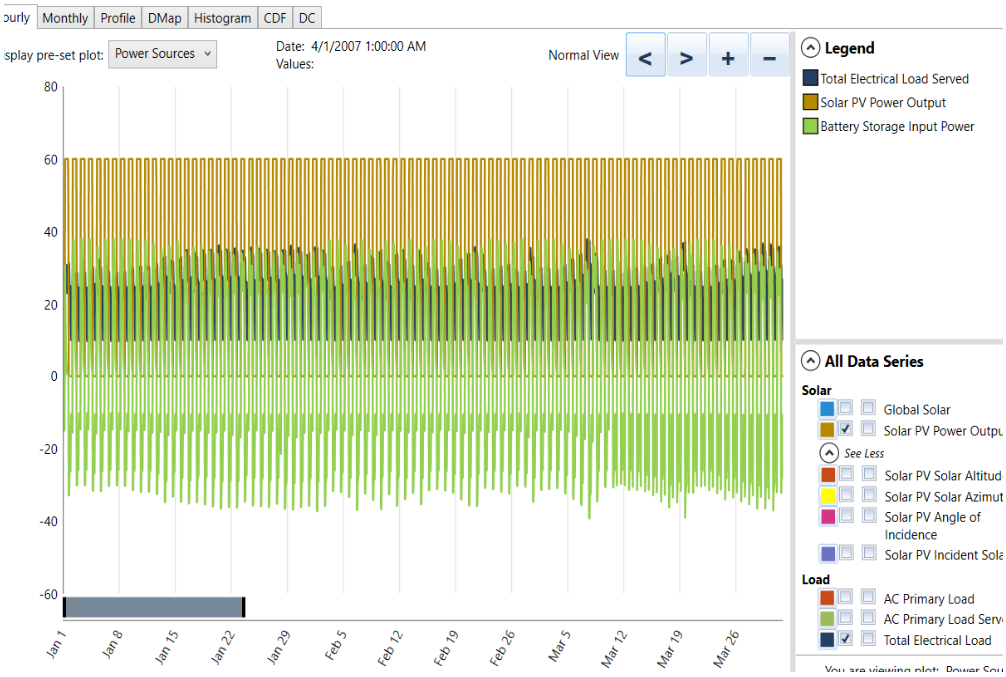

Fig.7 *Daily Solar Radiance Variation*

4.1.4 Economic Viability and Benefits of Solar Energy Implementation

Table 7 presents an economic analysis of implementing solar energy systems in Hargeisa, Somalia, focusing on costs such as upfront investment, operational expenses, replacement costs, and salvage values for key components like solar PV systems, inverters, and battery storage. The study reveals that while initial and replacement costs—particularly for battery storage, totalling $210,459.02—are substantial, operational expenses are relatively low, indicating potential long-term financial benefits.

The analysis also emphasizes the importance of accounting for depreciation and negative salvage values when assessing the overall financial feasibility of solar energy systems. This comprehensive approach provides a clearer understanding of the economic advantages and challenges associated with adopting solar energy in the region.

Table 8 *Overall Cost of the PV Energy System*

Name	Capital ($)	Replacement ($)	Op &Cost ($)	Resource ($)	Salvage ($)	Total ($)
Battery Storage	$150,000.00	$60,459.02	$19,391.27	$0.00	-$11,379.00	$218,471.30
Inverter	$454.42	$128.53	$195.82	$0.00	-$24.19	$754.58
Solar PV	$21,631.39	$0.00	$4,660.67	$0.00	$0.00	$26,292.06
System	$172,085.81	$60,587.55	$24,247.76	$0.00	-$11,403.19	$245,517.94

Fig. 8 provides a comprehensive financial analysis of the benefits and economic feasibility of solar energy implementation in Hargeisa, Somalia. The evaluation highlights the costs associated with capital investment, operations, replacements, and salvage values of solar energy components. The bar chart reveals positive salvage values, demonstrating substantial long-term financial benefits that help offset the high initial capital and replacement costs. The central argument of this research is that, despite significant upfront expenses, solar energy offers a sustainable and cost-effective solution for meeting Hargeisa's energy needs. Its lower operational costs and favourable long-term yield establish solar energy as an economically viable option for the region.

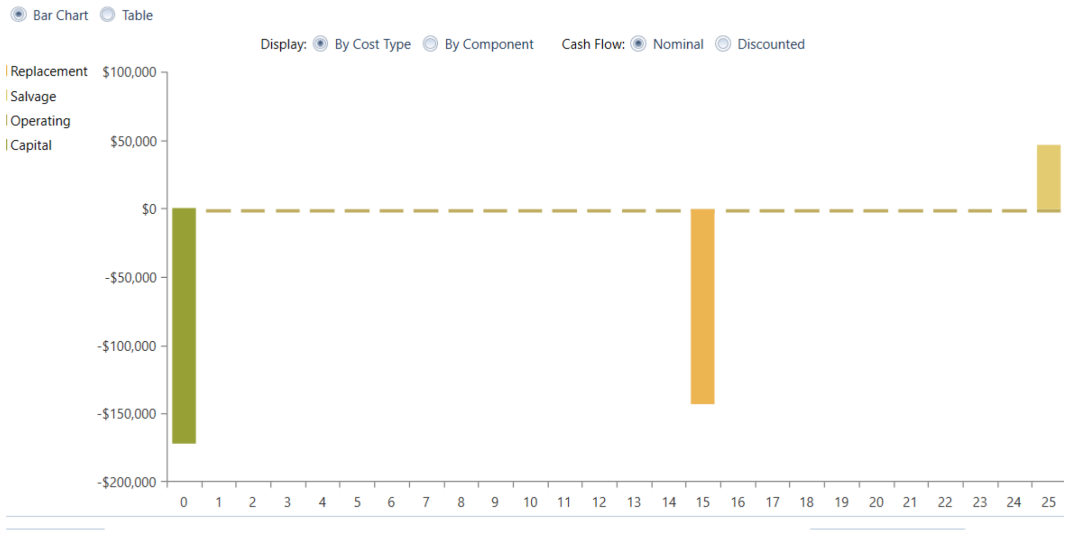

Fig.8 *Cash Flow by Cost Type*

Fig. 9 illustrates the financial breakdown of implementing solar energy in Hargeisa, Somalia, highlighting significant upfront capital investments and ongoing replacement costs. The analysis categorizes costs into capital, replacement, operational, and salvage values for components such as solar PV panels, inverters, battery storage, and the overall system. Notably, substantial salvage values and relatively low operational costs present a nuanced perspective on the financial feasibility of solar energy.

This graphical analysis supports the argument that solar energy is a viable solution for fostering sustainable economic growth and energy independence in Hargeisa. Despite high initial costs, the long-term benefits and positive salvage values underscore the economic and environmental advantages of adopting solar energy systems in the region.

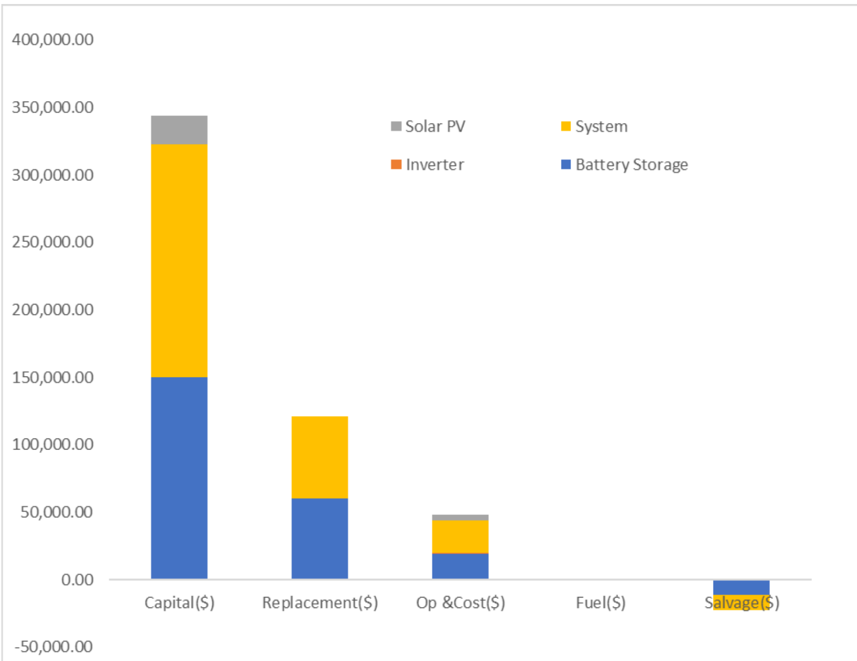

Fig. 9 *Cost Summary Based on Cost*

Figure 10 provides a detailed breakdown of the costs associated with installing a solar power system, emphasizing the financial requirements for each component. The chart reveals that solar PV panels incur the highest costs, reflected by their significant negative value. This is primarily due to the expense of the panels themselves, along with the necessary mounting and connection hardware, making this component the largest financial commitment in the system.

In comparison, the inverter and battery storage components show lower negative values, indicating comparatively lower costs. The inverter plays a critical role in converting the DC electricity generated by the solar panels into AC electricity for use in domestic appliances or integration with the grid. Meanwhile, battery storage costs are tied to the purchase of batteries used to store excess energy for later use, particularly during periods when solar generation is unavailable, such as at night or on cloudy days. This cost distribution highlights the relative financial priorities in solar power system installation, with PV panels as the primary expense, followed by the supporting components necessary for efficient energy conversion and storage.

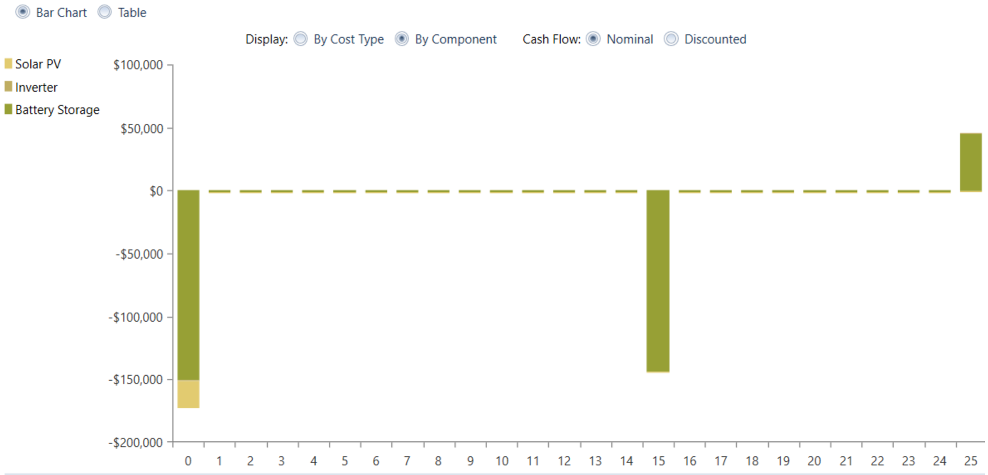

Fig.10 *Cash Flow by Component*

5. Conclusion

This study evaluates the economic and ecological viability of implementing solar energy in Hargeisa, Somalia, highlighting its potential to address the region's energy challenges. Solar energy offers a sustainable solution to Hargeisa's reliance on costly and environmentally detrimental fossil fuels. The findings underscore the significant benefits of adopting solar energy, including cost savings, job creation, and the reduction of carbon emissions. The analysis demonstrates that despite high initial investments, solar energy systems are economically viable in the long term, offering lower operational costs and positive environmental impacts.

Hargeisa's geographical advantages, including high solar irradiance and extended sunshine duration, make it an ideal candidate for solar energy deployment. The study also emphasizes the importance of supportive policies and regulatory frameworks to attract investment and ensure the successful integration of renewable energy into the region's infrastructure. Additionally, the use of modern technologies such as HOMER software for system optimization demonstrates the feasibility of deploying advanced solar systems tailored to local needs.

Overall, this research concludes that solar energy is a practical alternative and a transformative solution for achieving energy sustainability, economic growth, and environmental conservation in Hargeisa. Future efforts should focus on enhancing financial accessibility, improving infrastructure, and fostering public-private partnerships to scale solar energy implementation.

Acknowledgement

The authors sincerely thank Universiti Tun Hussein Onn Malaysia (UTHM) for providing the resources and facilities necessary for conducting this research. Special thanks are extended to the Combustion Research Group (CRG) for their invaluable guidance and technical support throughout the study. The authors also acknowledge the financial support provided by UTHM Research Management Center (RMC) through the GPPS Fund Q797, which made this research possible.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm their contribution to the paper as follows: ***study conception and design:*** *Abdikarim Abdillahi Arab, Nur Syafiqah Adha Narrudin, Mohd Azahari Razali;* ***data collection:*** *Abdikarim Abdillahi Arab;* ***analysis and interpretation of results:*** *Abdikarim Abdillahi Arab;* ***draft manuscript preparation:*** Abdikarim Abdillahi Arab, Nur Syafiqah Adha Narrudin, Mohd Azahari Razali*. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Gulaliyev, M. G., Mustafayev, E. R., & Mehdiyeva, G. Y. (2020). Assessment of solar energy potential and its ecological-economic efficiency: Azerbaijan case. Sustainability, 12(3), 1116, https://doi.org/10.3390/su12031116.

[2] Zhu, Z., & Yan, Y. (2019, September). Solar Energy Development in Africa: Economics and Policies. In 2019 3rd International Seminar on Education, Management and Social Sciences (ISEMSS 2019) (pp. 232-235). Atlantis Press, https://doi.org/ 10.2991/isemss-19.2019.45.

[3] Nadeem, T. B., Siddiqui, M., Khalid, M., & Asif, M. (2023). Distributed energy systems: A review of classification, technologies, applications, and policies. Energy Strategy Reviews, 48, 101096, https://doi.org/10.1016/j.esr.2023.101096.

[4] Tajouo, G. F., Kapen, P. T., & Koffi, F. L. D. (2023). Techno-economic investigation of an environmentally friendly small-scale solar tracker-based PV/wind/Battery hybrid system for off-grid rural electrification in the Mount Bamboutos, Cameroon. Energy Strategy Reviews, 48, 101107, https://doi.org/10.1016/j.esr.2023.101107.

[5] Samatar, A. M., Mekhilef, S., Mokhlis, H., Kermadi, M., Diblawe, A. M., Stojcevski, A., & Seyedmahmoudian, M. (2023). The utilization and potential of solar energy in Somalia: Current state and prospects. Energy Strategy Reviews, 48, 101108. https://doi.org/10.1016/j.esr.2023.101108.

[6] IEA (2022), Clean Energy Transitions in the Greater Horn of Africa, IEA, Paris https://www.iea.org/reports/clean-energy-transitions-in-the-greater-horn-of-africa, Licence: CC BY 4.0.

[7] African Development Bank, Somalia Energy Sector Needs Assessment and Investment Programme, *African Dev. Bank*, 2015.

[8] D. Poplack and K. Coolidge, Powering Progress 2, p. 12, 2016.

[9] Ronge, H., Niture, V., & Ghodake, M. D. (2016). A review paper on utilization of solar energy for cooking. Imperial Int J Eco-friendly Technolo, 1, 121-124, .

[10] Thulstrup, A. W., Habimana, D., Joshi, I., & Oduori, S. M. (2020). Uncovering the challenges of domestic energy access in the context of weather and climate extremes in Somalia. Weather and Climate Extremes, 27, 100185, doi: 10.1016/j.wace.2018.09.002.

[11] C. Guide, Country Guide- Somalia, *Soil Aggregates*, vol. 1, no. 6, p. 2, 2005.

[12] A. Igl and 2023 Archives, I G L, Start-up renewable energy company, Qorax Energy. Qorax is working to bring affordable," pp. 1–8, 2023.

[13] M. Garcia and C. M. T. Moore, *The Rise of Cash Transfer Programs in Sub-Saharan Africa*. 2012. doi: 10.1596/9780821388976_ch02.

[14] UNEP, Somalia Energy Profile, *Energy Resour.*, vol. 3, no. Table 1, pp. 2013–2016, 2015.

[15] C. Edwards, Powering ahead, *Eng. Technol.*, vol. 8, no. 11, pp. 52–57, 2013, https://doi.org/10.1049/et.2013.1105.

[16] C. Albian, "Why Exploration Offshore Somalia Could Reveal an Oily Surprise One of the Last True Hydrocarbon Frontiers," no. October, pp. 44–45, 2020.

[17] Liu, K., Chen, W., Chen, G., Dai, D., Ai, C., Zhang, X., & Wang, X. (2023). Application and analysis of hydraulic wind power generation technology. Energy Strategy Reviews, 48, 101117., https://doi.org/10.1016/j.esr.2023.101117.

[18] S. Kassinis, "Renewable Energy Sources in Cyprus," pp. 2493–2498, 2008.

[19] Geng, Y., Zhang, N., & Zhu, R. (2023). Research progress analysis of sustainable smart grid based on CiteSpace. Energy Strategy Reviews, 48, 101111, https://doi.org/10.1016/j.esr.2023.101111.

[20] E. A. E. Program, "Guide To Developing And Investing In The," 2018.

[21] Adam, J. S., & Fashina, A. A. (2019). Design of a hybrid solar photovoltaic system for Gollis University's administrative block, Somaliland. International Journal of Physical Research, 7(2), 37-47, https://doi.org/10.14419/ijpr.v7i2.28949.

[22] E. Solar, Solar Charge Controller Manufacturer, no. 48, pp. 60–61, 2022.