Energy Strategy Reviews 48 (2023) 101108

Contents lists available at ScienceDirect

Energy Strategy Reviews

journal homepage: www.elsevier.com/locate/esr

Review

The utilization and potential of solar energy in Somalia: Current state and prospects

Abdullahi Mohamed Samatar [a,b], Saad Mekhilef [a,c,f], Hazlie Mokhlis [d,*], Mostefa Kermadi [a], Abdulkadir Mukhtar Diblawe [e], Alex Stojcevski [c], Mehdi Seyedmahmoudian [c]

[a] Power Electronics and Renewable Energy Research Laboratory (PEARL), Department of Electrical Engineering, Faculty of Engineering, Universiti Malaya, 50603 Kuala Lumpur, Malaysia
[b] Department of Electrical Engineering, Faculty of Engineering, Hormuud University, Mogadishu, Somalia
[c] School of Science, Computing and Engineering Technologies, Swinburne University of Technology, Hawthorn, VIC, 3122, Australia
[d] Department of Electrical Engineering, Faculty of Engineering, Universiti Malaya, 50603 Kuala Lumpur, Malaysia
[e] Department of Telecommunication Engineering, Faculty of Engineering, Hormuud University, Mogadishu, Somalia
[f] Institute of Sustainable Energy, Universiti Tenaga Nasional, Jalan Ikram-Uniten, Kajang 43000, Selangor, Malaysia

ARTICLE INFO

Handling Editor: Mark Howells

Keywords:
Somalia
Electricity
Economic growth
Sustainable development
Solar energy
Utilization

ABSTRACT

In Somalia, access to electricity impedes economic growth and sustainable development. Despite having abundant solar energy potential due to its location near the equator, the utilization of solar energy in Somalia is still limited due to unfamiliarity, lack of energy awareness, high initial costs, and lack of infrastructure. The Somali government has established the National Regulatory Authority and set a goal to increase energy access from 15 to 45% by 2024 through the National Development Plan (NDP) 9th (2020–2024). This study aims to analyze and verify the utilization and potential of solar energy in Somalia to understand opportunities and challenges and identify suitable areas and technologies for development. This study explores Somalia's energy profile and the potential for harnessing solar energy. The installed photovoltaic capacity was found to be 41 MW and contributed 11.9% of the total electricity generation. A case study on a solar power microgrid system in Bacadweyene, Somalia, is also presented. The research provides valuable information on the status of the utilization and potential of solar energy in Somalia and aligns with the NDP 9th. The results can serve as a scientific framework for companies and researchers to seek feasible strategies for future investment in solar energy applications in Somalia.

1. Introduction

The current increase in urbanization, population growth, economic development, and technological advancement have proliferated the demands for global energy; these can be achieved through new power generation capacities. A report published by the International Energy Agency (IEA) and the World Bank exposes that the installed energy capacity may double over the next four decades to meet the projected electricity demands of developing countries [1–5]. Although conventional fossil fuels are widely used, they are increasingly concerned about their significant environmental impacts, particularly in climate change issues. These concerns have been the primary factors in accelerating the transition towards green energy. Furthermore, the power generated from favorable renewable energy (RE) resources has gained significant attention as clean power produced from environmental-friendly energy resources. For example, solar and wind energy systems are clean energy sources and are quickly growing in the electricity markets. Therefore, clean energy sources are more suitable than traditional ones, such as fossil fuels, coal, and nuclear energy [6–9]. The global public and private sectors are actively seeking new strategies to meet the demands on clean energy in reducing greenhouse gas emissions and the energy costs used in their operations. Resultantly, the installation of renewable and sustainable energy systems was prioritized [10–12]. Thus, solar energy remains the most promising alternative energy source as it offers various advantages over other alternatives [13]. Solar energy is naturally available as an environmental-friendly energy source produced from the sun, which can be utilized to generate power [14] directly. Moreover, solar energy causes no pollution, requires little maintenance, and the product technology has a long life expectancy of approximately 20–30

* Corresponding author.
E-mail address: hazli@um.edu.my (H. Mokhlis).

https://doi.org/10.1016/j.esr.2023.101108
Received 22 October 2022; Received in revised form 14 May 2023; Accepted 2 June 2023
Available online 12 June 2023

Nomenclature

AC	Alternating Current
BECO	Banadir Electric Company
BTS	Base Transceiver Station
CO_2	Carbon Dioxide
CSP	Concentrated Solar Power
DG	Diesel Generator
DC	Direct Current
ERC	Electricity Regulatory Commission
ESPs	Electricity Service Providers
EC-JRC	European Commission-Joint Research Centre
FGS	Federal Government of Somalia
FMS	Federal Member States
GW	Gigawatt
GWh	Gigawatt-hours
GHI	Global Horizontal Irradiation
GTI	Global Tilted Irradiation
HSDGs	High-Speed Diesel Generator Sets
HECO	Horn Electricity Company
IEA	International Energy Agency
IPPs	Independent Power Producers
ILO	International Labour Organization
ITCZ	Intertropical Convergence Zone
kW	Kilowatt
kWh	Kilowatt-hour
MJ	Megajoule
MW	Megawatt
MWh	Megawatt-hour
M	Metre
MoEWR	Minister of Energy and Water Resources
MERRA-2	Modern Era Retrospective-Analysis for Research and Applications
NASA	National Aeronautics and Space Administration
NDP	National Development Plan
NECSOM	National Energy Corporation of Somalia
NetEco	Network Ecosystem
PV	Photovoltaic
PVGIS	Photovoltaic Geographical Information System
RE	Renewable Energy
SPMP	Somali Power Sector Master Plan
SESNAIP	Somalia Energy Sector Needs Assessment and Investment Programmes
SOMINVEST	Somalia Investment
TW	Trillion Watts
UN	USA United Nations United States of America
USD	United States Dollar

years [14,15]. Although solar applications were initially introduced for rural electrification, telecommunication, and agriculture sectors, they are currently utilized in a wide range of applications, such as solar water heating, solar drying, and solar photovoltaics (PVs) [16–20]. Besides, solar power can meet 100% of the world's primary energy requirements [21].

In many countries, including Somalia, excessive reliance on fossil fuels is a serious concern. Continually, the desire to get relatively cheap energy by mainly burning coal is stronger than the desire to maintain a good state of the environment [22–24]. The study aimed to assess the status of solar energy utilization in Somalia, one of the world's least electrified countries, facing challenges such as a lack of infrastructure and a chaotic political environment. The research showed that there had been an increase in the use of solar energy in recent years, with efforts being made to develop small and large-scale solar power systems. The findings provide valuable information for future investment in solar energy in Somalia. However, the utilization and potential of solar energy in Somalia, including a lack of comprehensive and up-to-date data on solar radiation levels and energy potential, must be addressed to understand opportunities and challenges better and promote sustainable energy access and development. In addition, more comprehensive and detailed solar energy potential analyses are required to identify the most suitable areas and technologies for solar energy development in Somalia. This study could support and inform the development of policies and investment strategies to promote the country's energy sector's growth [25,26].

Based on the extensive review conducted by the authors, no study has been performed on solar energy potential and utilization in Somalia. Therefore, this paper presents a brief energy profile, utilization, and the status of the potential of solar energy in all Somalia regions. In addition, a case study on the PV systems in Bacadweyne, Somalia, was presented. Subsequently, the potential of the electricity generation in theoretical PV values and recorded PV generation yield at the Bacadweyne site were compared and analyzed. The PV installation's performance ratio (PR) was determined by the difference between on-site energy generation (energy production) and expected energy yield. The expected energy yield was determined based on the type of module and environmental sensor measurements. The PV system performance was also assessed using PR values ranging from 0 to 1. In this study, the theoretical data in estimating the PR values of PVs were obtained using the Photovoltaic Geographical Information System (PVGIS) and Solargis software.

2. Geographical and demographic conditions of Somalia

Somalia is located in the eastern part of Africa and is bordered by the Indian Ocean, Kenya and Ethiopia, Djibouti, and the Gulf of Aden (see Fig. 1). It is partitioned into 18 regions with a total area of 637,540 km^2. Moreover, it has a coastline of 3333 km, the longest in mainland Africa. The capital city, Mogadishu, is located just north of the equator in the Indian Ocean. According to the United Nations (UN) Population Division, the Somali population was estimated at 16.6 million, with a growth rate of 2.92% in March 2022 [27–30].

Somalia experiences four seasons based on the north-south variations of the Intertropical Convergence Zone (ITCZ). The main rainy seasons are the two monsoon seasons, "Gu" from April to June and "Deyr" from October to December. The dry season, "Xagga," is from July to September, and the winter season, "Jiilaal," extends from December to March. The northern highlands receive an average of 500 mm of rainfall annually, while the coastline and Southwest receive 50–150 mm and 300–500 mm, respectively [27,31,32]. The climate in Somalia is characterized by high levels of temperature and humidity, ranging from 70 to 85%. The average daily temperature is 27 °C with temperature fluctuations between 20 and 35 °C (68–95 °F). The monthly solar radiation in Somalia ranges from 518 to 8160 MJ/m2 [33,34].

2.1. Population distribution

The population distribution was referred from the UN Population Division, UN Statistical Division, and other statistical publications from national statistical offices. Based on the results, the Somali population increased from 15.01 to 16.84 million in the last five years (2018–2022). Fig. 2 depicts 80% of the population as youths, where females are almost 50.14% of the population, and the remaining population is males [35,36]. Furthermore, the various age groups can impact the economy of the country. For instance, the younger generation's lifestyle differs from those over 50. Nevertheless, the population growth for both age groups

Fig. 1. A map indicating the location of Somalia in the African continent with a small globe map representing the location of Somalia in the world. *Source:* https://www.nationsonline.org/oneworld/map/somalia-political-map.htm.

would still increase energy consumption. Fig. 3 reveals the population in Somalia by age group.

3. Research methodology

Globally, there is significant concern about pollution and energy demand. In order to achieve sustainable development, it is necessary to explore energy technology scenarios with low environmental impacts (local, regional, and worldwide) and reasonable resource allocation [5]. Somalia is known to be the most prosperous country with both conventional and solar energy potentials among other African countries [26]. This research aims to analyze and verify Somalia's utilization, energy profile, and solar energy potential status. Based on the current situation throughout the provinces of Somalia, a comprehensive economic perspective and social and environmental studies were conducted to highlight the potential of solar energy. Furthermore, the study would function as a roadmap to provide relevant information in promoting solar energy investments, attracting local and foreign investors, and

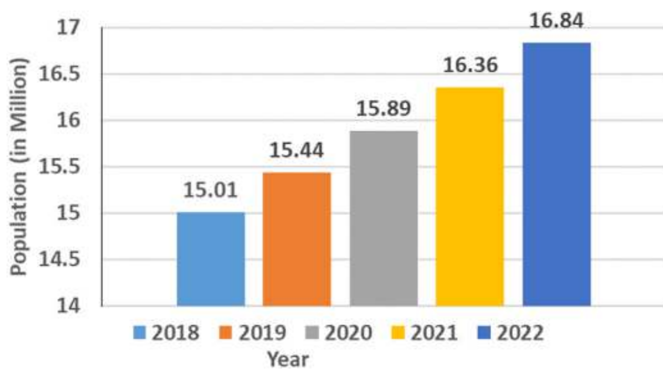

Fig. 2. The population in Somalia from 2018 to 2022 [35–37].

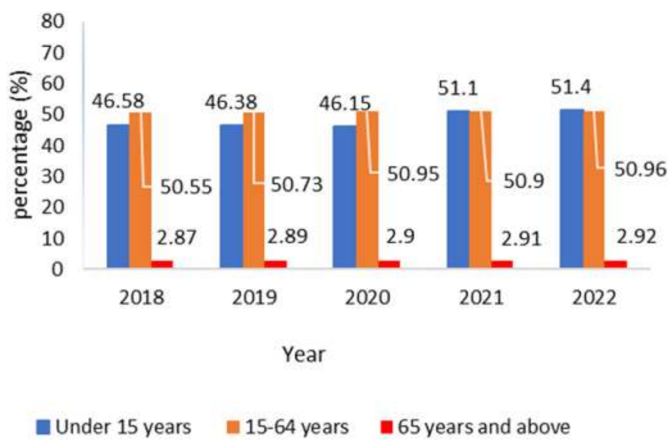

Fig. 3. The Somali population by age group from 2018 to 2022 [36,38].

raising public awareness. In addition, a case study was performed on a microgrid system in Bacadweyne, Somalia, to verify the economic feasibility of RE investments.

Moreover, this real case study was presented to demonstrate the technical viewpoint on the potential of solar energy. We used the problem-cause-solution technique to present our work and compensate for the lack of utilization analysis and the solar energy potential in Somalia. The methodology employed for analyzing the utilization and solar energy potential assessment is illustrated in the following systematic flowchart shown in Fig. 4. In addition, the PV generation yield's measured performance ratio (PR) in Bacadweyne, Somalia, was compared to the electricity generation of the theoretical PV values using PVGIS and Solargis software. This study collected information on the potential of solar energy from various sources. The data gathered are presented in paragraph form and table as shown in Table 1, which includes online scientific databases (ScienceDirect®, IEEE Xplore™, and other databases), official reports from the Minister of Energy and Water Resources (MoEWR) and Ministry of Natural Resources, authorized websites of regional and local and global organizations, scientific research works, and other agencies as tabulated in Table 1.

4. Current energy overview and prospects in Somalia

4.1. Primary energy production

According to the existing data, the utilization of RE in Somalia was still lacking compared to conventional sources [39]. Somalia relies mainly on high-speed diesel generator sets for electricity generation, using 121,000 L of diesel daily. This is expected to increase to 694,000 L by 2024 due to rapid urbanization [39,40]. RE is a viable option for long-term energy development. Integrating large grid-connected solar PV generators into HSDG-based energy generation and distribution networks through synchronizing diesel and solar PV generation systems can be developed by Electricity Service Providers (ESPs).

Table 2 compares Somalia's primary energy production for electricity generation to Kenya, Africa, and other countries (2015–2019). Fossil fuels are the primary energy source in Africa (82.44%) and globally (70.04%). In Somalia, 87.8% of electricity is generated from fossil fuels, while Kenya generates only 32.5% [41–43]. Nonetheless, a significant percentage of electricity in Somalia was generated from fossil fuels compared to the rest of the world.

4.2. Energy supply

Somalia's energy capacity is around 344 MW, mainly generated from imported diesel fuel. However, some ESPs have installed grid-connected solar PV systems. In Table 3, Energy supply and tariffs in the Federal Member States have seen a 36% yearly increase in the past six years. The Somali National Development Plan (NDP) Office reports that electricity generation, as shown in Fig. 5, is steadily rising, excluding electricity generated independently. The total installed capacity of RE is 41 MW for solar and 1 MW for wind. Most ESPs plan to increase their RE investments by the end of 2023, and as electricity demand rises, the generation capacity in ESPs also increases. Technical losses in the distribution network are being reduced from 40% to 20%, and electricity tariffs have dropped from ($1.5 to $0.79) per kWh since 2015. Nevertheless, the reduction was only observed in major cities near seaports like Mogadishu, Kismayo, Bosaso, and Berbera [39,46]. The energy demand is expected to increase as the private sector invests in buildings and other sectors like irrigation, cold storage, and small industries expand.

4.3. Energy utilization and prospects for Somalia

Somalia is undergoing political stabilization and reconstruction after years of conflict. Its economy is improving due to urbanization, population growth, technological advancement, improved security, and the return of the diaspora. In 2015, the Somalia Energy Sector Needs Assessment and Investment Programmes (SESNAIP) was introduced to reduce Somalia's overreliance on certain energy types and identify short-term assistance needs. The program aims to maintain, rehabilitate and develop energy infrastructure, meet current demand, and reduce unsatisfied demand for electricity and modern fuels. Objectives were examined from 2016 to 2018, and further assessments will be done to identify medium-term needs and investments from 2019 to 2025 to expand the generation capacity.

Somalia is moving towards a mix of energy sources, including solar, wind, and natural gas, which are imported. 65% of Somalis live in rural areas and rely on agriculture and charcoal production for income, using traditional biomass fuels (firewood and charcoal) for 82% of energy [45]. The national electricity access rate is only 36.03%, leaving 9.88 million people without adequate access [47]. According to the 8th (2017–2019) and 9th (2020–2024) National Development Plans (NDPs), the government aims to establish a National Regulatory Authority by 2021 as per the 8th and 9th National Development Plans. SOMINVEST, the investment promotion office, was established to promote foreign direct and energy investments. The target is to increase energy access from 15% to 45% by 2024 [40,48]. 85% of Somaliland state urban households and industries are aimed to receive electricity by 2021, and 25% of rural households and industries by the same year. The Somali NDP targets a 6% yearly increase in generating capacity, which was achieved with an increase from 115 to 344 MW (2015 to June 2021), while the current electrification rate is 36% and a target for Somalia to increase up to 1043 MW (2022–2027) and expect electrification rate will increase up to 75%. The Federal Ministry of Planning aims to deliver more than 200 MW of the state's energy production by RE sources. The increase in power generated target for Somalia was depicted in Fig. 6,

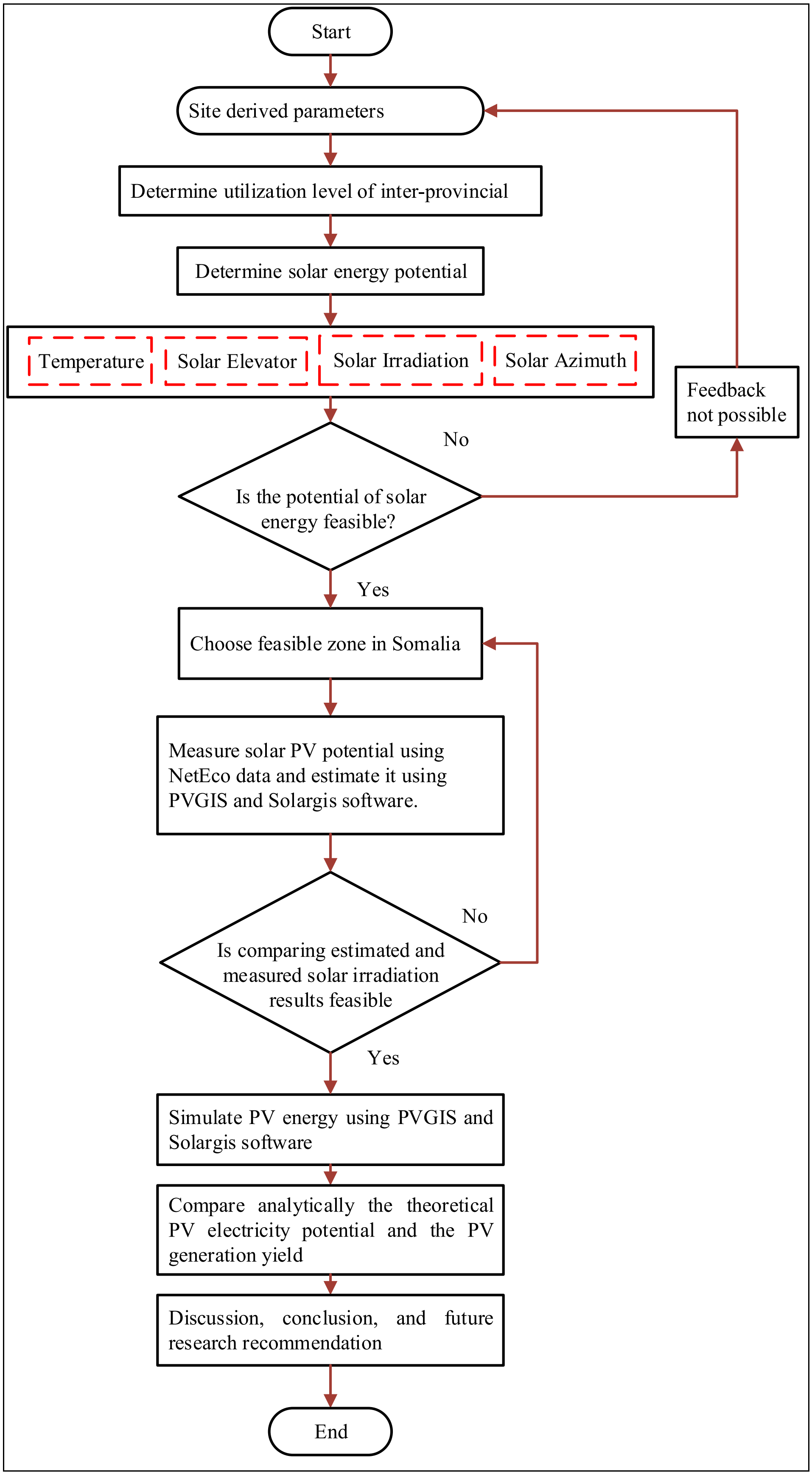

Fig. 4. Research framework outlining the fundamental steps of the methodology.

Table 1
Summary of the various sources used to obtain information on the solar energy potential in this study.

•EU Global Technical Assistance Facility on Sustainable Energy	• International Renewable Energy Agency
• National Energy Corporation of Somalia (NECSOM)	• Somaliland Power (Sompower)
• Renewables Global Status Report	• Hormuud Telecom Somalia Inc.
• US Agency for International Development	• Statistical Review of World Energy
• Ibrahim Index of African Governance	• World Bank Electricity Access
• Banadir Electric Company (BECO)	• Horn Electricity Company (HECO)

Table 2
Summary of the primary energy production of Somalia, Kenya, and the rest of the world [42,44,45].

Energy source	Total electricity production in Somalia (%)	Total electricity production in Kenya (%)	Total electricity production in Africa (%)	Total electricity production in the world (%)
Fossil fuels	87.8	32.5	82.44	70.04
Solar	11.9	1.0	0.99	4.35
Wind	0.3	0.4	2.23	8.25
Hydropower	0.0	33.9	11.92	7.71
Nuclear	0.0	19.0	1.68	9.19
Geothermal	0.0	13.2	0.73	0.47

Table 3
Summary of Somalia's energy supply with generating capacity and tariffs (data collected from ministries and ESPs) [34,39].

FMS	Generating capacity (KVA)		Tariff ($/kWh)
	Diesel (kW)	RE (kW)	
Banadir Regional Administration	124,920	9500	0.36
Somaliland	84,000	29,000	0.70
Puntland	52,750	2500	1.00
Southwest	17,800	0	0.70
Hirshabelle	9600	1000	1.00
Jubaland	8400	0	0.90
Galmudug	4880	0	1.00
Total	302,350	42,000	0.81

which signified an annual growth of 36% over the last six years and a target still enduring [39].

5. Potential of solar energy in Somalia

REs in Somalia are promising due to their strategic geographical location, which can support the international effort for sustainable development in Somalia. Although Somalia still lacks energy infrastructure, the current movement for alternative energy sources has gradually increased. Since developing a national grid is hardly feasible, integrating RE is the best short-term option for the national electrification agenda. Moreover, the cost of RE technologies has declined while technology efficiency has improved remarkably [49,50]. Somalia has abundant solar radiation and receives average solar energy insolation between 5 and 7 kW/m^2 per day based on the horizontal surface. In some parts of Somalia, the average daily solar radiation is among the highest [51,52].

The solar energy distribution in Somalia is typically uniform, with an average rise of no more than 16% between zones with higher and lower insulation. Based on the solar energy distribution, the solar panel produced similar energy output regardless of the location or installation angle. The average sunshine duration varies from 2900 to 3100 h per year (8–8.5 h daily). Thus, the temperature is not significantly high, with a yearly average temperature of 27 °C, which is suitable for the

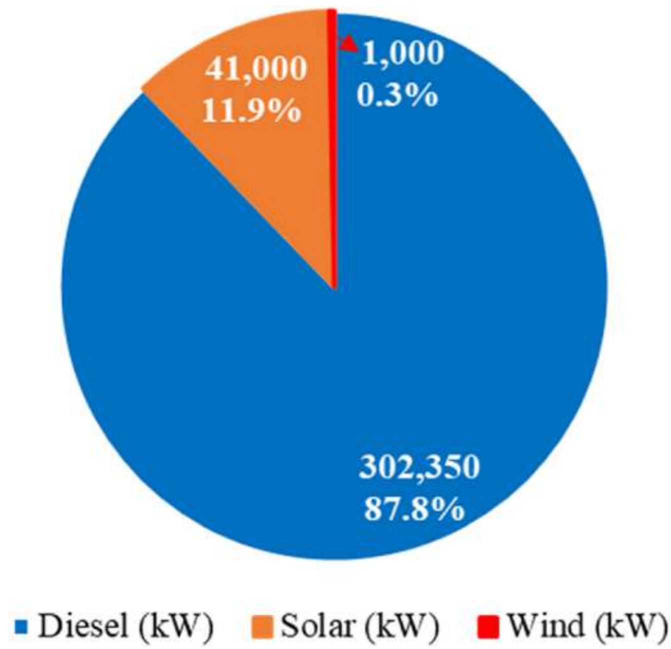

Fig. 5. The types of electricity generation in Somalia [39,40].

operational lifespan of solar PVs [39,46]. All these factors make Somalia the most appropriate location for a wide range of solar technology applications, particularly PV applications (off-grid electrification and grid-connected or Concentrated Solar Power (CSP) [53]. The simulation results using PVGIS revealed that the solar PV installation in Somalia produced two-fold the energy amount compared to PVs installed in Germany. Hence, RE, such as solar energy, can reduce electricity costs and the negative environmental impacts [54].

According to the energy statistics, Somalia can be the most prosperous country in Africa regarding RE adoption as it is primarily warm and dry throughout the year [55,56]. Moreover, the Somalia RE market has some of the highest prospects in Africa and global markets. Therefore, the potential of RE sources like solar energy can mitigate the lack of electricity access and environmental concerns [57].

5.1. *Radiation data for eighteen regions*

The irradiation data for eighteen regions in Somalia was collected from the National Aeronautics and Space Administration (NASA) and the Modern Era Retrospective Analysis for Research and Applications (MERRA-2). The global horizontal irradiation (GHI) of Somalia is presented in Fig. 7. Also, the selected areas' geographical location is illustrated in Table 4. The site elevation above sea level was determined using an application based on a digital elevation model [58]. We obtained the region name, elevation above sea level, and the period from 2010 to 2020 for each region using data from NASA and MERRA-2. Furthermore, the data was also time-based at 15 min as an output determination. The average yearly irradiation for 11 years of Somalia was obtained in terms of maximum radiation in Bari and minimum radiation in the Middle Juba region. Therefore, the data demonstrated that solar radiation is typically sound within Somali territory.

5.2. *Utilization of solar energy in Somalia*

The sun's energy potential is unmatched as the amount of solar radiation can meet the global electricity demand. Hence, the possibility of solar energy being exhausted in the future is insignificant as it is sustainable and renewable. Furthermore, solar energy is considered a non-polluting, reliable, and clean energy source [60–62].

The availability of solar energy potential in Somalia varies

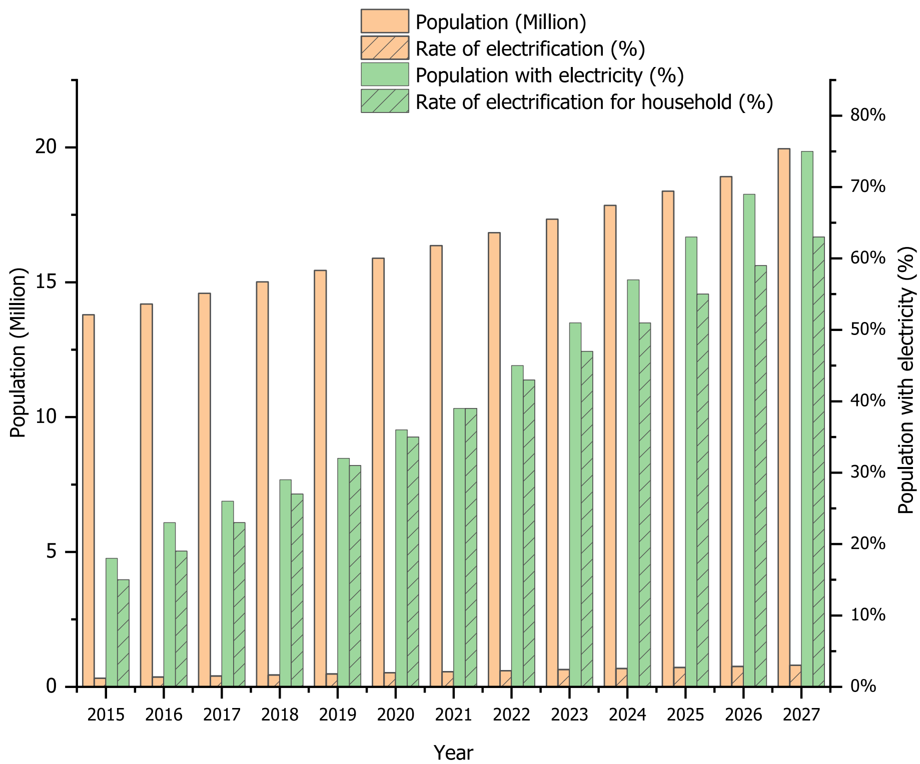

Fig. 6. Target for Somalia electrification rate from 2015 to 2027 [26,39].

significantly throughout the day, season, year, and even from one geographical location to another. Table 5 presents the status of Somalia's solar energy capacity established by ESPs. Solar energy was competitively pursued with conventional energy sources in Somalia. Moreover, solar energy significantly contributes to national power generation and reduces the environmental effect of fossil fuels. Most cities in the country have initiated the use of solar energy, which gradually increased based on the solar power generation capacities of ESPs in investment values and simultaneously reducing CO_2 emissions [57]. The overall energy generation in Somalia was 344 MW, with solar energy contributing 41 MW (11.9%) of the total power generation in the country. In addition, the rest was from DGs and wind power at 302 MW (87.8%) and 1 MW (0.3%), respectively. The details are presented in Table 5 according to the solar power generation capacity [33,39].

Since 2015, the most significant investment in solar energy in Somalia has been produced by leading ESPs. The companies, which include BECO, NESCOM, and Sompower, have invested in the solar system project in different capacities, with BECO producing the most significant investment in the Somali energy sector. Currently, BECO produces solar power (55 MW) from diesel engines, which were installed in 2016 (2.5 MW) and 2020 (5 MW) in the southern region of Somalia. BECO successfully decreased the tariff from $1.2 to 0.46 per kWh. Furthermore, BECO plans 25 MW of solar-diesel hybrid power plants to be installed at Jabad Gele and 100 MW of hybrid energy systems, including solar-diesel-battery, by 2022 and 2023, respectively. Alternatively, Sompower produced 38 MW of diesel engines and built solar power plants with an installed capacity of 20 MW in 2020. Sompower also successfully reduced the tariff from $0.79 to 0.57 per kWh in Hargeisa. Other ESPs like Mogadishu Power Supply installed 2 MW and planned to increase the output to 10 MW in the coming years, and Blue-sky Energy plans to install 4 MW. Overall, the combined capacity of Mogadishu Power Supply and Blue-sky Energy was 30 MW and 18 MW of diesel engines, respectively.

Although many solar projects have been implemented in Somalia, the cost of electricity remains high. This could be due to various factors, including limited infrastructure, high operational costs, limited demand, political instability, and low economies of scale. When planning and implementing solar projects in Somalia, it is essential to consider these factors and their potential impact on the project's success.

To ensure the success of a solar energy project from an economic point of view, it is essential to evaluate its financial viability and reliability beforehand. A techno-economic analysis should be conducted to compare the project's cost and profitability. Hybrid systems combining renewable energy sources, diesel generators, and battery energy storage can stabilize off-grid and grid-connected systems and provide a continuous power supply to the local loads. However, the feasibility of such systems varies by location and must be assessed individually. During the analysis, it is also vital to calculate surplus power in solar energy projects to avoid over-budget, power loss and ensure system consistency. This analysis can be complex due to the various energy generation systems involved. The optimal capacity of energy facilities is influenced by factors such as the level of solar energy usage, electric demand, levelized cost of energy (LCOE), return on investment (ROI), payback period, and capacity factor, which are difficult to predict with certainty beforehand. To prevent excessive energy consumption, the design capacity should be determined together with operational planning, which relies on projections of future demand and anticipated energy production.

6. Challenges and prospects of solar technology in Somalia

RE sources and technologies have the potential to solve energy-related issues. Hence, solar energy can be a significant aspect of the community strategy to add new electricity generation capacity and increase energy security while addressing environmental concerns [63–68]. Solar energy is one of the most outstanding solutions for fulfilling future energy demands. In addition, solar energy exceeds various RE sources in terms of accessibility, economic viability, capacity, and efficiency [69,70]. The global solar power installed was measured in a total of 1.25 TW, with 760 GW of solar PV, 6 GW of CSP, and 500 GW of

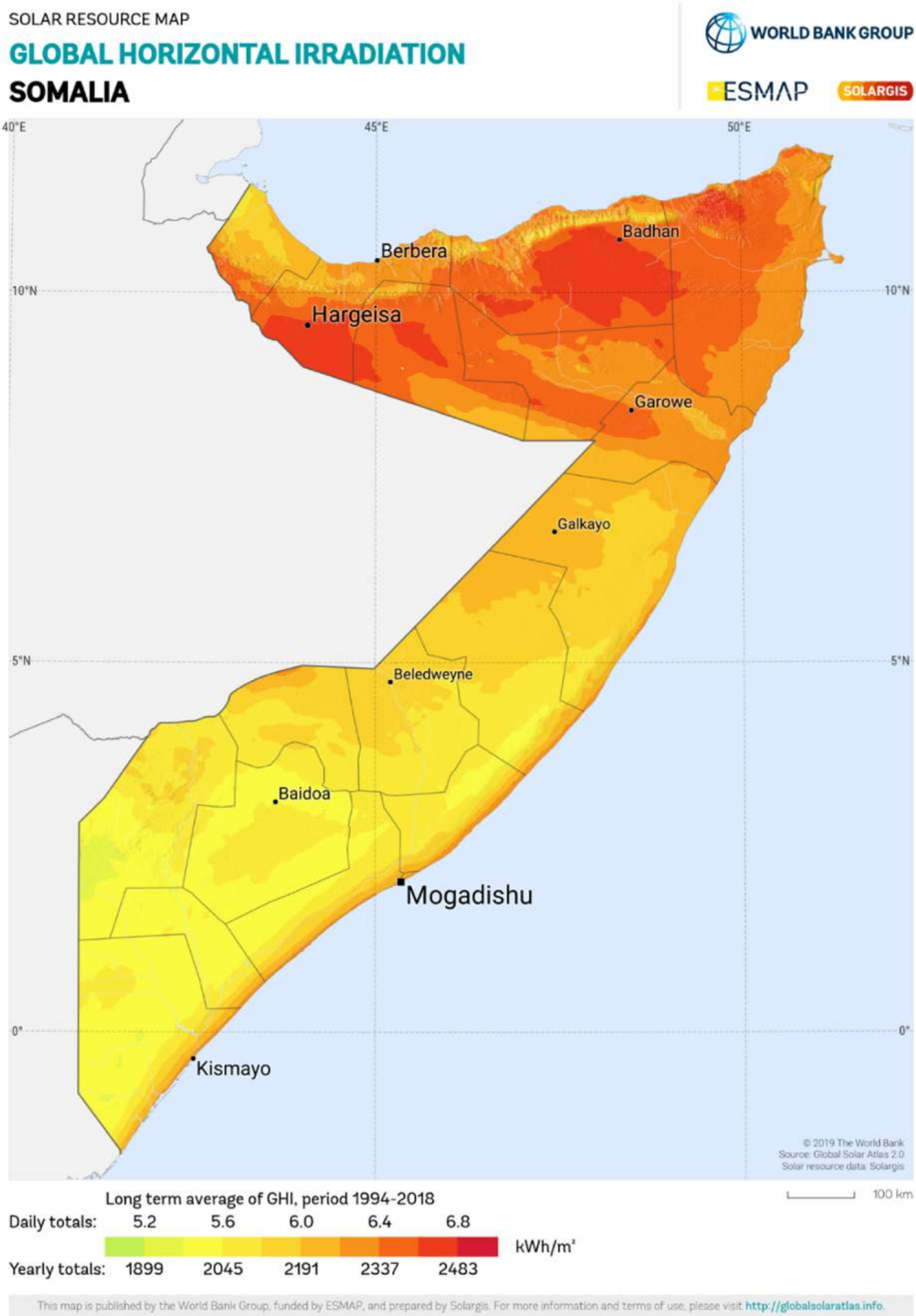

Fig. 7. Diagram indicating the potential of solar energy based on the map of Somalia [51,59].

Table 4
Summary of the solar radiation data obtained for 18 Somalia regions (2010–2020).

Order	Location	Latitude (°)	Longitude (°)	Elevation (m)	Radiation (kWh/ m^2)	Duration (year)
1	Awal	10.6334	43.3295	775.55	6.07	2010–2020
2	Bakool	4.3657	44.0960	489.87	6.05	2010–2020
3	Banadir	2.1187	45.3369	17.14	6.02	2010–2020
4	Bari	10.1204	49.6911	532.00	6.67	2010–2020
5	Bay	2.4825	43.4837	212.40	5.76	2010–2020
6	Galgaduud	5.1850	46.8253	172.69	6.23	2010–2020
7	Gedo	3.5039	42.2362	219.46	5.93	2010–2020
8	Middle Shabelle	2.9250	45.9040	131.25	6.02	2010–2020
9	Middle Juba	1.5623	42.6667	87.16	5.62	2010–2020
10	Nugal	8.2173	49.2031	346.97	6.60	2010–2020
11	Togdheer	9.4461	45.2994	1170.76	6.66	2010–2020
12	Mudug	6.5657	47.7638	251.74	6.39	2010–2020
13	Hiran	4.3210	45.2994	290.09	6.10	2010–2020
14	Lower Shabelle	1.8766	44.2479	73.29	6.20	2010–2020
15	Lower Juba	2.0780	41.6012	179.15	5.68	2010–2020
16	Sanag	10.3938	47.7638	1442.68	6.62	2010–2020
17	Sool	8.7222	47.7638	645.30	6.54	2010–2020
18	Woqooyi Galbeed	9.5424	44.0960	1147.21	6.65	2010–2020

Table 5
A summary of Somalia's solar power generation capacity from 2016 to 2020 [34, 39].

Order	State Name	Company Name	Installed (MW)	Total Capacity (MW)
1	Banadir Regional Administration	BECO	7.5	9.5
		Mogadishu Power Supply	2	
2	Somaliland	HECO	6	29
		SEPCO	1	
		Sompower	22	
3	Puntland	NESCOM	1.5	1.5
4	Hirshabelle	Dayah Electricity Company	1	1
Total				41

solar thermal power. Thus, the power equates to an annual energy generation of approximately 0.24 TWyr or 0.08% of the solar potential that can be reasonably exploited yearly [71].

In Somalia, there has been substantial progress in solar capacity installation in recent years. For example, ESPs have employed 27 MW of PV systems in 2021 and beyond, and this represents a notable increase compared to previous years. Implementing the systems depicted how Somali ESPs have gradually shifted to clean energy by improving energy efficiency and optimizing investment costs. Based on the current installed energy capacity in Somalia, solar energy contributes approximately 11.9% of total power generation in the country and is expected to increase in the upcoming years.

The ESPs and the MoEWR have also planned to increase electricity generation through solar energy, which can benefit the infrastructures in the energy sector and the environment. The BECO is Somalia's most prominent electricity provider, mainly covering Mogadishu (80%), the airport (100%), and Halane zone, Hirshabele, Jubaland, and Southwest. Additionally, BECO announced a large-scale solar power plant of 25 MW last December upon completing two other projects on solar power plants in Daarusalaam City and Jabad Gele, as indicated in Fig. 8(a) and (b). Therefore, the achievement demonstrated that the objectives of BECO in reducing electricity tariffs, carbon footprint, and protecting the environment were enduring as planned. Initially, the leading electricity supplier in Somalia aimed to reduce the risks of importing fossil fuels for electricity production, and thus, the electricity supplier shifted to RE, particularly solar energy [72,73].

RE utilization is known to be a free and clean energy source that reduces CO_2 emissions [71,74,75]. Recent efforts are being promoted and accelerated in conjunction with the country's National Renewable Energy Action Plan and National Energy Efficiency Action Plan. Both plans are committed to developing a sustainable and conducive investment environment for the energy sector in Somalia. Hence, the objective is achieved through solar energy technology capacity building to improve power generation and distribution efficiency [76–78].

6.1. Sustainability of the energy sector and financing challenges in Somalia

Somalia's energy sector has suffered for nearly two decades owing to extensive insecurity, the removal of governmental resources and control, and inadequate investments. Nevertheless, the financial challenges

Fig. 8. The solar power plants in (a) Daarusalaam city and (b) Jabad Gele.

hinder potential energy growth while the ability to finance is limited. On the other hand, ESPs are interested in shifting to REs for economic and environmental reasons, although lacking a functioning banking sector creates challenging RE funding requirements [79–81]. Furthermore, the Somali government can extend energy availability through RE in achieving various development, security, economic, and climatic objectives. Two Turkish corporations handling the port and airport of Mogadishu are taking their first tentative steps after the law enactment by the Federal Government of Somalia (FGS) on private foreign investments [39]. Many neighboring countries of Somalia do not impose tariffs on imported RE products and offer additional incentives to RE companies. Meanwhile, RE products in Somalia are heavily taxed as they are classified among luxury items, such as cell phones and televisions [39,82,83]. According to the current updates on investments and the enabling environments in the energy sector, the significant concerns and bottlenecks observed are as follows [33,84].

- The energy sector is concerned about limited regulations and oversights.
- The monopoly in distribution control still exists in some areas.
- There is a critical shortage of qualified personnel in the energy sector.
- Due to inadequate infrastructures and financial collection, there are significant losses in electricity generation and distribution (up to 15–40%).
- The existing insecurity and political instability issues.

6.2. *Regulation and energy policy frameworks*

Somalia generated the highest electricity tariffs globally compared to the United States of America (USA), China, Malaysia, and Algeria [46,72,73,85–89]. Most of the power is generated by the local Independent Power Producers (IPPs), with businesses and residences paying up to $0.30 to 1.00/kWh [26]. Somalia's citizens rely on charcoal and wood, which decimates the forest stock. The Somali government has undertaken several initial steps to produce favorable environmental-friendly policies and regulations. The Somali Power Master Plan (SPMP) outlines a strategy to increase energy production in RE sources and fossil fuels. The strategy permits an increase in energy access from 15% to 45% of the population by 2024, or a 6% annual rise, to cut energy prices.

The non-implementation of policies to improve market efficiency, generation, and reliability in Somalia is complex and cannot be attributed to a single factor. Factors such as lack of political will, insufficient funding, stakeholder resistance, technical difficulties, inadequate enforcement mechanisms, and difficulties coordinating with existing laws could all contribute to the issue. Understanding the root cause is essential for effective resolution. The legal framework favors promoting renewable energy and the construction of related infrastructure, encouraging stakeholders to provide affordable and efficient renewable energy, reducing investment risks, and promoting efficiency [34,40,90]. Somalia's regulations and policies aim to improve electricity tariffs and promote sustainable development. The framework includes regulations, energy policies, decrees, and ministerial directives to achieve these policies.

- A sector development plan (SPMP) must be made and approved to define the basic building blocks for a modern energy sector in Somalia.
- The Council approved the FGS Electricity Bill and Energy Policy of Ministers in December 2020.
- The Electricity Bill is expected to be approved by parliament and enacted by the mid of 2023.
- The Somali Cabinet approved the National Environmental Policy on February 13, 2020.
- The Cabinet passed the National Environment Management Bill of 2020 to strengthen environmental legal frameworks on November 26, 2020.
- The National Climate Change Policy 2020, Draft National Charcoal Policy, Draft National Forest Management Policy, and Draft Ozone Layer Protection Regulation are being drafted.

6.3. *Overreliance on biomass and diesel*

Somalia's reliance on biomass and diesel energy sources is due to a lack of infrastructure and access to other forms of energy. This leads to environmental degradation and harm to the country's economic growth and quality of life. Most energy service providers use diesel generators; however, solar PV systems are gaining popularity in certain regions [91–93]. Investments in renewable energy are necessary to improve sustainability and the reliability of power supply with suitable tariffs.

6.4. *The lack of qualified personnel*

The development of RE-based power technologies in Somalia faces challenges due to a lack of technical expertise and harsh security conditions, limiting access to high-quality technical assistance [94]. The International Labour Organization (ILO) and the Ministry of Energy and Water Resources report that a shortage of funds is a significant obstacle. Training must be accompanied by financial assistance to ensure implementation and address the energy gap in qualified personnel [95]. The energy sector has the smallest number of qualified personnel, particularly in primary industries, where 41% of workers are employed, followed by professionals (5%), skilled agriculture, forestry, and fisheries workers (10%), and craft and related industry workers (9%) [96,97]. This study presents the following recommendations to address the shortage of technical expertise in the RE sector and promote its expansion, reducing energy prices and driving economic growth.

- Establishing vocational schools and enhancing existing secondary schools is recommended to address the shortage of qualified personnel, particularly in the technology sector, in the country.
- The government of Somalia should develop a strategy to improve the soft skills of young graduates and address the shortage of qualified personnel.
- The Minister of Higher Education should prioritize the needs of technical schools and hold annual workshops to motivate and support young graduates.
- The government should encourage private sector involvement and foreign investment by creating supportive policies and regulations.

7. Case study of the microgrid system in bacadweyne, Somalia

Bacadweyne is a town in Somalia's North-Central Mudug region, known for small-scale farming and businesses. It is home to several schools administered by the Galmudug State. The town is located at 5.330° North latitude and 47.900° East longitude and receives an average monthly solar irradiation of 51–807 MJ/m2 or 5 to 7 kW h/m2 per day [98]. The annual average solar irradiation in Bacadweyne is shown in Fig. 9. In this study, the PVGIS and Solargis software was used. The European Commission (EC-JRC) developed the web-based PVGIS to estimate PV performance [99]. The system is updated regularly and uses solar irradiance measurements from 2005 to 2016 to estimate solar irradiation [100]. The Bacadweyne site's system type and technical specifications are outlined in Table 6.

In July 2020, Hormuud Telecom Somalia Inc. Installed a microgrid system at the Bacadweyne site. The microgrid includes a storage system (1600 A h lithium battery), power conversion system (rectifier), DG, main supply, and 6 kWp monocrystalline PV panels [101]. These components were connected to form a microgrid system to meet the DC load needs of the Bacadweyne town's base transceiver station (BTS). The

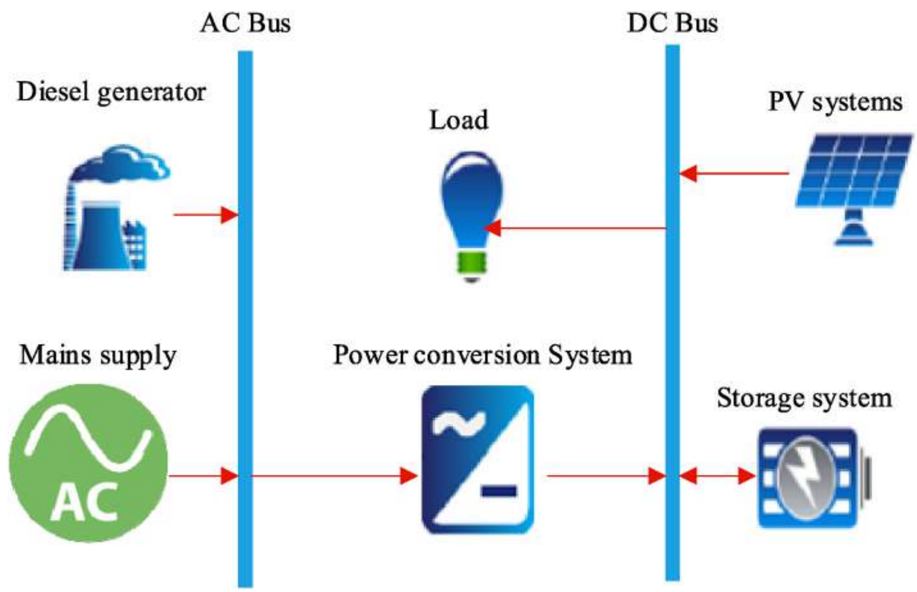

Fig. 9. Schematic representation of the microgrid system.

Table 6
Summary of the system type and the components in Bacadweyne.

Site Name	Centre	State	System Type	No. Of Solar Panels	Solar (KWp)	DG (kW)	Battery Capacity (Ah)	Max DC Load (kW)
Bacadweyne	Mudug	Galmudug	BTS	30	6	10	1600	3

measured minimum and maximum loads were 2.8 and 3 kW, respectively. The ground-based, fixed-mounted PV panels faced south (azimuth of 180°) with a tilt angle of 13°, and no tracker was used. The solar irradiation and temperature data were monitored every 5 min using Huawei's network ecosystem (NetEco), which provides energy and environmental management to reduce energy consumption and emissions [102]. The performance of the Bacadweyne PV system was evaluated based on its contribution to the load and its impact on the company's cost optimization and CO_2 emissions. Hormuud Telecom is the largest telecommunication company and private employer in Somalia, with over 30,000 employees.

7.1. The PV energy yield assessment study

Solar PV systems vary in power generation based on location and weather, so it's crucial to have proper monitoring equipment to measure installed capacity [103]. Energy output is a critical performance metric for PV systems, providing insight into their overall performance [104]. The annual average yield (kWh or kWp per year) is the ratio of yearly energy generated by the PV system to its total installed capacity [105]. Hormuud Telecom aims to reduce tariffs and emissions by connecting all current and future microgrid systems, particularly solar PV developments, to the grid, to increase PV installation at all sites [102].

7.2. Comparison study between the estimated and measured results of solar irradiation

A study was conducted at the Bacadweyne site comparing the estimated and measured results of the microgrid system for 2021 using PVGIS and Solaris software. Performance factors and component losses were obtained from Huawei's PV system design guidelines and measured, including PV system performance, module mismatch, shading, inverter losses, dirt, and cabling losses. The results revealed 12% measured losses and 21% estimated losses for monocrystalline PV systems. Fig. 10 compares the estimated and measured losses based on

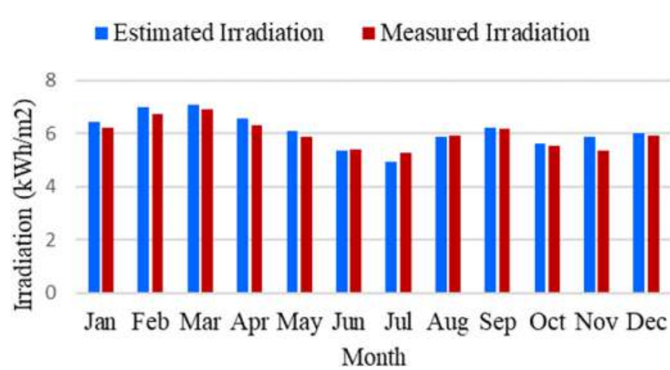

Fig. 10. The estimated and measured average monthly global horizontal solar irradiation at the Bacadweyne site.

average monthly global horizontal irradiation (GHI) at the Bacadweyne site, showing a similar trend each month with a maximum in March and a minimum in July.

7.3. Comparison of the theoretical PV electricity potential and PV generation yield

A study compared the estimated and measured results of a 6 kWp ground-mounted fixed-PV system in Bacadweyne, Somalia, disregarding long-term aging and degradation. Fig. 11(a)–(b) show the global tilted irradiation (GTI), air temperature, and total PV power output for the site. The Solargis method was used to obtain data and estimate the yearly average GTI, air temperature, specific PV power output, and total PV power output as 2266.4 kW h/m2, 27.3 °C, 1709.6 kW h/kWp, and 10,257.6 kW h, respectively. The site's recorded yearly average GTI, air temperature, specific PV power output, and total PV power output were 2179.05 kW h/m2, 27.03 °C, 1542.4 kW h/kWp, and 9247.72 kW h, respectively. The PR of the PV system was calculated using Equation (1),

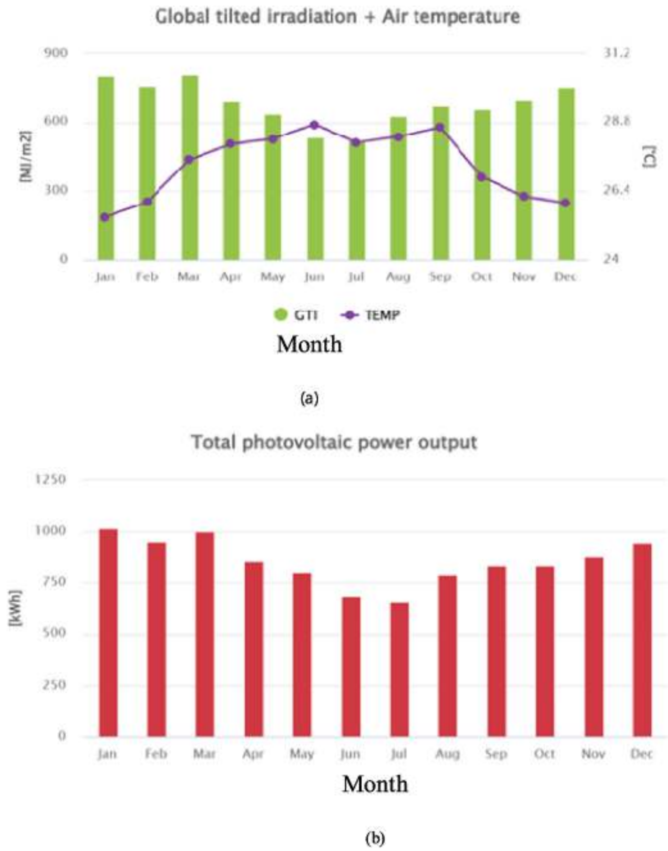

Fig. 11. The (a) GTI and air temperature and (b) total PV power output.

estimating the theoretical PV electricity potential and generation yield in Bacadweyne, Somalia [105,106].

Fig. 12 shows the comparison of monthly electricity generation from PVGIS-Solargis techniques and actual recorded data at the Bacadweyne site. The highest error of 8% was seen in June due to summer rains in 2021. The estimated total PV generation of 10,257.6 kW h and recorded data of 9247.72 kW h resulted in yearly PRs of 75.4% and 70.8%, respectively. In 2021, the Bacadweyne site consumed 22 million kWh, with PV systems contributing 45% of the total. This highlights the significance of PV systems in cost optimization and environmental protection. The PVGIS-Solargis database can be used to estimate PV energy yield for various locations in Somalia, demonstrating the potential of solar energy in the region.

8. Discussion of key findings

Based on the current energy profile in Somalia, The largest share of electricity was produced from fossil fuels (87.8%), while 12.2% was generated from RE. Since 2015, the Federal Ministry of Planning has increased its generating capacity from 115 to 344 MW. Solar energy contributed 11.9% to electricity generation, with an installed capacity that reached 344 MW in 2021. Additionally, the detailed results in Table 2 show that RE installed capacity in Somalia were still low compared to conventional due to a lack of investment, legislative framework, and limited technical capability.

The average sunshine duration in Somalia ranges from 2900 to 3100 h per year, averaging 8–8.5 h per day. The surrounding temperature, with a yearly average of 27 °C, is suitable for the operational life of PV systems. Additionally, the data reported for the monthly solar radiation in Somalia was approximately 518–8160 MJ/m2, which signifies the solar energy potential. The recent progress in REs, particularly in solar energy, has led to a better understanding of the potential for investing in REs and is expected to increase in the coming years. The increase in RE sources and fossil fuels in 2019 and 2021 has further contributed to this understanding. The objectives of increasing access to electricity from 15 to 45% of the population by 2024 and reducing energy tariffs are achievable and will continue to be pursued.

$$PR = \frac{\text{Production energy}}{\text{Expected energy}} = \frac{\text{Production energy [Wh] in specific PV power output in yearly average}}{\sum_t \left[\text{Irradiance}\left[\frac{Wh}{m^2}\right] \times \frac{\text{Peak power[W]}}{1000\ W/_{m^2}}\right] \text{ in total GTI in yearly average}} \quad (1)$$

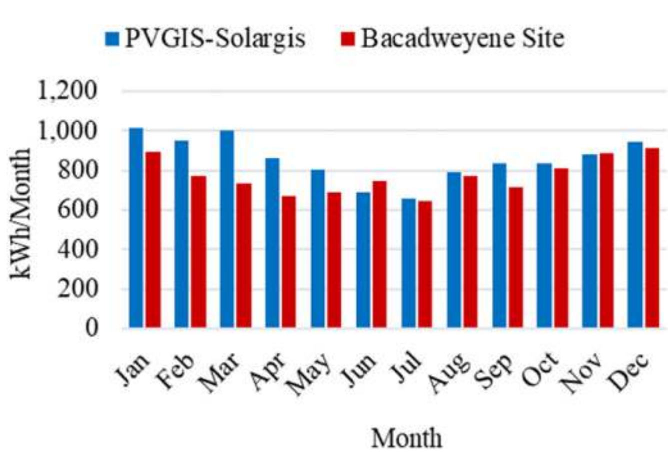

Fig. 12. The estimated monthly electricity generation and recorded PV generation in the Bacadweyne site.

The results of a case study conducted using the PVGIS tool revealed a high potential for solar energy utilization in Somalia. The solar PV system installed in the country was found to produce twice the energy compared to Germany. The recorded data on the Bacadweyne site showed that the estimated PV electricity generation was 10,257.6 kW h, while the recorded data was 9247.72 kW h, with an annual performance ratio of 75.4% and 70.8%, respectively. In 2021, the Bacadweyne site utilized 22 million kWh, with the PV system supplying 45% of the total electricity generation. This highlights the widespread use of PV systems and the positive impact on cost optimization and environmental protection. Hormuud Telecom has reduced its carbon footprint by utilizing solar energy for two-thirds of its technology masts. The widespread use of solar technology has led to cost optimization and a reduction in diesel costs, demonstrating the advancements in solar technology in the country and its potential to eliminate dependence on diesel generators in households, industries, and the commercial sector.

The performance of PV panels in Somalia is determined mainly by the country's climate, particularly the frequent dust storms. Dust accumulation on the surface of the panels negatively impacts their efficiency by reducing their ability to absorb sunlight and thus decreasing energy production. Furthermore, high temperatures can cause the operating temperature of the panels to rise, leading to further decreased efficiency and reduced energy production. The combined effects of dust and heat can also shorten the panels' lifespan, increasing maintenance costs and reducing their overall economic viability. On the other hand, mitigation measures such as regular cleaning, proper shading, and protective coatings can help reduce the impact of dust and heat on the performance of photovoltaic (PV) panels in Somalia. In addition, the best time to clean solar panels is typically early or late in the evening, when the panels are more excellent, and the sun is not shining directly on them. This minimizes the risk of damage to the panels and ensures that the cleaning solution has enough time to dry completely before the sun rises or sets. It is also advisable to clean solar panels after significant dust or sand storms or when there is an accumulation of dirt and grime on the panels that affect their performance.

9. Conclusions and future research recommendations

This study analyzed the utilization and potential of solar energy in Somalia, including a PV panel performance case study. The findings show that Somalia has strong potential for solar energy due to its location & ability to develop large-scale power. Solar is ideal for future energy generation with constant sunshine, low noise, cheap maintenance, environmentally friendly factors, and contributions to lower carbon emissions & zero fuel sources. However, the performance of PV panels is limited due to the technical challenges posed by dust and heat in Somalia's typical climate and the need for mitigation measures, such as regular cleaning and protective coatings, to improve performance. The study also highlighted the importance of investing in high-quality panels and incorporating shading and cooling measures. The study highlights the need for continued research and investment in sustainable energy planning to support the transition to more sustainable energy in the future.

Additionally, a comprehensive approach is needed to address the challenges of training specialists in renewable energy in Somalia, including a desires assessment, supportive learning culture, and resources such as textbooks, equipment, and information. Specialists should stay up-to-date with new technologies, which will help support the sector's growth and realize the potential of solar energy. Furthermore, some recommendations are provided by investors, industries, and legislative policies as follows.

- Regular cleaning, shading, and protective coatings reduce dust and heat impact, promote best cleaning practices, and maintain panels.
- Invest in high-quality panels that can withstand Somalia's harsh conditions.
- Implement shading and cooling measures to reduce operating temperature and improve performance.

  Based on legislative policies to improve solar energy utilization should also be established, including:
- Somalia needs to improve its infrastructure and technical capabilities of sustainable energy organizations.
- Regulatory authorities and legislative frameworks are required to improve energy efficiency, power generation, and supply systems.
- FGS are advised to encourage private investment for medium to long-term sustainable developments.
- FGS, member states, and private sectors are recognized to establish a national plan for decentralizing the energy sector, which reduces losses and increases energy efficiency.
- Specialized training programs should be created to train personnel for solar energy equipment maintenance.

Credit author statement

Abdullahi Mohamed Samatar: Data curation, formal analysis, performing the conceptualization, analysis, writing of the original draft preparation, and improving overall article quality. **Saad Mekhilef**: Supervision and authentication. **Hazlie Mokhlis**: Supervision. **Mostefa Kermadi**: Reviewing and editing the paper. **Abdulkadir Mukhtar Diblawe**: Reviewing the paper. **Alex Stojcevski**: Editing and revising the paper. Mehdi Seyedmahmoudian: Reviewing & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

Acknowledgments

We would like to extend our appreciation to thank Hormuud Telecom Somalia Inc. For providing the current study data. This work is supported by the Universiti Tenaga Nasional grant no. IC6-BOLDREFRESH2025 (HCR) under the BOLD2025 Program.

References

[1] R. Heffron, S. Halbrügge, M.F. Körner, N.A. Obeng-Darko, T. Sumarno, J. Wagner, et al., Justice in solar energy development, Sol. Energy 218 (2021) 68–75, https://doi.org/10.1016/j.solener.2021.01.072.
[2] M. Benasla, D. Hess, T. Allaoui, M. Brahami, M. Denaï, The transition towards a sustainable energy system in Europe: what role can North Africa's solar resources play? Energy Strategy Rev. 24 (2019) 1–13, https://doi.org/10.1016/j.esr.2019.01.007.
[3] P. Pandiyan, R. Sitharthan, S. Saravanan, N. Prabaharan, M. Ramji Tiwari, T. Chinnadurai, et al., A comprehensive review of the prospects for rural electrification using stand-alone and hybrid energy technologies, Sustain. Energy Technol. Assessments (2022), 102155, https://doi.org/10.1016/j.seta.2022.102155, 52.
[4] I.D. Ibrahim, Y. Hamam, Y. Alayli, T. Jamiru, E.R. Sadiku, W.K. Kupolati, et al., A review on Africa energy supply through renewable energy production: Nigeria, Cameroon, Ghana and South Africa as a case study, Energy Strategy Rev. (2021), 100740, https://doi.org/10.1016/j.esr.2021.100740, 38.
[5] E. Manirambona, S.M. Talai, S.K. Kimutai, A review of sustainable planning of Burundian energy sector in East Africa, Energy Strategy Rev. (2022), 100927, https://doi.org/10.1016/j.esr.2022.100927, 43.
[6] D. Erdemir, I. Dincer, A new solar energy-based system integrated with hydrogen storage and heat recovery for sustainable community, Sustain. Energy Technol. Assessments (2022), 102355, https://doi.org/10.1016/j.seta.2022.102355, 52.
[7] K. Almutairi, P. Aungkulanon, S. Algarni, T. Alqahtani, S.A. Keshuov, Solar irradiance and efficient use of energy: residential construction toward net-zero energy building, Sustain. Energy Technol. Assessments (2022), 102550, https://doi.org/10.1016/j.seta.2022.102550, 53.
[8] N. Yan, B. Zhang, W. Li, S. Ma, Hybrid Energy Storage Capacity Allocation Method for Active Distribution Network Considering Demand Side Response 29 (2019) 2–5.
[9] M. Nasir, M. Anees, H.A. Khan, I. Khan, Y. Xu, J.M. Guerrero, Integration and decentralized control of standalone solar home systems for off-grid community applications, IEEE Trans. Ind. Appl. (55) (2019) 7240–7250, https://doi.org/10.1109/TIA.2019.2911605.
[10] S. Mekhilef, A. Safari, W.E.S. Mustaffa, R. Saidur, R. Omar, M.A.A. Younis, Solar energy in Malaysia: current state and prospects, Renew. Sustain. Energy Rev. 16 (2012) 386–396, https://doi.org/10.1016/j.rser.2011.08.003.
[11] U. Kahraman, I. Dincer, Performance analysis of a solar based waste to energy multigeneration system, Sustain. Energy Technol. Assessments (2022), 101729, https://doi.org/10.1016/j.seta.2021.101729, 50.
[12] G. Tong, Q. Chen, H. Xu, Passive solar energy utilization: a review of envelope material selection for Chinese solar greenhouses, Sustain. Energy Technol. Assessments (2022), 101833, https://doi.org/10.1016/j.seta.2021.101833, 50.
[13] F. Ahmed, Sharizal Abdul Aziz M, Palaniandy P, Shaik F. A review on application of renewable energy for desalination technologies with emphasis on concentrated solar power, Sustain. Energy Technol. Assessments (2022), 102772, https://doi.org/10.1016/j.seta.2022.102772, 53.
[14] A. Jahid, M.K.H. Monju, M.E. Hossain, M.F. Hossain, Renewable energy assisted cost aware sustainable off-grid base stations with energy cooperation, IEEE Access (6) (2018) 60900–60920, https://doi.org/10.1109/ACCESS.2018.2874131.
[15] R. Saidur, S. Mekhilef, Energy use, energy savings and emission analysis in the Malaysian rubber producing industries, Appl. Energy 87 (2010) 2746–2758, https://doi.org/10.1016/j.apenergy.2009.12.018.

[16] R. Saidur, A review on electrical motors energy use and energy savings, Renew. Sustain. Energy Rev. 14 (2010) 877–898, https://doi.org/10.1016/j.rser.2009.10.018.
[17] Y. Zahraoui, M.R. Basir Khan, I. Alhamrouni, S. Mekhilef, M. Ahmed, Current status, scenario, and prospective of renewable energy in Algeria: a review, Energies 14 (2021), https://doi.org/10.3390/en14092354.
[18] S. Mohammed Wazed, B.R. Hughes, D. O'Connor, J. Kaiser Calautit, A review of sustainable solar irrigation systems for Sub-Saharan Africa, Renew. Sustain. Energy Rev. 81 (2018) 1206–1225, https://doi.org/10.1016/j.rser.2017.08.039.
[19] W. Huang, J. Dai, L. Xiong, Towards a sustainable energy future: factors affecting solar-hydrogen energy production in China, Sustain. Energy Technol. Assessments (2022), 102059, https://doi.org/10.1016/j.seta.2022.102059, 52.
[20] Q. Xiong, S. Altnji, T. Tayebi, M. Izadi, A. Hajjar, B. Sundén, et al., A comprehensive review on the application of hybrid nanofluids in solar energy collectors, Sustain. Energy Technol. Assessments 47 (2021), https://doi.org/10.1016/j.seta.2021.101341.
[21] M. Perez, R. Perez, Update 2022 – a fundamental look at supply side energy reserves for the planet, Sol Energy Adv (2022), 100014, https://doi.org/10.1016/j.seja.2022.100014, 2.
[22] M. Dzikuć, J. Gorączkowska, A. Piwowar, M. Dzikuć, R. Smoleński, P. Kułyk, The analysis of the innovative potential of the energy sector and low-carbon development: a case study for Poland, Energy Strategy Rev. 38 (2021), https://doi.org/10.1016/j.esr.2021.100769.
[23] P. Puranen, A. Kosonen, J. Ahola, Techno-economic viability of energy storage concepts combined with a residential solar photovoltaic system: a case study from Finland, Appl. Energy (2021), 117199, https://doi.org/10.1016/j.apenergy.2021.117199, 298.
[24] S. Mekhilef, R. Saidur, A. Safari, A review on solar energy use in industries, Renew. Sustain. Energy Rev. 15 (2011) 1777–1790, https://doi.org/10.1016/j.rser.2010.12.018.
[25] M. Harris, Powering ahead, Mater. World 14 (2006) 30–31.
[26] E. Sector, Investment Value Proposition Energy Sector, 2020.
[27] Federal Republic of Somalia, Somalia National Adaptation Programme of Action to Climate Change, 2013, p. 93.
[28] World population prospects - population division - united Nations n.d. https://population.un.org/wpp/. (Accessed 5 March 2022).
[29] M. Advisory, New UN Report Examines Links between Population Growth, Socioeconomic Development and Environmental Change, 2022.
[30] Somalia Population (2022) - worldometer n.d. https://www.worldometers.info/world-population/somalia-population/. (Accessed 5 March 2022).
[31] A. Islam, R. Shaw, F. Mallick, National Adaptation Programme of Action, 2013, https://doi.org/10.1007/978-4-431-54249-0_6, 93–106.
[32] Somalia | UNDP climate change adaptation n.d. https://www.adaptation-undp.org/explore/eastern-africa/somalia. (Accessed 5 March 2022).
[33] USAID. Power Africa Somalia Factsheet, 2018.
[34] Report F. Federal Republic of Somalia Ministry of Energy and Water RESOURCES (MoEWR) Somalia Electricity Sector Recovery Project - SESRP Environmental and Social Management Framework (ESMF) Final Report September 2021, 2021.
[35] Somalia Population (2022) - worldometer n.d. https://www.worldometers.info/world-population/somalia-population/. (Accessed 12 March 2022).
[36] Population Division | n.d. https://www.un.org/development/desa/pd/. (Accessed 12 March 2022).
[37] Population, total - Somalia | Data n.d. https://data.worldbank.org/indicator/SP.POP.TOTL?locations=SO. (Accessed 12 March 2022).
[38] - Somalia, Age structure 2010-2020 | Statista n.d. https://www.statista.com/statistics/452250/age-structure-in-somalia/. (Accessed 12 March 2022).
[39] E.U. Technical, A. Facility, E. Sector, The European Union Global Tech- Nical Assistance Facility on Sustainable Energy, 2022.
[40] S. Planning, Somalia National University, 2020.
[41] M. Takase, R. Kipkoech, P.K. Essandoh, A comprehensive review of energy scenario and sustainable energy in Kenya, Fuel Commun (2021), 100015, https://doi.org/10.1016/j.jfueco.2021.100015, 7.
[42] Supply – key world energy statistics 2021 – analysis - IEA n.d. https://www.iea.org/reports/key-world-energy-statistics-2021/supply. (Accessed 13 March 2022).
[43] Somalia, Energy mix for electricity generation | GlobalPetrolPrices.com n.d. https://www.globalpetrolprices.com/energy_mix.php?countryId=96. (Accessed 13 March 2022).
[44] G. Wind, E. Council, Gwec Global Wind Report, 2021, p. 2021.
[45] L. Ministries, Somalia'S intended nationally determined, CONTRIBUTIONS (INDCs (2015) 1–47.
[46] N. Nuñez 1 (2015) 2.
[47] T.W. Bank, Project Information Document (PID), 2020, pp. 1–10.
[48] N.D. Plan, 2019 2017 -, Federal Government of Somalia 234 (2016) 1–48.
[49] IRENA. World Energy Transitions Outlook., 2021.
[50] How falling costs make renewables a cost-effective investment n.d. https://www.irena.org/newsroom/articles/2020/Jun/How-Falling-Costs-Make-Renewables-a-Cost-effective-Investment. (Accessed 15 March 2022).
[51] Solar Resource Maps and GIS Data for 200+ Countries Solargis n.D.
[52] African Development Bank, Somalia energy sector needs assessment and investment programme, African Dev Bank (2015) 16.
[53] A. Background, Somalia through NOREPS Support, 2012, pp. 1–2.
[54] W. Cai, X. Li, A. Maleki, F. Pourfayaz, M.A. Rosen, M. Alhuyi Nazari, et al., Optimal sizing and location based on economic parameters for an off-grid application of a hybrid system with photovoltaic, battery and diesel technology, Energy (2020), 117480, https://doi.org/10.1016/j.energy.2020.117480, 201.
[55] S. Dursun, E. Aykut, B. Dursun, Assessment of optimum renewable energy system for the Somalia-Turkish training and research hospital in Mogadishu, J Renew Energy Environ 8 (2021) 54–67, https://doi.org/10.30501/jree.2021.245232.1140.
[56] IRENA. Renewable Energy Statistics 2019 Statistiques, 2019.
[57] Powering Progress, The potential of renewable energy in Somalia n.d. https://oneearthfuture.org/research-analysis/powering-progress-potential-renewable-energy-somalia. (Accessed 14 March 2022).
[58] G. Modeling, A. Office, E.S. Division, Global Modeling and Assimilation Office File Specification for MERRA-2 Climate Statistics Products, 2020, p. 19.
[59] Solar Photovoltaic Power Potential by Country n.D.
[60] M. Abdel-Basset, R. Mohamed, S. Mirjalili, R.K. Chakrabortty, M.J. Ryan, Solar photovoltaic parameter estimation using an improved equilibrium optimizer, Sol. Energy 209 (2020) 694–708, https://doi.org/10.1016/j.solener.2020.09.032.
[61] A.K. Singh, D.B. Singh, A. Mallick, N. Kumar, Energy matrices and efficiency analyses of solar distiller units: a review, Sol. Energy 173 (2018) 53–75, https://doi.org/10.1016/j.solener.2018.07.020.
[62] N. Jayaweera, U. Rajapaksha, I. Manthilake, A parametric approach to optimize solar access for energy efficiency in high-rise residential buildings in dense urban tropics, Sol. Energy 220 (2021) 187–203, https://doi.org/10.1016/j.solener.2021.02.054.
[63] E. Judson, F. Zirakbash, Investigating the potential of solar energy for low-income communities in Australia to reduce hardship, debt and inequality, Energy Res. Social Sci. (2022), 102386, https://doi.org/10.1016/j.erss.2021.102386, 84.
[64] A.R. López, A. Krumm, L. Schattenhofer, T. Burandt, F.C. Montoya, N. Oberländer, et al., Solar PV generation in Colombia - a qualitative and quantitative approach to analyze the potential of solar energy market, Renew. Energy 148 (2020) 1266–1279, https://doi.org/10.1016/j.renene.2019.10.066.
[65] B. Kumar, G. Szepesi, Z. Čonka, M. Kolcun, Z. Péter, L. Berényi, et al., Trendline assessment of solar energy potential in Hungary and current scenario of renewable energy in the visegrád countries for future sustainability, Sustain. Times 13 (2021), https://doi.org/10.3390/su13105462.
[66] P. Jiang, Y. Wang, Z. Peng, The application potential of solar energy sources in Shanghai's existing workers' village, Energy Proc. 152 (2018) 1085–1090, https://doi.org/10.1016/j.egypro.2018.09.127.
[67] Y. Fathi Nassar, S. Yassin Alsadi, Assessment of solar energy potential in Gaza Strip-Palestine, Sustain. Energy Technol. Assessments 31 (2019) 318–328, https://doi.org/10.1016/j.seta.2018.12.010.
[68] A. Teofilo, Q. Sun, (Chayn), radosevic N, tao Y, iringan J, liu C. Investigating potential rooftop solar energy generated by leased federal airports in Australia: framework and implications, J. Build. Eng. 102390 (2021) 41, https://doi.org/10.1016/j.jobe.2021.102390.
[69] C. McMillan, W. Xi, J. Zhang, E. Masanet, P. Kurup, C. Schoeneberger, et al., Evaluating the economic parity of solar for industrial process heat, Sol Energy Adv (2021) 1, https://doi.org/10.1016/j.seja.2021.100011, 100011.
[70] E. Kabir, P. Kumar, S. Kumar, A.A. Adelodun, K.H. Kim, Solar energy: potential and future prospects, Renew. Sustain. Energy Rev. 82 (2018) 894–900, https://doi.org/10.1016/j.rser.2017.09.094.
[71] M. Perez, R. Perez, Update 2022 – a fundamental look at supply side energy reserves for the planet, Sol Energy Adv (2022), 100014, https://doi.org/10.1016/j.seja.2022.100014, 2.
[72] Lima De, Oliveira R. Powering the Future: Malaysia's Energy Policy Challenges, 2018, p. 32.
[73] Y. Wang, Y. Liu, J. Dou, M. Li, M. Zeng, Geothermal energy in China: status, challenges, and policy recommendations, Util. Pol. 101020 (2020) 64, https://doi.org/10.1016/j.jup.2020.101020.
[74] A. Saleh, M. Faridun, N. Tajuddin, M. Ra, A. Azmi, M.A.M. Ramli, Optimization and sensitivity analysis of standalone hybrid energy systems for rural electri fi cation, A case study of Iraq 138 (2019) 775–792, https://doi.org/10.1016/j.renene.2019.02.004.
[75] J.O. Oladigbolu, M.A.M. Ramli, Y.A. Al-turki, Feasibility Study and Comparative Analysis of Hybrid Renewable Power System for off-Grid Rural Electrification in a Typical Remote Village Located in Nigeria 8 (2020) 171643–171663.
[76] A.V. Rodrigues, D.A.R. de Souza, F.D.R. Garcia, S.J.L. Ribeiro, Renewable energy for a green future: electricity produced from efficient luminescent solar concentrators, Sol Energy Adv (2022), 100013, https://doi.org/10.1016/j.seja.2022.100013, 2.
[77] Clean A, Technical E, Facility A, Taf ACE. Africa Clean Energy Technical Assistance Facility (ACE TAF) Terms of Reference (ToR) Somalia Off-Grid Solar (OGS) Strategy n.D.
[78] E. Content, Country Spotlight, 2021, p. 2021.
[79] M. McLennan, S. Group, The Global Risks Report 2022, 2022.
[80] International R. USAID Somalia Growth, Enterprise, Employment & Livelihoods (GEEL) FY 2019 Annual Progress Report, 2019.
[81] C. Edwards, Powering ahead, Eng. Technol. 8 (2013) 52–57, https://doi.org/10.1049/et.2013.1105.
[82] M. Blume, S. Westhof, Somali Renewable Energy Skilled Workforce Survey Report, 2016.
[83] The World Bank. Project Information Document, 2011, pp. 1–8.
[84] Workshop E. EU TAF for SE4ALL General Presentation, 2015, pp. 18–22.
[85] A. Pourdaryaei, H. Mokhlis, H.A. Illias, S.H.A. Kaboli, S. Ahmad, S.P. Ang, Hybrid ANN and artificial cooperative search algorithm to forecast short-term electricity price in de-regulated electricity market, IEEE Access (7) (2019) 125369–125386, https://doi.org/10.1109/ACCESS.2019.2938842.
[86] H. Yi, Clean-energy policies and electricity sector carbon emissions in the U.S. states, Util. Pol. 34 (2015) 19–29, https://doi.org/10.1016/j.jup.2015.04.001.

[87] I. Renewable, E. Consumption, E. Prices, E. Six, S. American, Electricity Prices : Prices : Evidence, 2022.
[88] Y. Lu, Z.A. Khan, M.S. Alvarez-Alvarado, Y. Zhang, Z. Huang, M. Imran, A critical review of sustainable energy policies for the promotion of renewable energy sources, Sustain. Times 12 (2020) 1–30, https://doi.org/10.3390/su12125078.
[89] A. Bouraiou, A. Necaibia, N. Boutasseta, S. Mekhilef, R. Dabou, A. Ziane, et al., Status of renewable energy potential and utilization in Algeria, J. Clean. Prod. (2020) 246, https://doi.org/10.1016/j.jclepro.2019.119011, 119011.
[90] G. Scorecard, P. Makers, A Global Scorecard for Policy Makers, 2016.
[91] Manfred Hafner, Simone Tagliapietra, Lucia De Strasser. Energy in Africa: Challenges and Opportunities, 2018.
[92] Iea Iuww, Tracking SDG7: The Energy Progress Report 2021 (2021) 20–30.
[93] A. Dolara, E. Donadoni, S. Leva, G. Magistrati, G. Marchegiani, Performance Analysis of a Hybrid Micro-grid in Somalia. 2017 IEEE Manchester PowerTech, Powertech 2017, 2017, https://doi.org/10.1109/PTC.2017.7980867.
[94] ILO, Scoping Study for a Renewable Energy Skills Development Public Private Development Partnership (PPDP) in Somalia, 2016.
[95] N.S. Ouedraogo, Africa energy future: alternative scenarios and their implications for sustainable development strategies, Energy Pol. 106 (2017) 457–471, https://doi.org/10.1016/j.enpol.2017.03.021.
[96] F. Borino, C. Sage, Employment Programs and Conflict in Somalia, 2019.
[97] Federal Republic of Somalia Ministry of Energy and Water Resources Draft Report, 2021, p. 2021.
[98] Bacaadweyn, Mudug, Somalia - Current Time, Map n.D.
[99] T. Huld, R. Müller, A. Gambardella, A new solar radiation database for estimating PV performance in Europe and Africa, Sol. Energy 86 (2012) 1803–1815, https://doi.org/10.1016/j.solener.2012.03.006.
[100] A.G. Amillo, T. Huld, R. Müller, A new database of global and direct solar radiation using the eastern meteosat satellite, models and validation, Rem. Sens. 6 (2014) 8165–8189, https://doi.org/10.3390/rs6098165.
[101] Smart C, Solution P V. FusionSolar n.D.
[102] P. Pilot, S. Bridge, ŽŵĐđĞŚĞŶƐŝǀĞ ůĞĐƚđŽŵĂŐŶĞƚŝĐ ^ ŽůƵƚŝŽŶƐ Installation Guide 1000 (2016) 1–4.
[103] R. Shah, N. Mithulananthan, R.C. Bansal, V.K. Ramachandaramurthy, A review of key power system stability challenges for large-scale PV integration, Renew. Sustain. Energy Rev. 41 (2015) 1423–1436, https://doi.org/10.1016/j.rser.2014.09.027.