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Techno-Economic Analysis of Off-Grid PV Solar System for Residential Building Load: A Case Study in Baidoa, Somalia

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Abstract

Currently, the majority of the Somali population does not have access to a regular source of power. The country does not have a national grid, relying on outdated, costly and inefficient diesel generators. The energy consumption in Somalia is dependent on firewood and charcoal, dependencies that rely on deforestation and desertification, which negatively influence the agricultural sector and also the environment. In this work, the potential of solar power in Somalia is assessed while estimating the cost of solar panels per household. This study aims to assess the cost, ecological and economic efficiency of the off-grid PV home system in residential buildings in Baidoa, Somalia. A stand-alone solar home system of 1.98kW PV capacity with battery backup is designed by using HOMER software. The daily primary load considered is 7.530 kWh, with a peak of the nominal power of 1.60 kW. The results show that renewable energy sources can replace conventional energy sources and that they would be a viable solution for generating electrical energy in residential houses in Baidoa with a reasonable investment. It was also found that the amount of power produced by solar panels is 7,400kWh/year. With an initial investment of $5580, the annualized life cycle cost of the system is $0.483, the payback period of initial investment is 2 years and 7 months period, and the net present cost (NPC) of the project is $18,684.

1. Introduction

The energy demand is increasing day by day globally. To overcome the problem of energy scarcity, renewable energy sources promise to be one of the appropriate solutions without a significant increase in the carbon footprint of the atmosphere [1]–[3]. The promotion of renewable energy technologies (RET) for more sustainable development has become one of the primary goals of energy policymakers in many countries. Deployment of Renewable Energy (RE) technologies around the world keeps increasing sharply as the effects of climate change demand more attention and concern in the near future [4]–[7]. Growth rates of RE differ substantially across regions and nations, however, the renewable power generating capacity experienced its largest annual increase ever in 2016, with an estimated 161 GW of capacity added and that way, solar Photovoltaic (PV) represented 47% of the new installed RE capacity in 2016, which, for the first time, accounted more additional power than any other RE generation technology [8]. Most countries have committed to doing more to achieve a clean energy transition in order to fulfill the ambitions of the Sustainable Development Goals (SDG) agenda regarding SDG 7 (Affordable and Clean Energy). Moreover, Africa faces a serious challenge in fulfilling the above-mentioned global commitment (SDG 7). Increasing access to reliable, affordable and clean energy resources is a key priority, particularly in sub-Saharan Africa. Around 600 million people in Africa still have no access to electricity, representing 48% of the continent's population of nearly 1.2 billion [9]. A number of initiatives have emerged to address Africa's energy challenges and to support the necessary expansion and modernization, notably Programme such as Sustainable Energy for All, the African Union's Programme of Infrastructure Development in Africa (PIDA), Power Africa, the Africa-EU Energy Partnership, the African Clean Energy Corridor. Lastly, in 2015, the African Union, supported by the G7 countries, officially launched the Africa Renewable Energy Initiative (AREI) at COP 21 in Paris. AREI objectives, aligned with the African Regional Flagship Programme (ARFP) on Sustainable Energy, include strengthening policy, regulatory support and incentive frameworks of African countries to develop their energy sector and achieve sustainable energy [10].

Somalia's energy sector was completely destroyed after 1991, electricity service has solely been a role of the dynamic Somali private sector. The country's system of governance disappeared and consequently lost the basic services of the country. Somalia's power sector faces significant challenges, including a lack of sufficiently trained labor, a weak regulatory environment, high investment costs, scarcity of energy production supplies, and poor infrastructure. With the growth in urbanization, combined with the return of the Somali Diaspora, energy demands increased. The view is that as an imperative for economic growth and nation-building, sustainable sources of energy will be needed, combined with more efficient use of existing energy sources. The electricity access rate is estimated at 15 percent, meaning that around 11 million Somalis lack access to electricity services, urban access is estimated at 33 percent, and rural access is at 4 percent. With an average household size of 5.9, this translates to approximately 1.8 million un-electrified households nationwide. Though estimates vary, the total operational generating capacity across Somalia is estimated at around 103MW in 2015, serving 270,000 connections and the African Development Bank (AfDB) estimates installed capacity at 45.5MW in South-Central regions of Somalia [11]. Furthermore, the unwavering quality and the high cost of energy are the major obstacles to monetary development in Somalia especially in south-central regions. In any case, power in Somalia is dependent upon diesel generators, which can't give enough power contrasted with their necessities and utilities in huge business zones, for example, water ventures, households, farmers, medical centers, and big hotels. Sustainable power source expands reliability and minimal effort of tariffs. Utilizing power from sustainable power sources gives ideal, economic, political and social advantages, as it expands local utilization adds to enhancing the exchange adjustment by bringing down petroleum product imports and offers a more noteworthy, assorted variety of vitality sources. Likewise expanded employment of sustainable power sources lessens current levels and future development rates of climatic CO2 discharges and reduces reliance on fossil fuels. Major conventional sources for powering water pumps, households, farmers, medical centers, and Schools are either fossil fuel generators or electricity from a nearby grid. Both methods have considerably expensive running costs, and varying implementation costs depending on the location, nature and budget. The choice of solar energy generation concept over conventional means of energy is gaining more and more popularity around the world, especially where electricity is either unavailable or unreliable [12], [13].

Somalia is ideally placed to utilize solar energy. Solar resources have been utilized for off-grid generation in the country, as well as for water pumping both in boreholes and agricultural sectors. Solar cooking has also seen some uptake in the country, and solar power is seen as the energy source of choice for the rehabilitation of many buildings in the country, particularly health centers. Average solar potential stands at 5-7 kWh/ m2/day. With over 3,000 hours of high and constant sunlight annually [14]. This study is carried out to assess the solar energy potentials of Baidoa, Somalia with special attention and consideration to the past, present and future of solar energy development in terms of Ecological-Economic Efficiency. The data required for this work sunshine hours were obtained from NASA's surface meteorology and solar energy website.

2. Energy Scenarios in Somalia

Somalia is situated in the horn of the African continent. Because of the country's political instability from the 1980s to the early 1990s the energy and, in particular, the electricity infrastructure of the country, as in the case of many African nations, is still massively underdeveloped [15]. People, whether urban or rural, rely mainly on biomass resources to meet their energy needs. It is estimated that 87% of the energy sources are biomass resources [16]. Electricity is only available in city areas and "is almost exclusively made from imported diesel" [11]. At the end of the 1980s, just before it collapsed, Somalia as a whole had built a power generation capacity of about 175–180MW, of which almost 100MW is in Mogadishu. In the past, many cities had grids, and the quality of service varied depending on the availability of fuel. Except for urban centers (Mogadishu, Hargeisa, and Kismayo), which had traditional grids, other smaller towns and cities relied on diesel generators and mini-grids for electricity, just like today. No two cities have become interconnected. Tariffs were low and level nationwide, so the major cities – which tended to be less expensive to serve as all load centers were serviced by the same utility, the Somali National Energy Corporation (ENEE) – subsidized high-cost isolated systems. According to historical figures, electricity production in Somalia was only 33 kWh/capita/year in 2008, compared to the world average of 2,777 kWh and the African average of 579 kWh [17]. The total installed electricity generation in Somalia in 2014 was estimated at 100MW, with approximately 250,000 connections. This number of connections means an average load per connection of 400 Watts (at the generation before line losses), which is very low but plausible in the Somalia context. The high generation costs, primarily the use of diesel generators and the low use and inefficiencies and losses of the system, mean that the costs of supply are high. While private companies are dramatically lowering their prices well below $1/kWh and lowering an earlier $400 connectivity charge, it is likely that most households that are able to bear high supply costs are already linked [18].

Somalia is rich in renewable energy resources, unexploited hydropower, vast geothermal energy resources, many promising wind sites, and plenty of sunshine that can generate solar power. Political, financial, and institutional barriers to the development of these potentially available energy resources are key. Traditional biomass fuels such as firewood and charcoal, mainly used in rural and deprived areas, account for 82% of the country's overall energy consumption [19]. Somalia, considering the protracted civil war and the least development status, has great potential to achieve environmental sustainability and contribute to the reduction of greenhouse gas emissions (GHG). There are already signs of recovery that could benefit from renewable energy, including solar, wind, hydropower, and geothermal energy. Some developments in solar energy use are taking place in the capital of Mogadishu and some cities in Puntland and Somaliland. Wind energy was in use before the Civil War, but the infrastructure, which was mostly in Mogadishu, was destroyed. The Fanoole Dam in the Middle Jubba, which was built with the help of China from 1977 to 1982 at a cost of about US$ 50 million, is presently in need of rehabilitation for irrigation and hydroelectricity generation. In addition, there was a plan to build the Baardheere Dam upstream of the Fanoole Dam, which was interrupted by the civil conflict. In addition, there is great potential for renewable energy in Somalia, as demonstrated in a recent report by the Federal Government of Somalia (FGS) and the African Development Bank (AfDB). The solar energy potential ranges from 5 to 7 kWh/day with more than 310 sunny days per year, or between 2500 and 3000 hours of sunshine per year [18].

3. Methodology

3.1 Site Description and Data Collection

Baidoa or Baydhabo, as is locally known is the capital of the Bay region; a strategic town in south-central Somalia situated approximately 250 kilometers west of Mogadishu and 240 km southeast of the Ethiopian border. The town is divided into four quarters, namely Isha, Berdaale, Horseed and, Hawl Wadaag. Each quarter is further divided into six sections. The city is traditionally one of the most important economic centers in southern Somalia, conducting significant trade in local and imported cereals, livestock and non-food items. The combined effects of drought and the ongoing crisis in Baidoa have had a harmful impact on economic stability and livelihoods, leading to a chronic humanitarian situation and major displacements of the population. Baidoa has traditionally been a major economic center of southern Somalia. The main city that has been covered in this study as shown in Figure 1, is Baidoa. The geographic coordinate of the site is given in Table 1.

For this research, both primary and secondary data have been collected. Primary data has been collected through a comprehensive questionnaire of the load profile of the 100 households in the south-central region of Somalia. The selected case study is located in Baidoa, as shown in Figure 1. Secondary data has been collected from NASA's surface meteorology and solar energy website by inserting the location's coordinates. The design and optimization of photovoltaic systems need the collection of data as an initial platform for the successful implementation of the task. This includes choosing sites for implementing the project, load analysis of selected sites, solar irradiance analysis of selected areas, and available renewable resource assessments, considering the geographic characteristics of the location. Since the performance of a renewable energy system is highly dependent on the environmental conditions, a site-specific analysis is required to investigate the associated cost, component size and overall economics. In this paper, a feasibility study is conducted for medium households in Baidoa using HOMER.

Table 1 *Geographic coordinates of the selected area*

Station	Latitude (°N)	Longitude (°E)	Altitude (M)
Baidoa	3.11383	43.6498	490

Fig. 1 *Map of Baidoa, Somalia [20]*

3.2 HOMER Software

The hybrid optimization model for electric renewable (HOMER) is a simulation software developed by the National Renewable Energy Laboratory (NREL). The software is used for sizing, optimization and techno-economic and environmental analysis of RESs. It has the ability to carry out simulation, optimization and sensitivity analysis of a hybrid energy system, and it can be used for analyzing grid-connected and off-grid distributed generation systems. It has the capability of analyzing both economic and technical aspects of an energy system. During the simulation process, the system is completely modeled, and HOMER determines the system's lifecycle and technical feasibility. In the optimization step, HOMER simulates various configurations until an optimal solution is achieved based on the least NPC and COE. Finally, during the sensitivity analysis, several optimizations are performed using different input variables range, this is done to determine the effect of a change in input parameters on the configuration selected. The HOMER input data includes component prices and sizes, load profiles, meteorological data, and other economic constraints. The HOMER software provides the system cost, components sizing, and other economic aspects based on the input values [21]–[23]. The modeling process is done every hour over the project's lifespan whereby the technical feasibility of a system and whether the demand can be fulfilled is first determined. Consequently, the cost of installing and operating the system over its lifetime is estimated [24].

Table 2 *Daily electrical consumption of a medium home in Baidoa*

Appliances	Quantity	Power (W)	Total Watt	Hours (H)	Total Energy Demand (Wh)
Lamps	8	15	120	10	1200
Iron	1	1200	1200	1	1200
Washing machine	1	350	350	3	1050

TV	1	80	80	6	480
Fridge	1	150	150	24	3600
Total		**1900**			**7530**

3.3 Electrical Load

The first major undertaking within the confines of this study was the collection and analysis of energy consumption data for a typical residential home in Baidoa. One of the most essential steps in this type of analysis is to suggest a practical electrical load model. The key users of energy in this house are primarily illumination, television and cooling. This data was needed to get numerical values on the amount of energy consumption in a typical residential home. Therefore, the average daily estimation load profile of a medium-typical household in the study area is indicated in Table 2 and Figure 2.

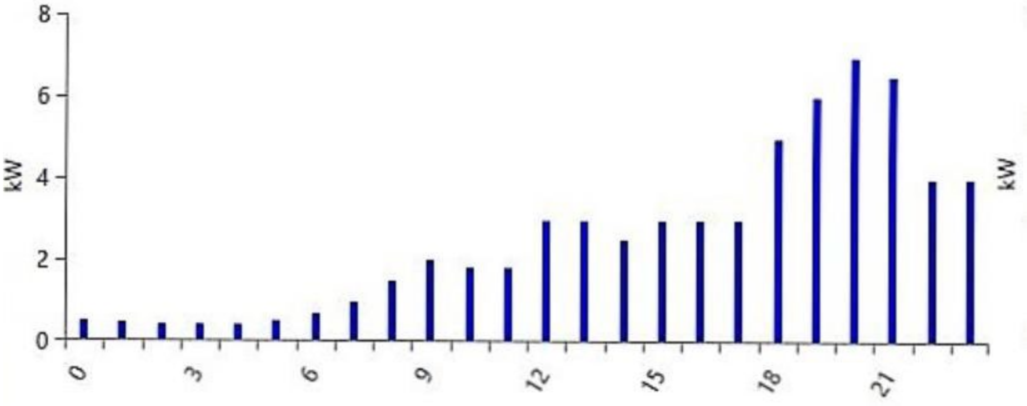

Fig. 2 Daily *profile load of a typical medium house in Baidoa*

3.4 Solar Energy Resources

HOMER introduces the clearness index and average daily radiation from the latitude information of the site under investigation Figure 3. The solar radiation data can be directly accessed from the NASA Surface Meteorology and Solar Energy website by inserting the location's coordinates. The data obtained consists of daily solar radiation, clearness index and air temperature. Somalia enjoys bright sunshine throughout the year. The average daily solar energy received on a horizontal surface is about 5-7 kWh/m2. The daily average total solar radiation in parts of Somalia, calculated from the relative sunshine duration indicates one of the highest in the world. The solar energy distribution in Somalia is also almost uniform with modest gradients, not higher than 16% between zones with higher insolation and others with less insolation. This means that a Photovoltaic panel gives almost the same energy regardless of the place or angle of installation. The average sunshine duration is estimated between 2900 – 3100 hours/year (8-8.5 hours/day). The temperature is not so high with a yearly average of 27°C which in turn adds to the operational life of solar PVs [25].

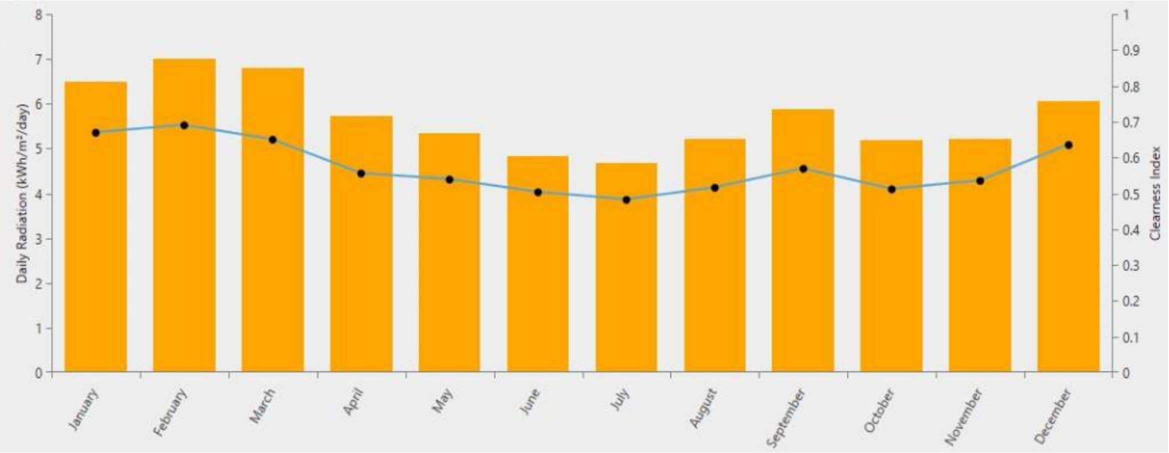

Fig. 3 *Monthly global horizontal radiation data for Baidoa*

3.5 Photovoltaic Arrays

To calculate the PV size, different combinations along with other parameters for the panel were given. As input in the software to get optimized performance for the proposed system. The chosen Panel for this study is a Canadian solar panel, CS6U-330P 72 Cell, 330W. The cost of the 330W Yingli solar panel is about $165. Here we have considered a lifetime of 25 years for the PV. The cost of the PV has been considered as $0.50/ WP. For the other costs such as installation we have considered $400, and for operation/maintenance $20/year considering the standard current market value.

3.6 Battery Bank

Energy generated by the PV cells is accumulated and stored in batteries to use as needed. The battery's capacity for storing energy is rated in amp-hours. Battery capacity is listed in amp-hours at a given voltage. Manufacturers typically rate storage batteries at a 20-h rate. This rating system is used to compare different batteries to the same standard and not as an indicator of battery performance. The batteries used can be able to supply the energy required at night. Batteries are sensitive to climate, charge/discharge cycle history, temperature, and age.

3.7 Inverter

Inverters change direct current (DC) to alternating current (AC). Stand-alone inverters are used to convert DC from the battery to AC to run electronic equipment. The inverter is required in solar home systems to change the DC input signal from the battery to its suitable AC power for the electrical outlet. As regards the size of the inverter, the input rating of the inverter must not be lower than the total wattage of the device. Since we are using a stand-alone system, the inverter must be large enough to handle the total wattage used at one time. For the suggested PV system in this paper, the needed inverter should give 220–240 V AC, 50 Hz. The chosen inverter for the study is the Leonics S-219Cp 5kW solar inverter.

3.8 Selection of Charge Controller

The basic role of the charge controller in an independent photovoltaic system is to keep the battery in an optimal state of charge while protecting the battery from over-discharge caused by array overcharging and loading. In principle, lead-acid batteries are the most basic in photovoltaic systems and sealed lead-acid batteries are most commonly used for off-grid connection systems and grid connections. Solar charging controllers are typically rated in amps and voltage capacity. The charge controller is equal to the maximum current of the panel multiplied by the number of parallel strings. The selection of the solar charge controller depends on the voltage of the solar panel and the battery.

3.9 Economics and Constraints

Considering the project lifetime to be 20 years, since operations and maintenance costs are given in the individual components. For renewable output, this reserve is 100% for solar energy. The effectiveness of the developed solar system can be analyzed by identifying the economic parameters such as leveled cost of energy (LCOE), net present cost (NPC), system capital cost, and salvage cost.

Fig. 4 *System architecture of the off-grid solar energy generation system*

3.10 System Structure Description

In this analysis, four key components of the energy system were planned. There are photovoltaic modules, converters and battery banks. For any of these machines, it is important to determine the prices, the number of units to be used, the operational hours, etc. in the HOMER program. These components are defined in the sections below. The following system modules were configured to suit the AC load profile of the user. The schematic diagram of the system is seen in Figure 4.

4. Simulation Results

4.1 Production and Consumption of Electrical Energy

The production and consumption of electrical energy of the optimal configuration over a year are shown in Table 3 and Table 4, respectively. It should be noted that 100% of the site's needs will be provided by the PV generator, which is equivalent to a total produced energy of 7,400kWh/year (100%). Also, Figure 5 and Figure 6 show the daily and monthly electrical production of the system. This energy distribution gives a renewable energy fraction of 100%, which is satisfactory in view of the PV generator power.

Table 3 *Production summary*

Component	Production (kWh/year)	Percent
Canadian Solar MaxPower CS6U-330P	7400	100
Total	7400	100

Table 4 *Consumption summary*

Component	Consumption (kWh/year)	Percent
AC Primary Load	2,746	100
DC Primary Load	0	0
Total	2746	100

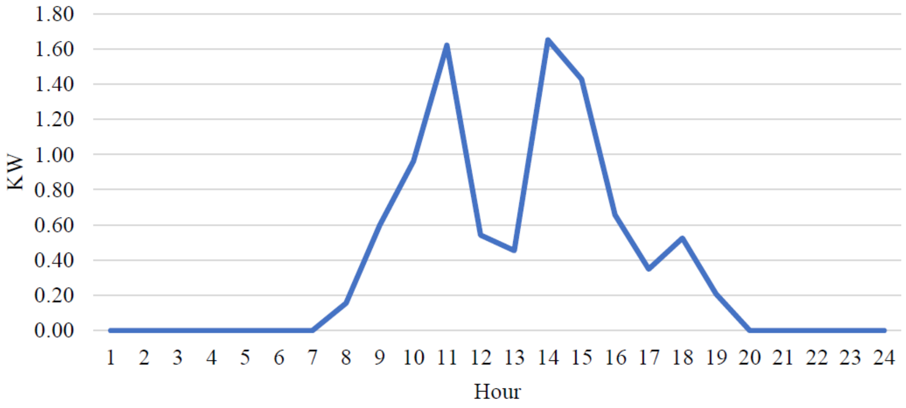

Fig. 5 *Production of daily electrical energy*

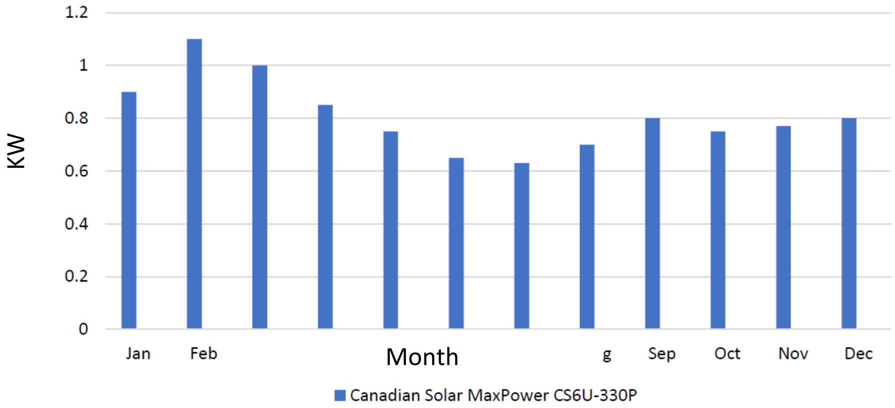

Fig. 6 *Production of monthly electrical energy of the optimal configuration*

4.2 Cost of Installation

The net cash cost calculated by Homer is equal to $18,684 and the average energy cost (LCOE) and operating value are $0.483 per kWh and $564.97 per year as shown in Figure 7 and Figure 8. These costs are calculated by the software and are long-term costs. The estimated cost becomes the recommended cost. The resulting system architecture is based solely on detailed simulation results of cash flow summaries and NPC classifications, considering funding, replacement, remediation, operations and maintenance costs. Figure 7 and Figure 8 show details of NPC by cost type (capital, replacement, maintenance and recovery operation) and NPC by component (PV, Converter, battery and converter) is represented by different colors of the optimal configuration.

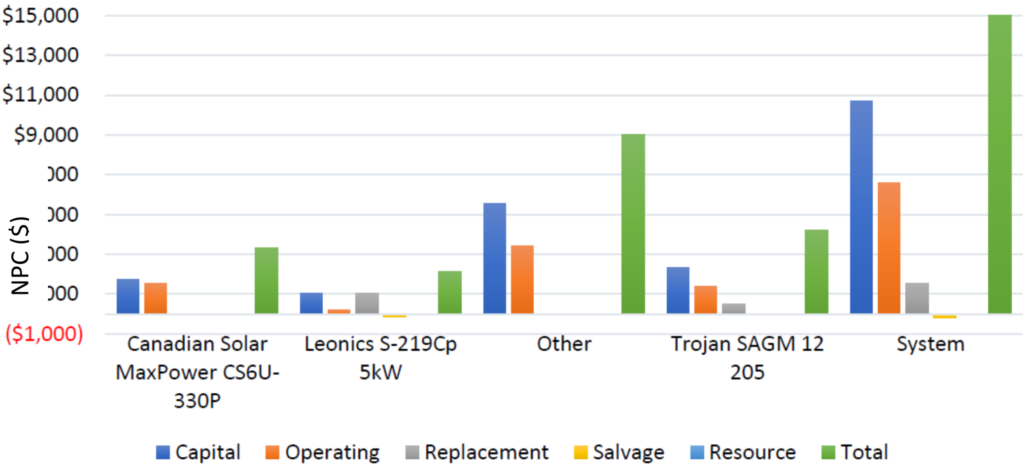

Fig. 7 NPC details by component

4.3 Payback Period

In markets with expensive utility rates, the payback period from installing solar is comparatively short. Therefore, the first step in beginning your solar PV project is evaluating your current energy bill to obtain a view of your energy consumption and spending over the course of the past several electricity bills from your utility company. The payback period characterizes the amount of time that it takes for a solar home system user to recover the initial cost of investment. For this solar home system project, the initial cost was estimated at $5,580 which returned $ 2,160 per year and thus, its payback period will be a 2-year and 7-month, as shown in Table 5. The calculations were based on the given load profile that was found during data collection. Moreover, the costs obtained for every year as return costs were based on the current electricity rate provided by Baidoa Electric Company (BECO), which is the electricity company in Baidoa. The rate of electricity per kWh in general is $0.8 which is considered the base value obtained from the electrical company. This means the payback period will be 7 years and 9 months based on this $0.8 COE. However, the payback period in this proposed project is $2,160 per year is considered acceptable and corresponds to the initial cost of the implementation.

Table 5 *Payback cost period*

Parameter	**Amount/Period**
Capital cost	$5580.00
Annual savings	$2,160.00
Payback period	2 years and 7 months

4.4 Optimization Results

With the help of the HOMER software, the analysis was improved by the size of the PV system, especially for systems with a capacity of 7.530kW, as it is more economical and does not interfere with accessibility. Considering all inputs, HOMER simulates repeatedly to get a suitable solution. Optimization results are displayed in terms of categorization and overall, showing the most feasible architecture that satisfied all inputs and constraints that designers give. After simulating all possible configurations, we obtained the overall results shown in Table 6.

The results are ranked in order (from top to bottom) from the most profitable to the least profitable according to the NPC as shown in Table 6. It should be noted that the off-grid system is the least expensive configuration over the life of the project with $18,684 and a COE of $0.483/kWh. This system consists of a 1.98kW PV field, a 4-cell battery storage system and a 5kW converter, with an investment cost of $10,721 which is the highest compared to other configurations. In the simulation results window, several technical and economic details about each system configuration that HOMER simulates can be seen.

Table 6 *Optimization result*

	Architecture				**Cost**			**System**		
Scenario	CS6U-330P (kW)	SAGM 12 205	Leon5 (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)
PV/Battery/Inverter	4.39	8	1.42	LF	0.48	18684.13	564.97	10721.47	100	0
PV/Battery/Inverter	4.39	8	1.42	CC	0.48	18684.13	564.97	10721.47	100	0
PV/Battery/Inverter	4.39	8	1.41	LF	0.48	18684.49	565.34	10716.60	100	0
PV/Battery/Inverter	4.39	8	1.41	CC	0.48	18684.49	565.34	10716.60	100	0
PV/Battery/Inverter	4.37	8	1.40	LF	0.48	18685.50	566.65	10699.16	100	0
PV/Battery/Inverter	4.37	8	1.40	CC	0.48	18685.50	566.65	10699.16	100	0
PV/Battery/Inverter	4.36	8	1.45	LF	0.48	18687.61	564.54	10730.96	100	0
PV/Battery/Inverter	4.36	8	1.45	CC	0.48	18687.61	564.54	10730.96	100	0
PV/Battery/Inverter	4.41	8	1.43	LF	0.48	18687.9	564.31	10734.52	100	0
PV/Battery/Inverter	4.41	8	1.43	CC	0.48	18687.94	564.31	10734.52	100	0
PV/Battery/Inverter	4.40	8	1.39	LF	0.48	18688.57	566.5162	10704.12	100	0

5. Conclusion

This work presents an economical expediency of off-grid solar power systems for urban area applications in a southern city of Somalia, Baidoa. The analysis is carried out by investigating mainly the potential of solar energy and collecting data from different sources. We have focused in this work on the technical, economic and environmental profitability of the off-grid solar system compared to other conventional solutions. HOMER software is used to analyze the available data and economic feasibility of the proposed off-grid power system. For a typical house in an urban area in Somalia, the complete, sizing, and optimization of a stand-alone PV system with detailed cost calculations have been presented in this study. The daily electric load of a medium household in Baidoa is 7.530KW and the maximum hourly electrical energy production of the system is 1.65KW. The designed system consists of 1.98 kW PV, six batteries of 12 V and 219 Ah, and a 5-kW inverter, and overall, it costs $5,580 and produces electricity at $0.483/kWh. The rate of electricity per kWh in general is $0.8 which is considered the base value. The initial cost was estimated at $5,580 which returned $ 2,160 per year which will be a 2-year and 7-month payback period.

This work presents a detailed procedure to design a PV system for urban areas where grid supply is not economically viable. Following this method, one can estimate the load, size a system, simulate the system, and determine the expected performance. Somalia is under developing country and conventional energy sources may no longer be feasible in the future given increasing fuel costs and environmental concerns. The stand-alone solar PV energy system is an excellent way to power, heat, cool, and light our homes and businesses. The solar PV electric power system is fuelled by the sun and provides emission-free electricity, which is reliable, secure, noisefree, friendly to use and does not necessitate refueling. It also helps to reduce the consumption of fossil fuels in power plants, pollution and greenhouse gas emissions causing climate damage. Based on the daily utilization and load demand, the capacity sizing of the PV array, solar charge controller, backup battery storage, DC/AC inverter and connecting cables is provided in this work.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Abdullahi Abdulkadir Ahmed;* ***data collection:*** *Bashir Ali Hussein;* ***analysis and interpretation of results:*** *Djamal Hissein Didane;* ***draft manuscript preparation:*** *Sami Al-Alimi, Yazid Saif, Bukhari Manshoor. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Alquraishi, B. A., Asmuin, N. Z., Mohd, S., Abd Al-Wahid, W. A., & Mohammed, A. N. (2019). Review on diffuser augmented wind turbine (dawt). International Journal of Integrated Engineering, 11(1). https://doi.org/10.30880/ijie.2019.11.01.021

[2] Loutun, M. J. T., Didane, D. H., Batcha, M. F. M., Abdullah, K., Ali, M. F. M., Mohammed, A. N., & Afolabi, L. O. (2021). 2D cfd simulation study on the performance of various naca airfoils. CFD Letters, 13(4), 38-50. https://doi.org/10.37934/cfdl.13.4.3850

[3] Halmy, M. S. M., Didane, D. H., Afolabi, L. O., & Al-Alimi, S. (2021). Computational Fluid Dynamics (CFD) Study on the Effect of the Number of Blades on the Performance of Double-Stage Savonius Rotor. CFD Letters, 13 (4), 1-10. https://doi.org/10.37934/cfdl.13.4.110

[4] Didane, D. H., Ab Wahab, A., Shamsudin, S., & Rosly, N. S. (2016). Wind as a sustainable alternative energy source in Malaysia-a review. ARPN Journal of Engineering and Applied Sciences, 11(10), 6442-6449.

[5] Didane, D. H., Anuar, M. A. Z. S., Batcha, M. F. M., Abdullah, K., Ali, M. F. M., & Mohammed, A. N. (2020). Simulation study on the performance of a counter-rotating savonius vertical axis wind turbine. CFD Letters, 12(4), 1-11. https://doi.org/10.37934/cfdl.12.4.111

[6] Didane, D. H., Maksud, S. M., Zulkafli, M. F., Rosly, N., Shamsudin, S. S., & Khalid, A. (2019, June). Experimental Study on the Performance of a Savonius-Darrius Counter-Rotating Vertical Axis Wind Turbine. In IOP Conference Series: Earth and Environmental Science (Vol. 268, No. 1, p. 012060). IOP Publishing. https://doi.org/10.1088/1755-1315/268/1/012060

[7] Didane, D. H., Mohd, S., Subari, Z., Rosly, N., Ghafir, M. A., & Masrom, M. M. (2016, November). An aerodynamic performance analysis of a perforated wind turbine blade. In IOP Conference Series: Materials Science and Engineering (Vol. 160, No. 1, p. 012039). IOP Publishing. https://doi.org/10.1088/1757-899X/160/1/012039

[8] Zurita, A., Castillejo-Cuberos, A., García, M., Mata-Torres, C., Simsek, Y., García, R., ... & Escobar, R. A. (2018). State of the art and future prospects for solar PV development in Chile. Renewable and Sustainable Energy Reviews, 92, 701-727. https://doi.org/10.1016/j.rser.2018.04.096

[9] Vidican, G. (2016). Scaling up renewable energy deployment in North Africa. In Regulation and Investments in Energy Markets (pp. 73-87). Academic Press. https://doi.org/10.1016/B978-0-12-804436-0.00004-7

[10] Kazimierczuk, A. H. (2019). Wind energy in Kenya: A status and policy framework review. Renewable and Sustainable Energy Reviews, 107, 434-445. https://doi.org/10.1016/j.rser.2018.12.061

[11] Rawlins, M. E., Limon, G., Adedeji, A. J., Ijoma, S. I., Atai, R. B., Adole, J. A., ... & Alarcon, P. (2022). Financial impact of sheeppox and goatpox and estimated profitability of vaccination for subsistence farmers in selected northern states of Nigeria. Preventive Veterinary Medicine, 198, 105503. https://doi.org/10.1016/j.prevetmed.2021.105503

[12] Didane, D. H., Zulkafli, M. F., Mohd, S., Batcha, M. F. M., & Khalid, A. (2021). Development and performance investigation of a unique dual-rotor Savonius-type counter-rotating wind turbine. International Journal of Integrated Engineering, 13(6), 89-98. https://doi.org/10.30880/ijie.2021.13.06.008

[13] Didane, D. H. (2018). Wind and solar assessment in the sahelian zone of chad. International Journal of Integrated Engineering, 10(8). https://doi.org/10.30880/ijie.2018.10.08.026

[14] Amugune, I., Cerutti, P. O., Baral, H., Leonard, S., & Martius, C. (2017). *Small flame but no fire: Wood fuel in the (Intended) Nationally Determined Contributions of countries in Sub-Saharan Africa* (Vol. 232). CIFOR.

[15] Rosnes, O., & Shkaratan, M. (2011). *Africa's power infrastructure: investment, integration, efficiency*. World Bank Publications.

[16] Abdilahi, A. M., Yatim, A. H. M., Mustafa, M. W., Khalaf, O. T., Shumran, A. F., & Nor, F. M. (2014). Feasibility study of renewable energy-based microgrid system in Somaliland' s urban centers. Renewable and Sustainable Energy Reviews, 40, 1048-1059. https://doi.org/10.1016/j.rser.2014.07.150

[17] African Development Bank, "Somalia Energy Sector Needs Assessment and Investment Programme," *African Development Bank*, 2015, [Online]. Available: https://www.afdb.org/fileadmin/uploads/afdb/Documents/Generic-

[18] African Development Bank, "African Development Bank - Building today, a better Africa tomorrow," *Http://Www.Afdb.Org/En/*. 2022, Accessed: May 08, 2023. [Online]. Available: https://www.afdb.org/en.

[19] Northrop, E., Biru, H., Lima, S., Bouye, M., & Song, R. (2016). Examining the alignment between the intended nationally determined contributions and sustainable development goals. *World Resources Institute*.

[20] AFP, "Baidoa: Crossroads of despair in drought-ravaged Somalia," *FRANCE24*, 2022. https://www.france24.com/en/live-news/20220223-baidoa-crossroads-of-despair-in-drought-ravaged-somalia (accessed Nov. 06, 2023).

[21] Hassane, A. I., Didane, D. H., Tahir, A. M., Mouangue, R. M., Tamba, J. G., & Hauglustaine, J. M. (2022). Comparative analysis of hybrid renewable energy systems for off-grid applications in Chad. International Journal of Renewable Energy Development, 11(1), 49. https://doi.org/10.14710/ijred.2022.39012

[22] Hassane, A. I., Didane, D. H., Tahir, A. M., Hauglustaine, J. M., Manshoor, B., Batcha, M. F. M., ... & Mouangue, R. M. (2022). Techno-economic feasibility of a remote PV mini-grid electrification system for five localities in Chad. International Journal of Sustainable Engineering, 15(1), 177-191. https://doi.org/10.1080/19397038.2022.2101707

[23] Chandran, Y., Didane, D. H., & Ogab, M. (2021). Assessment of wind energy potential at Gong Kedak and Pantai Chendering, Malaysia. *Journal of Design for Sustainable and Environment*, *3*(1), pp. 1-7.

[24] Salisu, S., Mustafa, M. W., Olatomiwa, L., & Mohammed, O. O. (2019). Assessment of technical and economic feasibility for a hybrid PV-wind-diesel-battery energy system in a remote community of north central Nigeria. Alexandria Engineering Journal, 58(4), 1103-1118. https://doi.org/10.1016/j.aej.2019.09.013

[25] Samsudin, M. Z., Didane, D. H., Elshayeb, S. A., & Manshoor, B. (2021). Assessment of solar energy potential in johor, malaysia. *Journal of Design for Sustainable and Environment*, *3*(1), pp. 1-6.