Assessment of Hybrid Renewable Energy System in Beledweyne city Somalia, Technical and Economical Analysis

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ABSTRACT

The rapid depletion of conventional fossil fuels with each passing day and increasing environmental concerns have given a great impetus to the studies on clean and renewable alternative energy sources. This study aims to investigate the feasibility of an on-grid, and off-grid hydro-wind-solar-battery hybrid system for electricity generation in Beledweyne, Somalia. The model is simulated with the HOMER program based on the energy-efficient system, has been successfully applied to find the best optimization result for the required amount of load. The economic and technical performance of a stand-alone combination of 100 kW hydropower, 200 kW solar photovoltaic, 400 kWh battery, and 80 kW wind power was investigated. Grid-connected megaprojects, such as large dams and energy pools, are essential but slow and expensive to increase national and regional power generation and transmission. This study is expected to shed light on investments to be made in Africa's off-grid and mini-grid solutions that are cheaper and faster to install and emphasizes that investments to be made in this direction can be a solution to Somalia's electricity crisis.

Keywords: Hybrid Renewable energy systems; Modelling and optimization; Optimal configuration; Semi-urban electrification; Simulation; Rural community.

1. INTRODUCTION

Nowadays, most of the energy demand in the world, excluding Europe, is met by using conventional energy sources such as coal, natural gas, and oil. In addition, the energy need in the world is increasing day by day, which increases the need for conventional fuel. On the other hand, the reserves of the mentioned conventional fuels are limited in the world and are gradually depleted due to the increasing energy demand. The problems of global warming and global climate change mechanisms are considered to be among the crucial ecological problems of the world, which is the only habitable planet in the solar system for now, that require urgent solutions (Mikhaylov et al., 2020). In the context of alleviating and slowing down the aforementioned global ecological balance problems, it is extremely important to restrain and limit the world's fossil fuel uses (Newell & Simms, 2020). As a result of the increase in fossil fuel consumption in African countries, carbon dioxide emissions are increasing (Ayompe et al., 2020).

According to data compiled by the International Energy Agency, the International Renewable Energy Agency, the United Nations, the World Bank, and the World Health Organization, close to one billion people in the world are without electricity and 50% of them are in Sub-Saharan Africa (Avila et al., 2017). Despite this, the research also states that progress has been made in the last decade in the use of renewable electricity from water, solar, and wind energy. If people living in Africa had capital and other means, they would be very productive people. It is really important that we do not overlook these people in our goal of growing economies and reducing unemployment after Covid-19 (Coban, 2021). How can people be brought out of extreme poverty without wrecking the climate in the process? Many say it will require the burning of sufficient fossil fuels. But in rural Africa, a small simulation and experiment can be observed to see if it is possible to have green energy by reducing the environmental catastrophe as well.

In Somalia, where 64% of the population cannot reach electricity, and 60% of these people live in villages far from the center; those who do have electricity face very high prices. Somalia, which went into civil war in 1991, does not have a national network and its major cities are powered by diesel generators (Shortland, 2012). A capacity of 200 MW is required to meet the total installed power demand of the capital Mogadishu, but currently, this capacity is only 35 MW (Abdi & Abdirahman, 2020). The electricity consumption is less than 1 kWh per day for a five-person household and the average per capita is 20 kWh per year (Hannah & Max, 2022). This annual electricity consumption per capita is significantly lower than in South Sudan and Tanzania with 44 kWh and 104 kWh respectively as of 2014, compared to 15588 kWh per capita in Canada (Our World in Data, 2021). Somalia's electricity generation capacity is very low. Many individuals and businesses depend on off-grid solutions (Bahtiyar Dursun et al., 2020). Although investment is needed to revive the electricity sector, there are no planned projects. On the other hand, wind and solar energy potential are high (Bahtiyar Dursun et al., 2020). The country has the highest electricity price in the world due to its dependence on diesel generators (Nuñez, 2015). Although Somalia is estimated to have large oil reserves, the political situation hinders production. With Somalia's rich renewable energy resources, many villages can be operated at the micro-grid level and generate power from renewable energy sources; this energy can be stored in batteries. In the 1990s, a solar panel cost five or six dollars per watt, but nowadays it's 20$cents (O'Shaughnessy & Margolis, 2018). The fall in solar panel prices in recent years has opened up a huge opportunity to supply energy in Africa.

What if, wind, hydro and solar technologies could work together on one site? The use of renewable energy sources together in a hybrid system has positive features in many respects (Lian et al., 2019). The fact that solar energy is only available during daylight hours and the wind is not continuous limits the independent use of these systems, or by installing and storing at high capacities, the stored energy can be used in cases where it cannot produce energy. The combined use of wind, hydroelectric and solar energy in hybrid energy systems, which leads the renewable energy sector, is increasing day by day.

Due to the intermittent nature of wind and solar power, it alone cannot meet 24-hour load requirements (Khalid et al., 2018). Wind and solar energy sources can complement each other's production in the hybrid system with a negative correlation in the field. In this scenario, they have less ramping problems and more stable power output by avoiding sudden peaking compared to only wind or only solar power plants. More scheduled electricity output provides a flatter generation profile throughout the day/season/year, making it easier for the plant to meet system requirements. Hybrid systems can deliver uninterrupted energy if combined with storage technologies (Bonkile, 2019). Thus, storage systems can ensure the continuity of the electricity supplied to the grid/facility in cases such as outages and constraints where energy cannot be produced. The use of a diesel generator system in addition to renewable energy in hybrid systems prevents the continuity of energy and the installation of unnecessary solar or wind energy and reduces the energy unit cost price.

It is stated that there are energy interruptions and fluctuations in systems that operate independently of the grid, as the wind constantly changes speed and direction during the day and the intensity of the sun's radiation increases and decreases (Sun et al., 2021). The batteries not only store generated electricity but also they are electronic devices that provide the output, voltage, frequency, and quality of the system to meet the energy needs of the loads connected to the hybrid system (Krishan & Suhag, 2019). Hybrid power generation systems are units that produce energy from at least two or more raw energy sources and contribute to each other in parallel (Kocaman & Abut, 2015). The purpose of hybrid systems is to increase efficiency by using energy sources together and to ensure that the others meet the energy needs of the system in case one of the sources is absent or reduced. The hybrid micro-grids are small energy grids that can be managed either connected to the grid or independently of the grid, using energy sources within certain limits (Zhu et al., 2015).

Although the history of micro-grids created using renewable energy sources is not very long, the study subjects on this type of network are very popular recently. Incentives for electricity generation with renewable energy sources and therefore studies on this type of production are increasing rapidly around the world. The process of estimating input variables to minimize or maximize an objective function determined by the constraints defined in renewable micro-grids is called optimization. The optimization process in micro-grids is an important issue and literature review software tools, methods, and applications related to energy management and sizing optimization are examined. (Connolly et al., 2010) reviewed 68 tools of renewable energy simulation tools. According to the research results, only a few of them are suitable to be used as modeling tools for hybrid system applications. It is depicted that the annual energy yields estimated by most of the existing software in the literature are very close to the actual energy production from the real system. The closest estimates are HOMER and PVsyst with an error of 5.52% and 6.90%, respectively (Komrit, 2020). Therefore, in this study, hybrid renewable energy systems are modeled for comparison based on economic energy analysis to fill the gap between the real-life operation of the projects and the simulation process.

In this study, the most suitable hybrid system type and size based on hydroelectric, wind, solar, and battery technology were investigated for Beledweyne city of Somalia. The daily and hourly electrical load profile values used in this study are taken from the literature study by (Abdilahi et al., 2014). Furthermore, a technical and economic feasibility study of the hybrid energy system was performed taking into account uncertainties. In addition, the contribution of renewable energy resources to energy production, total system cost, and energy cost have been investigated for various hybrid systems. Lastly, the sensitivity analysis of the off-grid hybrid power system was studied in multiple optimizations, each with a different set of input assumptions. In the sensitivity analysis, the effects of the changes in the parameters of the model on the optimal solution are investigated.

2. SELECTED SITE and RENEWABLE ENERGY RESOURCES

The area chosen for the case study is located in Somalia and the country is located in the Horn of Africa and has a total area of 637,657 km² (246,201 sq mi) and lies between the latitude of 10°00'N and longitude of 49°00'E. In fact, Somalia is very rich in terms of energy resources, but due to technological inadequacies, infrastructure deficiencies, and political factors, it cannot generate electricity from these resources at the desired level. Solar and wind are the country's main current renewable energy sources that can generate electricity. The site chosen for this study is located 342 km (210 miles) outside of the capital Mogadishu, in the city of Beledweyne in the Hiran region in central Somalia, located at 4°43'N latitude and 45°18'E longitude and approximately 182m above sea level. Solar radiation intensity, sunshine duration, and clarity index are the basic data used in the design, modeling, and performance evaluation of solar energy systems. The solar radiation distribution over the whole of Somalia, shown in Figure 1, it shows that the country is in a suitable region, the global solar radiation is between 5.2 and 7.5 kWh/m²/day (*Solar Maps of Somalia*, 2021). Somalia has one of the highest total daily radiation in the world, receives an average of 2,900 to 3,100 hours of sunshine per year (*Sunrise and Sunset in Somalia*, 2021).

The clearness index is evaluated as the ratio of total solar radiation to total extraterrestrial radiation for the corresponding month, in another word it is a measure of the clearness of the atmosphere, and it is expressed as a number between 0 and 1 (Alam et al., 2019). The minimum value was observed in July and the maximum value in February. It is seen that the clearness index varies between 0.51-0.66 and the fluctuations can be seen in Figure 2.

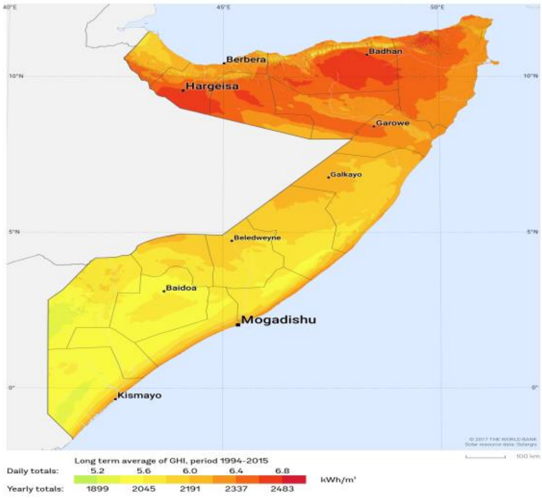

Figure 1. Solar radiation map of Somalia (*Solar Maps of Somalia*, 2021)

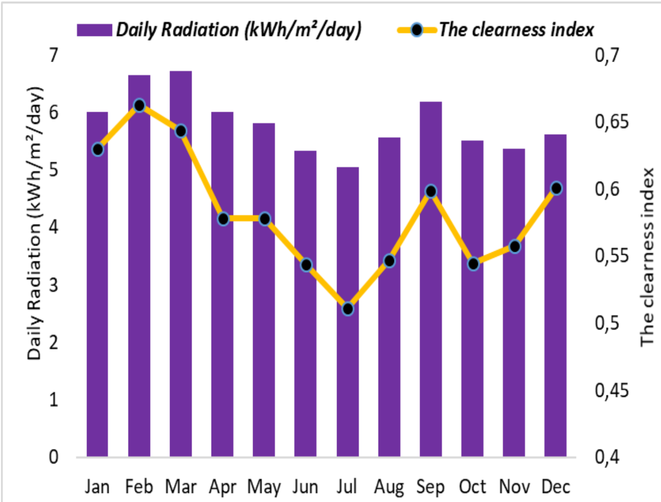

Figure 2. Averaged solar irradiance and clearness index for the selected area

Monthly wind speed data for the city of Beledweyne are shown in Figure 3. It is noticeable that the lowest measured wind speed is in the period of April, and the maximum is in the period of June-August and the average annual wind speed exceeds 7.7 m/s. Based on wind speed data it is proven that wind energy is available in Beledweyne most of the year and can be used to generate energy by reducing the use of diesel fuel.

The intermittency in wind and solar energy both increases the costs in terms of planning and makes the applicability questionable. Therefore, hydroelectric power plants and solar-wind power plants can produce energy together. It is anticipated that intermittency problems will be greatly reduced by the hybrid use of these three sources. The efficiency of hybrid systems will increase by the small hydroelectric power plant to be established in addition to the wind and solar power plant. While wind-solar hybrid energy systems emerge as an economical option for feeding small-scale loads, wind-hydro generators are a more economical option for feeding medium-sized loads. The flow rate of the Shabelle river passing through of city Beledweyne is given in Figure 4.

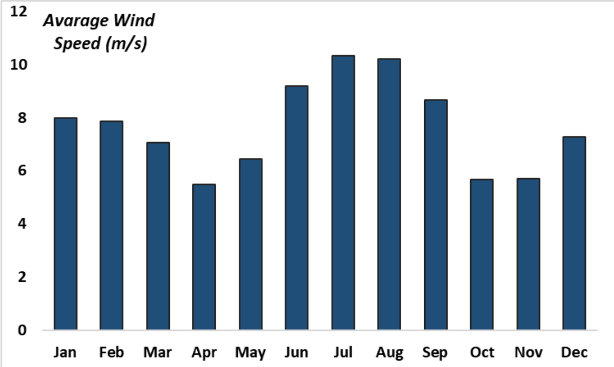

Figure 3. Monthly variation of the mean wind speed

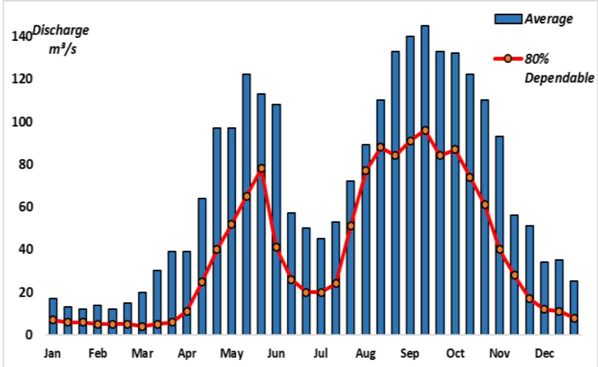

Figure 4. Long-term flow statistics of Shabelle River (m³/s)

The monthly average daily global solar radiation values, clearness index, and wind speed for the province of Beledweyne are taken from NASA Surface Meteorology while the flow rate of the Shabelle river used in this study is taken from the literature study (Komrit, 2020).

3. ELECTRICAL LOAD and HYBRID ENERGY COMPONENTS

The daily average electricity consumption used in this study was found to be approximately 25 kWh for each household in the research conducted by (Abdilahi et al., 2014). The electrical load changes over 24 hours and the hourly power consumption is shown in Figure 5 for an arbitrary day. In this study, the predefined ensemble load profile was used in the HOMER program. The average daily electrical energy requirement was 13060 kWh/d and the peak load value during the day was 2132.46 kW. Electrical energy consumption reaches different values in different periods during the day and seasons. The maximum energy demand is experienced between 6:00-9:00 a.m. and 5:00-10:00 p.m.

Apart from this, it is assumed that there is a 15% difference between the weekend and weekday electricity consumption profiles. In the simulation analysis, 500 households can benefit from this opportunity with an average consumption rate of 2.6 kWh per day. The optimization and feasibility study will be compared with a system with and without a grid system consisting of diesel generators, battery packs, hydroelectric, solar, and wind energy conversion systems. The schematic figure of the hybrid energy system with and without a grid is shown in Figure 8 and Figure 10 respectively. In addition, considering the climatic conditions of the region, producing materials and equipment that are resistant to dust and heat will increase the life of the electrical systems to be installed. The use of transformers, which are used at temperatures up to 50°C in Somalia, inside metal buildings causes frequent burning of transformers. As a solution to this situation, pole-type transformers or underground transformers should be encouraged. Technical data and capital costs for the hybrid energy system used components in the simulation are described below.

3.1. Grid system

In this study, the network is modeled in such a way that electricity can be purchased when needed and electricity can be sold in appropriate situations. If there is excess electricity in the power plant and the owner of the power plant sells this electricity to the grid; it is assumed that the price will be $0.09/kWh and consumers will receive electricity from the grid at a price of $0.13/kWh. The fixed energy cost of the grid is zero, and the marginal energy cost is equal to the sum of the grid energy price and the cost from emissions penalties. As the applicable rate changes, the grid energy price can change from hour to hour, so the grid's marginal cost of energy can also change from hour to hour. This can have significant effects on the system’s behavior simulation. Unfortunately, currently, there is no legislation governing electricity in Somalia although Somaliland and Puntland regions have developed energy sector laws. Electricity prices in Somalia are among the highest in the world at $0.5–1 per kWh (Abdilahi et al., 2014).

3.2. Photovoltaic and converter

For each hour of the year, HOMER calculates the global solar radiation incident on the outer surface of the photovoltaic array using the Hay-Davis-Klucher-Reindl model (Sharma et al., 2020). This model takes into account the current value of the solar source, the orientation of the photovoltaic array, the location on the earth, the time of year, and the time of day. The orientation of the photovoltaic array can be fixed or changed according to one of several tracking patterns. Photovoltaic panel output is direct current. Therefore, a converter is needed to feed the load. With the direct current/alternating current converter, the energy needed by the load is met. The initial investment cost is $1800 for 1 kW, the renewal cost is $1000 and the annual maintenance value is $10. The reduction factor is a 90% value that takes into account the losses that will occur at the output of the photovoltaic arrays due to dirt, temperature, shade, snow cover, and aging. Quick and easy response Solectria String Sizer Tool (Yaskawa, 2021) was used when selecting the transducer size. It has been determined that a grid-connected photovoltaic (PV) inverter system has been created and the modeled PVI 50 kW inverter model can provide the required AC power output. Data including investment, replacement, and operation and maintenance (O&M) cost of the components used in the system are given in Table 1.

3.3. Battery

The main handicap of renewable energy is that the energy produced is intermittent and changes hourly, monthly, or seasonally. For this reason, it is inevitable to use energy storage systems to effectively use systems that depend on sustainable resources such as wind and solar energy. In this study, batteries provide the storage of excess energy and keep the frequency constant. The battery can be selected in both large power and small power; however, the overall costs will increase significantly as power increases. The O&M cost was considered negligible and therefore set to 0. Because battery prices are still high today, battery cost has a very significant impact on Net Present Cost, and hybrid systems cost less if batteries are not used for backup power. The technical and economic specifications of the system components are given in Table 1.

3.4. Hydro Turbine

The site chosen for the hydroelectric power plant described in Chapter 3 is rich in water resources. It is assumed that the flow rate is $5m^3/s$, the efficiency rate is 80%, and the current height is 25m. The micro-hydro model in Homer software is not designed for a specific resource. The lifetime of the micro-hydro power model in the simulation is taken 25 years. The subsystem is designed for a capacity of 100 kW and a capital cost of $459,845. The O&M cost is 3% of the capital cost and the replacement cost is $13,795.

3.5. Wind Turbine

HOMER calculates the output power of the turbine for each hour in a four-step process: i) HOMER determines the average wind speed at the height of the wind speed meter for each hour based on wind source data. ii) the software calculates the wind speed at the height of the rotor hub of the wind turbine using either the logarithmic law or the power law. iii) the software references the power curve of this wind turbine to calculate the output power of the wind turbine at this wind speed at rotor hub height, taking into account the standard air density. iv) HOMER multiplies this output power value by the air density ratio. Figure 6 shows the energy production and the power-speed curve of the selected wind turbine. The air density ratio is calculated at site altitude using the United States Standard Atmosphere. It is assumed that the air density ratio is constant throughout the year.

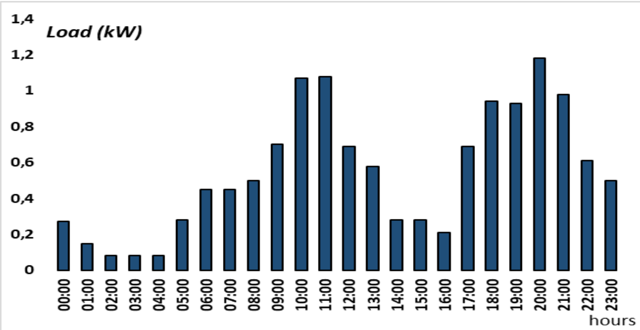

Figure 5. Typical daily electricity demand profile of the household in Somalia.

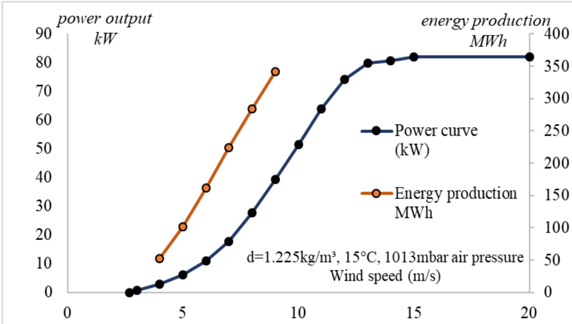

Figure 6. The energy production curve and the power-speed curve of the wind turbine

3.6. Diesel generator

Diesel generators (DG) (139 kW and 410 kW) are alternative energy sources used to meet the demand in places where there is no network or in cases where electrical energy is off. It is assumed that the large generator is used for baseload generation and the small generator is used to meet peak demand. Various reports of Kohler brand generators were obtained from the manufacturer's data specification sheet (*Kohler Co.*, 2022). Although large-capacity production of one of the generators is preferred, the main objective of this study is to find a commercial, cost-effective, and technically viable alternative to reduce reliance on diesel generators. Therefore, optimized use of batteries has been proposed, which can economically replace the use of diesel due to the intermittent nature of renewable energy sources. The fuel consumption and produced power/efficiency curves for generators are shown in Figure 7.

Table 1. The details of different system components used in this study

	DG-1	DG-2	Solar PV	Inverter	Battery	Wind Turbine
Capital Cost	28000$	72000$	1800$	1000$	900$	24000$
Size (kW)	139	410	200	30	471Ah	80
Replacement Cost ($)	25000	68000	1000	1000	750	16000
O&M cost	0.09$/h	0.1$/h	10$	0	0	200$
Model	Kohler 139kW	Kohler 410kW	SG200M5	Ideal-30kW	ESS 100kW/400kWh	WES-18
Lifetime	40000 h	40000 h	25 years	10 years	20 years	25 years

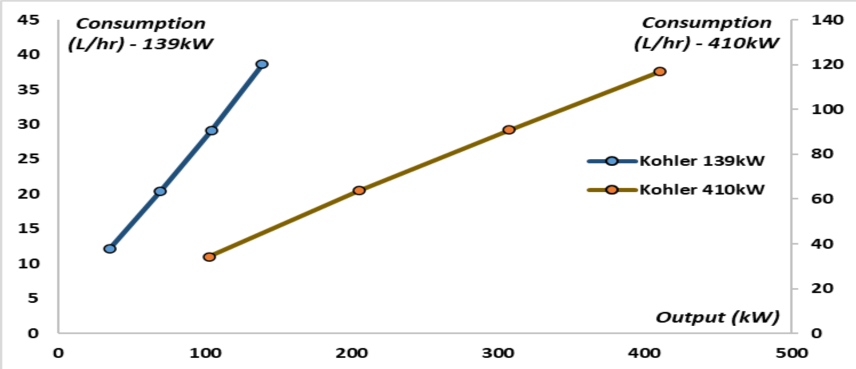

Figure 7. The fuel consumption curve of diesel generators

In addition, to examine how the optimum system will change in case of an increase in the price of fuel purchased, it will be considered that the diesel fuel prices will increase by 0.9$/l, 1.2$/l, and 1.5$/l and the results will be given in the sensitivity analysis part.

3.7. Simulation settings and financial assumptions

In addition to modeling the behavior of each element, HOMER also simulates how these elements work together as a system. This requires hourly decisions about which generators should operate at what power level, whether to charge or discharge batteries, and whether to buy or sell energy from the grid. The construction period of the project is taken as 2 years and the project lifetime is taken as 25 years. Even though the real interest rate in Somalia has fluctuated significantly in recent years, it is not possible to reach precise information. According to the latest available information, the inflation rate in Somalia is 4.1% (*Inflation Rate in Somalia*, 2021).

3.8. Homer Software

It has been observed that cost analyzes are made according to annual average values and deterministic data are used in the calculations of many systems established with renewable energy sources. Stochastic changes in the nature of renewable energy are not taken into account by most programs (Anoune et al., 2018; Forough & Roshandel, 2018). The Homer software models the effect of time-varying inputs such as electrical load, water flow, wind speed, and solar radiation, developed to design micro-power systems and compare power generation technologies, and generates 8760 values (hourly data) for each of the inputs for a year in the software. In this study, a hybrid system is modeled with HOMER software to meet the energy demand of the city of Beledweyne, and the systems are compared by economic-technical analyzes to choose the most suitable system model. The effect of time to be imported into the HOMER program are the features and costs of system components, load, renewable resources, and various information about optimization. These data were obtained -varying inputs such as solar radiation, river flow, electrical load, and wind speed is modeled and 8760 values (hourly data) are generated for each of these inputs in the simulation for a year. The data from manufacturers and literature surveys.

4. FINDINGS and DISCUSSION

Hybrid energy systems examined within the scope of the study were examined in two different aspects as on-grid and off-grid systems. The most possible or optimal system configuration is the one with the lowest total net present value (NPV) that is able to meet user-specified limits. To find the optimal system configuration, HOMER simulates many different system configurations, then ranks the appropriate ones (within user-specified limits) according to their total NPVs. The configuration with the lowest NPV is optimal. The purpose of the optimization process is to give the designer the optimal value of the decision variables that are the number of batteries, number of wind turbines, PV array size, the existence of hydro energy system, the size of each generator, and size of DC/AC converters.

4.1. Design of on-grid and hybrid renewable energy system

In this system; 100kW micro-hydro, 24 m high 80 kW wind turbine, 200 kW flat type PV panel, 30 kW converter, 400 kWh Lithium-Ion battery, and grid line were selected. Figure 8 shows the renewable on-grid hybrid energy system for electricity generation.

The installation cost is 2.78M$, the annual maintenance and operating cost is $190,000/year, and the unit cost of the consumed energy is $0.1074/kWh. It is assumed that the unit price of the mains electricity is $0.13/kWh. 7% of the generated energy, 359.005kWh, was sold to the grid. 20.6% of the consumed energy was produced from hydro turbines, 31.2% from PV, 48.2% was provided by the grid (if there was a healthy electricity grid in Somalia), and HOMER simulation results are shown in Figure 9. The Return on Investment is 9.7%, the

Internal Rate of Return (IRR) is 13%, and the payback period is 7.2 years.

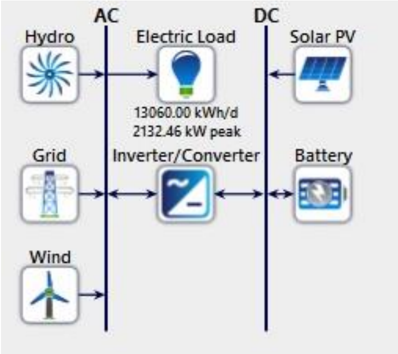

Figure 8. Schematic diagram of the on-grid hybrid system

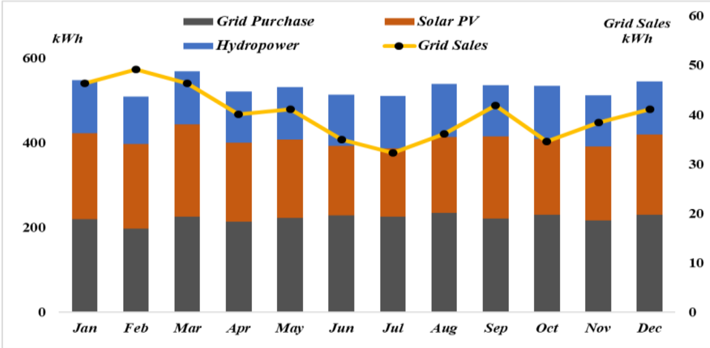

Figure 9. Monthly average electric production for the period of one year

4.2. Design of stand-alone and hybrid renewable energy system

In this system; 100kW hydro, 24 m high 80 kW wind turbine, 200 kW flat type PV panel, 58.5 kW converter, 139 kW, 410kW two diesel generators, and 400 kWh Lithium-Ion battery was selected, and the number of components was determined by Homer. The schematic diagram of the stand-alone hybrid power generation system is shown in Figure 10. In this scenario, most of the electrical load of the selected site is covered by solar PV. With HOMER, the most suitable generator power was found to be 160kW. Using the values in Table 2, the NPC was found to be 7.59M$ and the Levelized-Cost of energy to be 0.107$/kWh for the project life of 25 years. If there was no micro-hydropower plant in the system, a diesel generator would be needed. In this case, fuel consumption would affect NPV. Annual production and consumption results are given in Table 2-3, and HOMER simulation results are given in Figure 11.

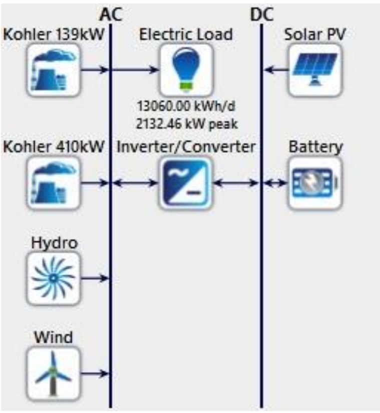

Figure 10. Schematic diagram of the off-grid hybrid system

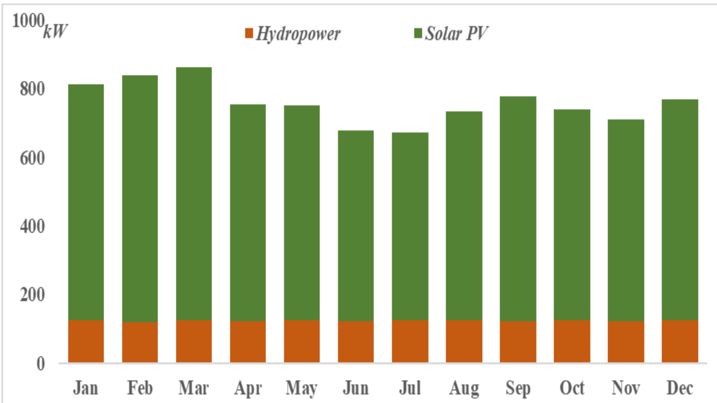

Figure 11. Monthly average electric production for the period of one year

The fact that the wind energy generation in the grid system has a higher share in electricity generation compared to the off-grid scenario shows the effect of the electricity sales and purchase price in the grid on the energy generation strategy. It has been concluded that the grid system is better in terms of economy and greenhouse gas emissions compared to the system that produces with a diesel generator. While the renewable energy usage rate is 97.2% in the non-grid system, it is 94.5% in the on-grid system. The fact that 94.5% of the electrical power of the system is provided by solar panels shows that the grid is not needed effectively and that Somalia is rich in renewable energy resources.

Table 2. Annual electricity production

ON-GRID			OFF-GRID		
Production	**kWh/yr**	**%**	**Production**	**kWh/yr**	**%**
Solar PV	1,658,621	31.2	Solar PV	5,643,294	83.7
Grid Purchases	2,561,556	48.2	Hydro	1,095,679	16.3
Hydro	1,095,679	20.6			
Total	5,315,856	100	Total	6,738,972	100

Table 3. Annual electricity consumption

ON-GRID Renewable Fraction 50%			OFF-GRID Renewable Fraction 100%		
Consumption	**kWh/yr**	**%**	**Consumption**	**kWh/yr**	**%**
AC Primary Load	4,766,900	93	AC Primary Load	4,765,787	100
Grid Sales	359,005	7			
Total	5,125,905	100	Total	4,765,787	100

The micro-hydro power plays a key role in the modeled system. Because the flow rate of the Shabelle river is very rich and productive. If micro-hydro is removed from the system; diesel generator(s) will be activated, and will meet the electrical energy demand. Total production is 7,476MWh/yr which is supplied by solar PV panels and the renewable fraction is 100%.

4.3. Sensitivity analysis

Sensitivity analysis can assist the designer in understanding the effects of uncertainty and making sound design decisions despite uncertainty. The analysis defines how sensitive the output values are to changes in the input values of the system. In sensitivity analysis, the investor can change variables with different value ranges for each input variable. Almost all input variables that are not defined as decision variables in HOMER can be defined as 'sensitivity variables'. These variables are grid electricity price, fuel price, interest rate, or components lifetime. In addition, sensitivity analysis can be performed on hourly data sets such as electrical load, solar radiation data, and wind speed. HOMER evaluates renewable resource data in the same way. The purpose of sensitivity analysis is to overcome uncertainties. If the investor is not sure about a certain variable value, values can be changed to see and evaluate the changes in the system output as a result of these values. In addition, with sensitivity analysis, the user can predict at what price and under what conditions a system configuration can compete with its alternatives. In the study, 20 different scenarios were simulated and the results were evaluated to offer the best results to the investors. Considering the situation in Beledweyne for the proposed hybrid energy system; for HOMER modeling it is necessary to consider O&M as a sensitive variable. This is because solar and wind turbine panel technology is not manufactured in Somalia and there are hardly any engineers who can fix technical faults. Therefore, if foreign experts are called for any malfunction in the system, the cost of O&M may increase. Therefore, it is decided to consider an O&M cost of two and three times the estimated cost in the simulation. Also, it is extremely important to have accurately measured weather data, as renewable energy data is based on a satellite forecast of the region. Accordingly, annual averages of renewable energy sources have been changed with a 15% increase or decrease. Another variable to consider is the effect of the interest rate on optimal system configurations. The increase in interest rates increases investment costs and negatively affects investments. The interest rate was increased from 5% to 11% in 1% increments. The fourth variable to consider is the change in diesel fuel price. Because the generator is an important system component of the micro-grid system components. Diesel prices increased by \$0.3/l from \$0.9/l to \$1.5/l. Table 4 summarizes the source sensitivity variables in the simulation study.

Table 4. Summary of component and resource sensitivity variables used in the simulation.

	The interest rate	**Diesel fuel cost**	**Annual average wind**	**Annual Global solar**	**O&M cost**

			speed	radiation	
Unit	%	$/l	m/s	kWh/m²/d	$/year
Changes	5, 6, 7, 8, 9, 10, 11	0.9, 1.2, 1.5	±15	±15	1, 2, 3 times multiplier

The cost of energy is most sensitive to the diesel prices and O&M cost as the spider graph shown in Figure 13 which is produced by HOMER. The cost increase of the NPC is around 30,000$ for every 0.3$ diesel price change. For every wind turbine O&M cost multiplier the NPC increases around 100,000$. Consequently, investors should take out loans at the lowest rate and have a local mechanic and engineer for the wind turbine. On the other hand, a 15% decrease or increase in solar radiation and wind speed had an almost negligible effect on the total NPC as shown in the Figure below. Therefore, this is a key issue that these parameters should be taken into consideration during future investments.

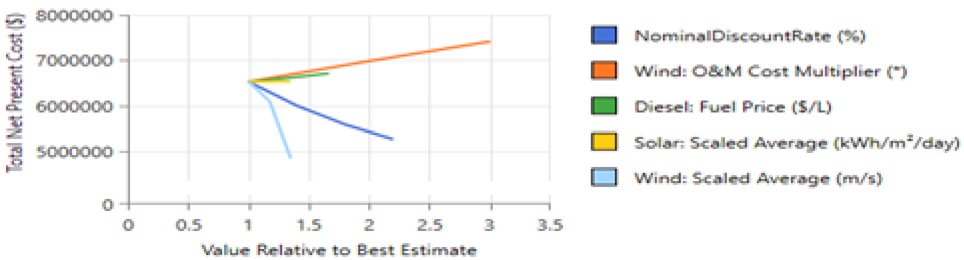

Figure 13. The spider graph of five sensitive variables

5. CONCLUSION

The electricity demand of Beledweyne, which the city does not have a secure and sufficient network line, is not met by a single energy transmission line. This situation is risky for the continuity of energy. Due to a fault that may occur in the transmission line, the entire region may be without electricity. In this study, hybrid energy systems originating from a diesel generator, battery, hydro, wind, and solar energy were examined and the performances of these systems were evaluated, and suggestions were presented for performance improvement. System models are created as realistically as possible. Each system is considered separately and the results and recommendations analysis are presented. In the study, the technical and economic performances of hybrid energy system applications that use different energy sources, with and without a grid, are examined and compared.

Hybrid energy systems for different energy storage alternatives have been extensively compared in terms of different parameters such as the annual amount of fuel they consume, the energy surplus they produce, and the leveled energy costs.

According to the simulation results, it was observed that the batteries should be used effectively in the hybrid system, and the installation cost of the selected system was 215,958$, the operation cost was 18,029$ and the net current cost of the whole project was 598,958$. It has also been revealed that the unit energy cost has decreased to 0.164$.

Furthermore, 20 different scenarios were simulated within the scope of sensitivity analysis and the results were compared. The findings of this study and the sensitivity analysis results can be applied to evaluate other parts of Somalia and communities in neighboring countries with similar global solar radiation data, fuel prices, and wind speeds as in this study.

As a result; in this study, renewable energy systems were introduced and, in the simulations, made with the HOMER program, it is seen that meeting the electricity demand of Beledweyne with wind energy would be a suitable investment. According to the simulation results, it is stated that the required energy demand is also available in Somalia by its rich resources. In this study, no modeling of greenhouse gas emissions was performed. If reliable information is obtained for Somalia about the number of greenhouse gases emitted against the amount of electricity produced; in future studies, the net greenhouse gas emissions can be determined by modeling greenhouse gas emissions and calculating the greenhouse gas emissions of the hybrid energy system.

REFERENCES

Abdi, S., & Abdirahman, H. (2020). Choking on diesel costs, Somali firm turns to solar for cheaper power. *Reuters*.

Abdilahi, A. M., Mohd Yatim, A. H., Mustafa, M. W., Khalaf, O. T., Shumran, A. F., & Mohamed Nor, F. (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

Alam, F. E., Ur Rehman, S., Rehman, S., Jahangir, M., Shoaib, M., Siddiqui, I., & Ulfat, I. (2019). Empirical model development for the estimation of clearness index using meteorological parameters. *Turkish Journal of Electrical Engineering and Computer Sciences*, *27*(6), 4429–4441. https://doi.org/10.3906/ELK-1903-27

Anoune, K., Laknizi, A., Bouya, M., Astito, A., & Ben Abdellah, A. (2018). Sizing a PV-

Wind based hybrid system using deterministic approach. *Energy Conversion and Management*, *169*(May), 137–148. https://doi.org/10.1016/j.enconman.2018.05.034
Avila, N., Carvallo, J., Shaw, B., & Kammen, D. M. (2017). The energy challenge in sub-Saharan Africa: Generating energy for sustainable and equitable development. *Oxfam Research Backgrounder Series*, 100.
Ayompe, L. M., Davis, S. J., & Egoh, B. N. (2020). Trends and drivers of African fossil fuel CO2 emissions 1990-2017. *Environmental Research Letters*, *15*(12). https://doi.org/10.1088/1748-9326/abc64f
Bahtiyar Dursun, Sibel Dursun, & Ercan Aykut. (2020). An Assessment of Renewable Energy Options for Somalia Turkey Hospital. *J. of Electrical Engineering*, *8*(1), 27–45. https://doi.org/10.17265/2328-2223/2020.01.005
Bonkile, M. P., & Ramadesigan, V. (2019). Power management control strategy using physics-based battery models in standalone PV-battery hybrid systems. *Journal of Energy Storage*, *23*(April), 258–268. https://doi.org/10.1016/j.est.2019.03.016
Coban, H. H. (2021). While Covid-19 Outbreak Affects Economies and Societies; Exploring the Energy Demand in Turkey. *European Journal of Technique*, *11*(2), 126–135. https://doi.org/10.36222/ejt.894463
Connolly, D., Lund, H., Mathiesen, B. V., & Leahy, M. (2010). A review of computer tools for analysing the integration of renewable energy into various energy systems. *Applied Energy*, *87*(4), 1059–1082. https://doi.org/10.1016/j.apenergy.2009.09.026
Forough, A. B., & Roshandel, R. (2018). Lifetime optimization framework for a hybrid renewable energy system based on receding horizon optimization. *Energy*, *150*, 617–630. https://doi.org/10.1016/j.energy.2018.02.158
Hannah, R., & Max, R. (2022). *Somalia: Energy Country Profile*. https://ourworldindata.org/energy/country/somalia
Inflation rate in Somalia. (2021). https://www.statista.com/statistics/863082/
Khalid, M., AlMuhaini, M., Aguilera, R. P., & Savkin, A. V. (2018). Method for planning a wind-solar-battery hybrid power plant with optimal generationdemand matching. *IET Renewable Power Generation*, *12*(15). https://doi.org/10.1049/iet-rpg.2018.5216
Kocaman, B., & Abut, N. (2015). The Role of Energy Management in Microgrids With Hybrid Power Generation System. *Bitlis Eren University Journal of Science and Technology*, *5*(1), 31–36. https://doi.org/10.17678/beujst.77662
Kohler Co. (2022). 410 KW Diesel Generator. https://www.kohlerpower.sg
Komrit, S. (2020). *Comparative Analyses of Solar Photovoltaic, Wind, And Hybrid Energy Systems: Case Study of Thailand*. California State University.
Krishan, O., & Suhag, S. (2019). An updated review of energy storage systems: Classification and applications in distributed generation power systems incorporating renewable energy resources. *International Journal of Energy Research*, *43*. https://doi.org/10.1002/er.4285
Lian, J., Zhang, Y., Ma, C., Yang, Y., & Chaima, E. (2019). A review on recent sizing methodologies of hybrid renewable energy systems. *Energy Conversion and Management*, *199*(April), 112027. https://doi.org/10.1016/j.enconman.2019.112027
Mikhaylov, A., Moiseev, N., Aleshin, K., & Burkhardt, T. (2020). Global climate change and greenhouse effect. *Entrepreneurship and Sustainability Issues*, *7*(4), 2897–2913. https://doi.org/10.9770/jesi.2020.7.4(21)
Newell, P., & Simms, A. (2020). Towards a fossil fuel non-proliferation treaty. *Climate Policy*, *20*(8), 1043–1054. https://doi.org/10.1080/14693062.2019.1636759
Nuñez, N. J. (2015). *The Potential of Renewable Energy policy breif in Somalia, the Affordable Energy Deficit in Somalia*.
O'Shaughnessy, E., & Margolis, R. (2018). *Solar Buyer's Markets: Unlocking Lower Photovoltaic and Battery Prices on Online Quote Platforms* (Issue November).
Our World in Data. (2021). *Per capita electricity consumption*.

https://ourworldindata.org/grapher/per-capita-electricity-consumption
Sharma, M. K., Kumar, D., Dhundhara, S., Gaur, D., & Verma, Y. P. (2020). Optimal Tilt Angle Determination for PV Panels Using Real Time Data Acquisition. *Global Challenges*, *4*(8), 1900109. https://doi.org/10.1002/gch2.201900109
Shortland, A. (2012). "Robin Hook": The Developmental Effects of Somali Piracy. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.1940271
Solar maps of Somalia. (2021). https://solargis.com/maps-and-gis-data/download/somalia
Sun, X. Y., Zhong, X. H., Wang, C. Z., & Zhou, T. (2021). Simulation research on distributed energy system based on coupling of PV/T unit and wind-to-heat unit. *Solar Energy*, *230*(July), 843–858. https://doi.org/10.1016/j.solener.2021.11.011
Sunrise and sunset in Somalia. (2021). https://www.worlddata.info/africa/somalia/sunset.php
Yaskawa. (2021). *Solectria Solar*. http://stringsizing.solectria.com
Zhu, X., Han, X. Q., Qin, W. P., & Wang, P. (2015). Past, today and future development of micro-grids in China. *Renewable and Sustainable Energy Reviews*, *42*, 1453–1463. https://doi.org/10.1016/j.rser.2014.11.032