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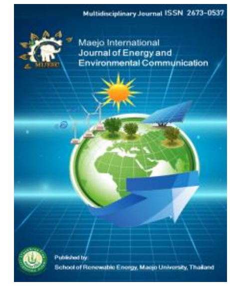

ARTICLE

Providing electricity access for unelectrified people in remote areas: demonstrated to a case study in Libya

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A B S T R A C T

Power generation in rural areas of the world, whether through renewable energy sources or grid expansion, is critical to increasing the monetary value of life. The cost of extending the national grid or installing off-grid systems is determined by a variety of factors, including the area's location, geography, population, distance from a grid point, and land size. Due to their cost-effectiveness and ease, off-grid rural electrification systems that incorporate a variety of renewable energy sources (RESs) have become unavoidable in areas where grid connectivity is neither available nor feasible. A hybrid combination of renewable energy technologies (RETs) has demonstrated to be a viable alternative to costly grid extension in remote areas throughout the world. The purpose of this study was to plan and assess the techno-economic feasibility of providing electricity to rural Enttelat in Libya using renewable energy sources, considering 70 houses with a combined load of 875 kWh/d. Three significant outcomes were obtained because of the techno-economic design using the HOMMER tool. These three primary outcomes were chosen for their resource availability and cost-effectiveness. When several input parameters such as annual average load, scaled annual average solar resource, wind speed, annual real interest rate, and solar PV and wind component prices were varied, the sensitivity analysis revealed that hybrid system solar PV-wind renewable resource has a high potential, especially if the location is remote from a grid source.

1. Introduction

The world was taken aback by technological advancement and the digital revolution, both of which were expected to invest heavily in resolving the world's numerous problems, particularly those in remote areas. Despite the advancements in technology, many developing and underdeveloped countries continue to struggle with a lack of necessities. Electricity was first made available to the public in the mid-nineteenth century in the United Kingdom, and it spread rapidly throughout Europe and the United States. According to the most recent statistics, 1.5 billion people worldwide do not have electricity or have limited access (Doll and Pachauri, 2010). Another billion people live in areas where electricity is not reliable. Some people have electricity but can't use it because they can't afford it (Harris, 2017). In 2011, the United Nations launched the world's first major campaign to end energy insecurity. Securing equal access to modern energy services and

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increasing the global share of green energy are two of the three goals of the Sustainable Energy for All (SE4All) initiative by 2030 (Bank et al., 2015). Rural areas in Sub-Saharan Africa (0.590 billion people), South Asia (0.610 billion people), and East Asia (0.0195 billion people) are home to most people who lack access to electricity (Green et al., 2021). Data on non-electrified people, on the other hand, is minimal. In its 2002 "World Energy Outlook," the International Energy Agency (IEA) aimed to provide accurate global data to contain the world's unelectrified population (Doll and Pachauri, 2010). Sub-Saharan Africa's rural electrification rates are pitiful when compared to the rest of the world (Almaktar and Shaaban, 2021). On the other hand, Libya contributes a negligible percentage to this rate due to its small population. Libya's rural areas consist of six villages that lack electricity (Yahaya et al., 2020). Due to the estimated time required for the depletion of conventional fossil fuels and the pollution caused by emissions has become a significant issue in the modern world, and the need for alternative energy sources has become a big deal. While fossil fuels are necessary for transportation, sustainable energy sources are more appealing in the long run (Ehsani and Al-masri, 2016; Abdelnaser et al., 2021).

As a result, Renewable energy is being replaced in many devolved countries. RE is a long-term renewable solution that will eventually replace our dependence on fossil fuels and raise living standards. In 2017, renewable energy sources contributed 26.5% to global electricity demand (Almaktar and Shaaban, 2021). RE is a long-term renewable energy solution that will eventually eliminate our reliance on fossil fuels and improve living standards. Renewable energy sources supplied 26.5 % of global electricity demand in 2017. At the end of 2019, have installed renewable energy capacity totaled 2,588 GW, an increase of 8.4 % over the same period in 2018. Additionally, renewable energy production will account for more than half of all electricity generation in California and New York by 2030 (Saber et al., 2021). As a result, renewable energy sources are being phased out in several devolved countries. Libya has many real estate opportunities due to its unique geographic location. The Ministry of Electricity and Renewable Energy (MERE) established the REAOL in 2007 to evaluate and support renewable energy sources through research and development of emerging technologies to realize some of their potential (Almaktar and Shaaban, 2021).

In many rural/remote areas of Libya, electricity is unavailable. The significant gap between demand and supply continues to grow more expansive, with 2018 demand expected to reach 8000 megawatts (MW). According to reports from the energy and electricity ministry, the national grid generated 6000 MW. Various social and geographical factors constrain electricity access, and rural regions share the same geography, climate, and social status indicators. Due to the higher costs associated with grid extension, these areas do not have a visible option for grid extension. A mini- or micro-scale grid or distributed energy system based on renewable resources may be the answer for powering these rural areas in Libya. However, while providing stable access to electricity in rural regions in Libya may not be feasible if only one energy source is considered, combining renewable energies could provide sustainable electricity and compensate for the non-linearity of alternative resources throughout the year. This study aims to find the most cost-effective ways to get electricity to rural areas in Libya, develop, optimize, and analyze the sensitivity of a renewable energy system in the chosen region, and look at the least-cost technology options.

2. Materials and Methods

This section discussed the procedures followed to complete the project's tasks. The method for calculating the load demand for the research region is demonstrated, as are the methods for designing, configuring, and analyzing solar photovoltaic and wind turbine systems. The study's overall framework is depicted in Figure 1.

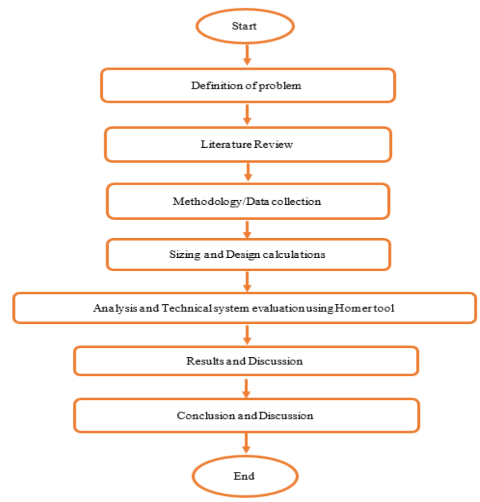

Figure 1 The overall framework of study

2.1 Assessment of Renewable Energy Resources

Any self-contained renewable energy source must undergo a thorough feasibility analysis and a precise design process. A feasible system is practical, cost-effective, and simple to install and one that adheres to the constraints. The system design specifies the overall parameters of the components based on the RES technology's technical and economic viability in the specified location. In comparison, the feasibility study has an impact on the RES technology that is selected for the specified location. Additionally, the feasibility analysis considers potential sites' technical and economic viability. The evaluation of relevant renewable energy technology should be based on precise data and information collected from all possible renewable energy sources via meteorological, solar radiation, and other renewable energy source measurements (Ssekulima et al., 2016). The most critical technical factor to consider when comparing various systems is reliability, which ensures that load demand is met within the constraints of available generated and stored electrical energy. Numerous variables can affect the energy consumption and its utilization of villages such as:

- The number of houses there are, and how many people live in each one.
- Electrical equipment is used in homes daily.
- Change throughout the year.
- Industries and sources of income to the residents of the village.

2.2 Systematic Framework

This section will examine the methodology used to develop the strategy, the analysis performed, and the decisions made. It details the entire process, from off-grid energy generation selection to HOMER analysis and its relationship to various factors. Figure 2 illustrates the numerous steps involved in selecting off-grid electricity generation for a remote village location. Following a preliminary assessment of the village, energy consumption and sources are determined. Following the initial evaluation of the settlement, the available energy sources and usages were determined.

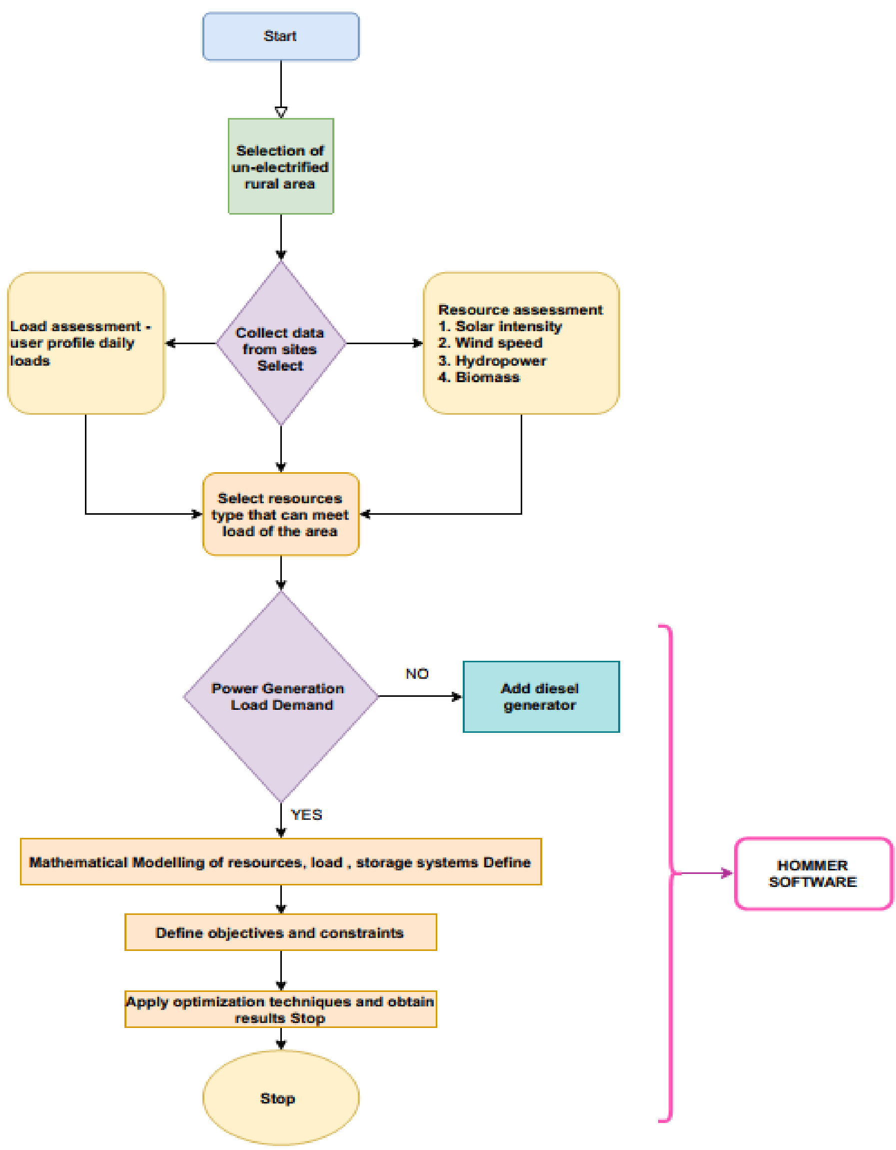

Figure 2 Systematic framework for off-grid electricity generation

2.3 The location

Entellat is a rural village in Libya located at 30° 51.2'N 20° 35.2'E latitude. Around 900 people live in the village, including 70 houses, one primary health care centre, one primary school, one mosque, and three minimarts. This project aims to detail the design and implementation of a sustainable off-grid rural energy generation plan for electrifying this village. The settlement is accessible only via the road from Ajdabiya city. It is approximately

45 kilometres. Despite its proximity to Ajdabiya, the village remains without electricity. Due to the town's remote location from the national electricity grid. However, the town is powered by a small generator. Nonetheless, this generator is insufficient for daily needs and is prone to mechanical failure. As a result, it is ideal for providing electricity via an off-grid renewable energy-based power system.

2.4 Data Collection

The data for this study were gathered through technical inspections and my familiarity with the research field. The anticipated load was calculated using assumptions about the primary devices in rural households and the appliances used in nearby villages connected to the national grid. The cost of the equipment (photovoltaic panel, wind turbine, diesel generator, and battery) was calculated by averaging market prices from local retailers and suppliers. Light bulbs, televisions, refrigerators, fans, air conditioning, radios, and phone chargers are evaluated. Assume that the hamlet is electrified due to the completion of this project. In that case, the study area is unlikely to expand beyond the bare minimum electrical requirements for lighting and entertainment.

2.5 HOMER Software Brief Description

HOMER Pro® is a microgrid management software developed by HOMER Energy (Homer, 2021). It has become the global standard for optimizing microgrid design in all sectors, from village electricity and island utilities to grid-connected campuses and military locations. These choices are complicated by the vast array of technological possibilities, pricing variations, and available energy resources. The optimization and sensitivity analysis techniques built into HOMER simplify analyzing the numerous alternative system configurations. HOMER simulates the characteristics of power systems and their life cycle costs based on the user-supplied data. The total cost of installing and operating a system over a specified time is the life cycle cost. Depending on the user's requirements, the user may compare several design options based on their technical and economic advantages as determined by the simulation results. HOMER can simulate both on-grid and off-grid micro power systems that serve electrical loads (Nebey, 2021). HOMER affects energy systems, visualizes cost-effective system designs, and performs sensitivity analysis. HOMER is responsible for three primary functions.

- HOMER simulates the operation of a system by calculating energy balances at each time step (interval) over a year. It affects the performance of a particular micropower system configuration hour by hour throughout the year to determine its technical feasibility and life cycle cost.
- Optimization: Configurations with the lowest total cost of ownership. It simulates many different system configurations to determine the one that best meets the technical constraints while maintaining the lowest life cycle cost. The optimization process identifies the optimal system configuration; in HOMER, the optimal system configuration satisfies the user-specified conditions at the lowest total net present price (NPC).
- Sensitivity Analysis: Examines the effects of the uncertainty associated with sensitivity variables such as the yearly real interest rate and component pricing. HOMER performs multiple optimizations under various input assumptions to assess the effects of model delay or input changes. Additionally, this analysis aids in determining the impact of uncertainty or changes in variables over which the designer has no control.

Figure 3 illustrates various standard RES components, including a generator, a solar panel, a wind turbine, a storage battery, a converter (inverter), and hydropower. Our selection will be based on the resources available in the chosen location, including a generator, a solar panel, a wind turbine, a storage battery, and a converter.

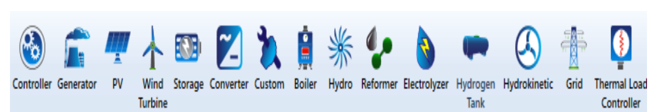

Figure 3 Input Window in HOMER for Components Selection

2.6 Electricity Load Demand & Inputs Estimated for the Selected Area

Simple appliances are used in this rural location. Electricity is needed in this community primarily for lights, television, fans, air conditioning, and refrigerators, among other things, as shown in Table 1 below. Based on the information collected on the villagers, the below load profile was built regarding the intended and prospective use of electrical appliances

Table 1 Detailed load data of village consumers

Time	Load								
	Lamp1 (15W)	Lamp2 (15W)	Lamp3 (15W)	Mobile phone and charger (15W)	Radio and Tape Player (50W)	Air conditioning (800W)	Refrigerator (150W)	TV (80W)	Total power consumption per day (kWh/day)
00:00-01:00	15		15	15			150		195
01:00-02:00	15		15	15			150		195
02:00-03:00	15		15	15			150		195
03:00-04:00	15		15	15			150		195

04:00-05:00	15		15	15			150		195
05:00-06:00	15		15	15			150		195
06:00-07:00			15	15			150		180
07:00-08:00				15			150		165
08:00-09:00					50	800	150	80	1080
09:00-10:00					50	800	150	80	1080
10:00-11:00					50	800	150	80	1080
11:00-12:00					50	800	150	80	1080
12:00-13:00					50	800	150	80	1080
13:00-14:00					50	800	150	80	1080
14:00-15:00					50	800	150	80	1080
15:00-16:00					50	800	150	80	1080
16:00-17:00					50		150	80	280
17:00-18:00				15	50		150	80	295
18:00-19:00	15	15		15	50		150	80	325
19:00-20:00	15	15		15	50		150	80	325
20:00-21:00	15	15		15	50		150	80	325
21:00-22:00	15	15		15	50		150	80	325
22:00-23:00	15	15		15			150	80	275
23:00-24:00	15	15		15			150		195

Total Load Per day (kW) for one household Energy consumption Per day (kWh/day) 12.500KW. Total Load Per day (kW) for 70 households Energy consumption Per day (kWh/day) 12.500*70 = 875.000

Figure 4 shows that the usage of electricity is the lowest during the night from midnight to 8 am. There is an increase in usage electricity from 9 am to 5 pm which is lunch hour for the work of the villagers. From 9 am to 5 p.m., the peak hours of power usage span around 8 hours, with loads coming from the refrigerator, television, radio, and air conditioning. The community uses 12500 Whr per day on average.

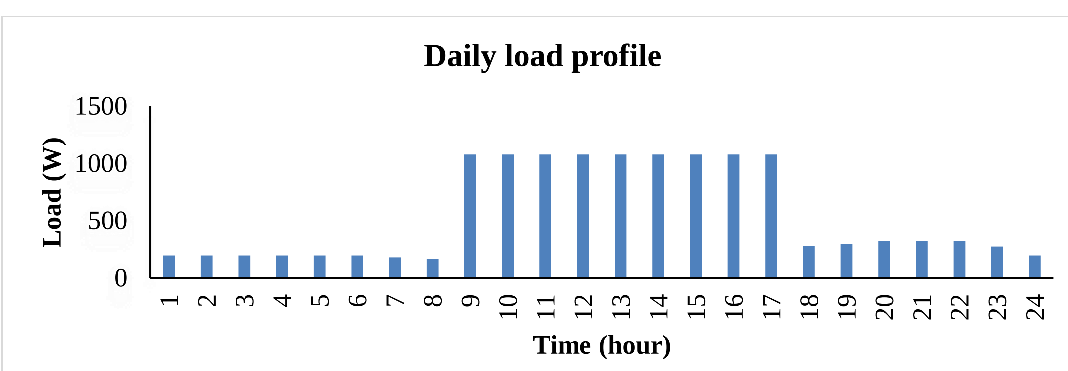

Figure 4 Daily Average from HOMER Window

2.7 Solar (PV) Panel Power, Specifications, And Selection

The system's PV array output is influenced by cell temperature and solar irradiance; a rise in temperature lowers the PV array's output and vice versa, whilst a rise in irradiance raises the power output (Akinyele et al., 2015). In the simulation study, the PV array power was computed using Eq. (2.1) (Nebey, 2021).

$$P_{pv} = Y_{pv} * Y_{pv} \left(\frac{GT}{GT_{stc}}\right) * [1 + \alpha P[T_c - T_{c,stc}] \quad (2.1)$$

Y_{pv}= The rated capacity of the PV array.

f_{pv} = The PV derating factor [%].

GT = The solar radiation incident on the PV array in the current time step [kW/m^2].

GT_stc = The incident radiation at standard test conditions [1 kW/m^2].

αP = The temperature coefficient of power [%/°C].

T_c = The PV cell temperature in the current time step [°C].

T_s, stc = The PV cell temperature under standard test conditions [25°C].

As input to the simulation, Homer needs information on the PV array, such as the capital cost, replacement cost, operation and maintenance cost, the size range of the PV array, and the lifetime of the PV array. The price of a standalone photovoltaic system in Libya ranges from LD 1500 to LD 8000 kW^{-1}. Table 2 below lists the PV input data utilized in the design and optimization. Some of the specifications of the PV are in the database of the software while the price and the quantity are selected based on the needs of the project (Wijeratne et al., 2019).

Table 2 Input data for solar panel in HOMER

S/No	Description	Values	Unit
1	PV capacity	345	W
2	Capital cost	120	LD
3	Replacement cost	120	LD
4	Operating and maintenance cost	5	LD
5	Lifetime	25	Year
6	Temperature Coefficient	-0.390	% / ^{0}C
7	Efficiency	17.8	%

2.8 Batteries Specifications and Selection

A storage unit is required for a microgrid or off-grid system to store surplus power generated from a renewable resource for usage at night. Because sun radiation disappears at night and wind speed varies from time to time, batteries act as a backup for the system in the event of a power outage or when a steady voltage is necessary, such as during peak loads (Ugirimbabazi, 2015). The maximum charging power of the storage bank is limited in three ways by HOMER. The kinetic storage concept is the source of the first constraint. Eq (2.2) gives the maximum amount of power that the two-tank system can absorb:

p_batt,_cmax ,_kbm=(kQ_1 e^(-kΔt)+Qkc(1-e^(-kΔt)))/(1-e^(-kΔt)+c(kΔt-1+e^(-kΔt))) (2.2)

Q_1 = The available energy [kWh] in the storage at the beginning of the time step.
Q= The total amount of energy [kWh] in the storage at the beginning of the time step.
c= The storage capacity ratio [unitless].
k= The storage rate constant [h-1].
Δt= The length of the time step [h].

Table 3 below shows the battery input values utilized in this study, as well as some of the study's parameters. The price is calculated based on local market prices also the number of batteries is set based on the result obtained from the HOMER optimizer.

Table 3 Battery Input Data

S/No	Description	value	unit
1	Quantity of batteries	1	-

2	Cost of capita	600	LD
3	Maximum charge current	279	A
4	Rate constant	0.478	1/hr.

2.9 Converter Selection and Specification

To keep the energy flowing between the AC and DC buses, a power electronic converter is employed. These devices convert DC electricity to AC electricity and offer backup power in the event of a power loss. When an electrical appliance is utilized, it only uses DC power, which necessitates the usage of an inverter with the same nominal voltage as the battery. The converter in a standalone system must be capable of handling the complete quantity of watts that will be consumed at any given moment. In this project, the converter is built on a power unit that has high efficiency and great dependability as shown in Table 4. Eq (2.3) is used to calculate the size of the inverter (In VT) used to convert direct current (DC) from a solar system to alternating current for household appliances.

lnv_T=l_o+3*l_i (2.3)

l_o and l_i describe inductive load

Table 4 Converter Input Data

S/No	Description	Values	Unit
1	Capacity	30	Kw
2	Cost of capital	12000	LD
3	Operating and maintenance	100	LD
4	Lifetime	10	Year

2.10 Wind Turbine Specifications and Selections

A three-step technique is used by HOMER to determine the wind turbine's power output at each time step. First, HOMER determines the wind speed at the wind turbine's hub height. The wind turbine's output power is then calculated at that wind speed and standard air density. Finally, HOMER compensates for the real air density by adjusting the power output value. The hub height wind speed is calculated by HOMER using Eq (2.4).

$$U_{hub} = U_{anem} * \frac{ln(z_{hub}/z_0)}{ln(z_{anem}/z_0)} \quad (2.4)$$

U_{hub} = The wind speed at the hub height of the wind turbine [m/s].
U_{anem}= The wind speed at anemometer height [m/s].
z_{hub} = The hub height of the wind turbine [m].
z_{anem} = The anemometer height [m].
z_0 = The surface roughness length [m].
$ln(..)$ = The natural logarithm.

The SWP25-16TV20 wind turbine has been chosen for the village because, in comparison to other common wind turbines, it can operate at low wind speeds. The details of the selected wind turbine are shown in Table 5.

Table 5 Wind Turbine Technical Data

Description	Value	Unit
Rate Power	25	kW
Rotor Diameter	14/16	M
Design Wind Class	3	-
Storm Survival Speed	60	m/s
Hub Height Offered	15/17/18	m
Cut off wind peed	25	m/s
Rotation per minute	38/50	RPM

2.11 Calculating Net Present Cost (NPC) and Cost of Energy (COE)

2.11. 1 Net Present Cost (NPC)

The present value of all expenses of installing and running the Component over the project lifespan, minus the present value of all revenues earned over the project duration, is the component's net present cost (or life-cycle cost). HOMER determines the net present cost of each component in the system, as well as the total cost of the system. The optimization result was derived using Eq. (2.5 & 2.6) and was based on net present cost (Net, 2021).

$$C_{NPC} = \left(\frac{C_{Annual,Total}}{CRF_{i,N}}\right) \quad (2.5)$$

$$CRF_{i,N} = \frac{i(1+i)^N}{(1+i)^N-1} \quad (2.6)$$

C_{Annual} = The total annualized cost.
$CRF_{(i,N)}$ = The capital recovery factor.
. i = The interest rate.

2.11.2 Cost of Energy

This window shows cash flows as a present value or an annualized cost, with components and cost types classified. The average cost per kilowatt-hour of usable electrical energy generated by the system is known as the cost of energy. It was computed with the help of Eq (2.7).

$$COE = \frac{C_{Annual,Total}}{E_{primary,AC}+E_{primary,DC}} \quad (2.7)$$

COE= The cost of energy.
$E_{primary,AC}$ = AC primary load served.
$E_{primary,DC}$ = DC primary load served.

In HOMER software, if a system can yield low COE values, it is regarded as economically beneficial.

3.0 Results and Discussion

3.1.1 Cost Summary for System 1

The total net present value (NPC) is 98,941.52 LYD, and the cost of energy is 0.1266 LYD. This value gives attention to the project to be funded. The cost of energy is cheaper than the electricity tariff obtained from the national grid for Libyans in the cities. Table 6 illustrates the summary cost of the system. The initial capital cost of this system is 98,941.52 LYD.

The system's optimum and sensitivity results were shown and evaluated for all feasible configurations. In this study, we will initially compare three configurations based on the input and availability of resources, and then compare them with grid extension from the aspect of economics, longevity, and maintenance. Two types of systems would be evaluated in terms of technology and economics.

3.1 Optimized System (PV), Diesel Generator, and Storage Batteries

The primary results of the simulation showed that the optimized system is a hybrid of a diesel generator, solar PV, and storage batteries to meet the load requirements for this village which is estimated by (165.59 kW/d). Figure 5 illustrates the main components of the first optimized system 1.

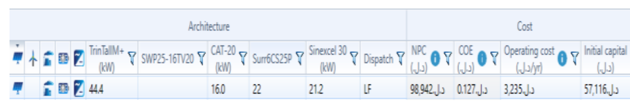

Figure 5 Components of system 1

This system requires 129 PV solar panels to generate a rated capacity of 44.4 kW. This type of PV panel can generate about 85,202 kW/yr with a capacity factor of 21.9%. The PV system in this configuration produces a maximum output of 45.4 kW. Furthermore, this system requires 22 batteries with a string size of 2 to serve the load of the village. These batteries are installed in the 12V bus, and the output is converted by an inverter to an AC. This type of battery generates about 15,363 kW/yr. The main support to the renewable source in this configuration is the diesel generator, which can be used for 363 starts/yr and operate for 858 hrs/yr. The maximum output of this generator is 16 kW. The fuel consumption of this generator reaches 0.398 L/kWh. The configuration requires a converter to transform the DC that comes from PV panels and batteries to AC (Walker and Sernia, 2004). The simulation shows that a 22.6 kW inverter is sufficient to meet the load requirements. This inverter can operate for 8,460 hrs/yr. and converts the energy of 57,013 kWh/yr. The configuration is designed and optimized to meet the peak load which is estimated at 26.27 kW.

Table 6 The cost summary of System 1

S/No	Component/Parameter	Quantity	Unit of scale
1	PV panels	129	kW
2	Batteries	22	-
3	Inverter	1	kW
4	Total NPC	98,941.52	LD
5	Cost of energy	0.1266	LD

The initial capital cost of this system is 98,941.52 LYD. The highest number is coming from the generator purchase cost (Rehman and Al-Hadhrami, 2010). It accounts for about 20,000 LD with 554.59 LYD for maintenance expenses. However, the portion of fuel accounts for about 9,761.49 LYD. This implies that the Generator accounts for a large amount of NPC, with the fuel cost being the largest of the generator sub-costs at 9,761.49 annually. The solar panels take second place from the aspect of expenses of the configuration and the cost is calculated as 15,437 LYD for the initial installation and 8,315.09 LYD for maintenance cost. Batteries come in the third order of the configuration cost, it reaches 13,200 LYD for the purchase cost and 5,688.11 LYD for maintenance and operation costs. The least cost is for the inverter which is calculated by 8,479.21 LYD for initial installation and 1,826.92 for maintenance and operation expenses. From the evaluation, the capacity shortage was calculated as 0.0680 % which gives 41.1 kWhr/yr. Figure 6 shows the capital cost and maintenance expenses for each component in the configuration.

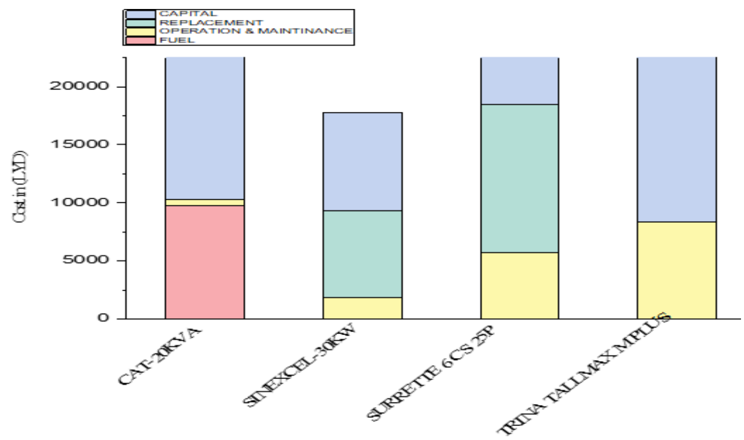

Figure 6 Components Cost of System 1

3.1.2 Electric Production for System 1

The output power in this configuration mostly depends on the PV array which generates 95.7% of the load demand. In other words, PV panels generate 85,202 kWh/yr from the total output of the system which is 88,997 kWh/yr. The generator works as a backup for the configuration in the period when sun irradiation is not sufficient (Abdelshafy et al., 2018). The generator can produce about 3,795 kWh/yr which comprises 4.26 % of the output. The unmet power from this configuration is calculated as 0.291 kWh/yr which is 0.000500%. This percentage is very low, it gives implementation that the system can meet the load of the village. Figure 7 shows the comparison between the power output from each system and the load consumption in 7 days' time step.

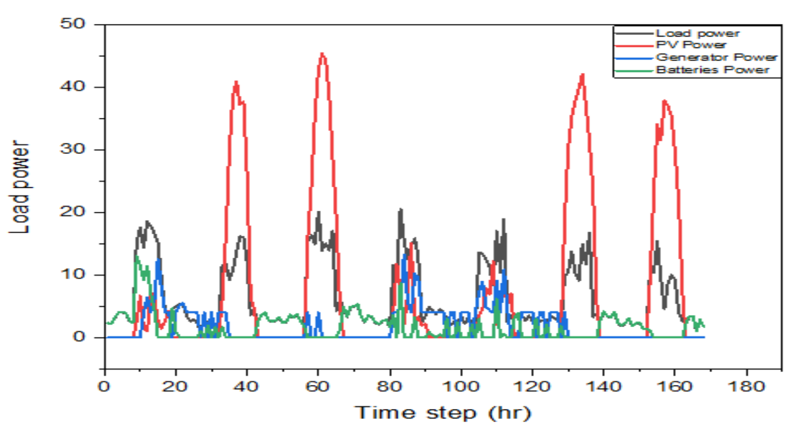

Figure 7 Produced Electricity in System 1

3.2 Optimized System (PV), Diesel Generator, Wind Turbine, and Storage Batteries

This system uses both renewable and non-renewable energy sources to generate electricity. The system consists of solar PV panels, wind turbines, storage batteries, and diesel generators to generate power that meets the load of (165.59 kW/d). Figure 8 illustrates the main components of the system. The system requires 50 solar panels to meet the load required in the village. These PV panels can generate a total output of 33,196 kW/yr with a capacity factor of 21.9%. The total hourly operation of these PV panels is calculated as 4,391 hr/yr. In addition, the configuration takes into consideration 28 batteries in 14 strings to generate an output of 7,863 kW/yr. However, the power loss of batteries is calculated as

1,964 kWh/yr. This system differs from the previous system because it has a wind turbine generator connected to the AC bus. This type of wind generator can produce energy calculated as 24.5 kW. The wind turbine system operates for 7,339 hr/yr which is higher than the operating time of PV panels. This implies that the location is appropriate to install a wind turbine generator and the output power is sufficient to meet the load required (Abohedma and Alshebani, 2010).

TrinTallM+ (kW)	SWP25-16TV20	CAT-20 (kW)	Surr6CS25P	Sinexcel 30 (kW)	Dispatch	NPC (د.ل)	COE (د.ل)	Operating cost (د.ل/yr)	Initial capital (د.ل)
~~14.4~~		~~16.0~~	~~22~~	~~21.2~~	~~LF~~	~~98,942د.ل~~	~~0.127د.ل~~	~~3,235د.ل~~	~~57,116د.ل~~
17.3	1	16.0	28	20.3	LF	105,276د.ل	0.135د.ل	1,883د.ل	80,939د.ل

Figure 8 Main components for System 2

3.2.1 Cost Summary for System 2

This system has a total net present cost (NPC) of 105,276 LYD, and the cost of energy is 0.1347 LYD. This value is higher than the previous project with a low negative environmental impact. The cost of energy slightly increased from the previous project. Table 7 illustrates the summary cost of the system.

Table 7 Summary Cost of System 2

S/No	Component/Parameter	Quantity	Unit of scale
1	PV panels	50	KW
2	Batteries	28	-
3	Inverter	1	Kw
4	Total NPC	105,276	LD
5	Cost of energy	0.1347	LD

The total net present cost (NP) is calculated as 105,276 LYD which is 6.40% higher than the previous system. Despite the slight increase in the energy cost of this system compared to the previous system, the price is still less than the electricity tariff set by the government. The initial cost for purchase the wind turbine is the highest among the other components, the value is estimated at 30,000 LYD. In addition, about 1292.75 is allocated for maintenance and operation expenses. The generator costs 20,000 LYD for initial installation and 69.81 LYD for operation and maintenance. The cost of fuel consumption is calculated as 1,211.84 LYD. In contrast, solar PV panels are the least cost in this system, therefore 50 panels cost 6,014.49 LYD for initial installation and 3,239.69 LYD for operation and maintenance. The additional number of batteries added to this system increases as the number of batteries is required to operate in this system (Williams et al., 2012) . The initial capital of batteries cost 16,800 LYD and 5,355.96 is calculated as operational expenses. From the simulation, the capacity shortage was calculated as 0.00580 % which gives 3.52 kWhr/yr. Figure 9 shows the capital cost and maintenance expenses for each component in the configuration.

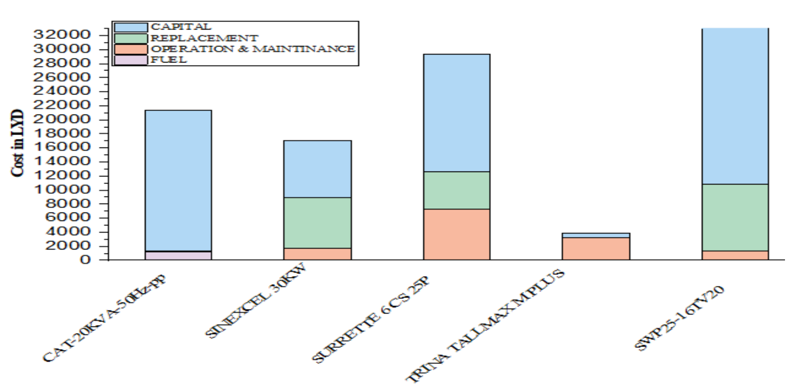

Figure 9 Initial Cost of System 2 Components

3.2.2 Electric Production for System 2

The wind turbine provides 75.9% of the load required in this system, thus the output power is heavily reliant on it. In other words, the wind turbine generates 105,831 kWh/yr of the system's total output of 139,496 kWh/yr. The power obtained from PV panels comprises 23.8% of the total power output produced in this system, it is calculated as 33,196 kWh/yr. The generator supports the system in a time when renewable energy is not sufficient to meet the load required. This generator produces only 0.336% of the power output which gives 469 kWh/yr. The unmet power of this system is 0 which makes it an appropriate system for the village. Figure 10 demonstrates the comparison between the power output from each system and the load consumption in 7 days' time step.

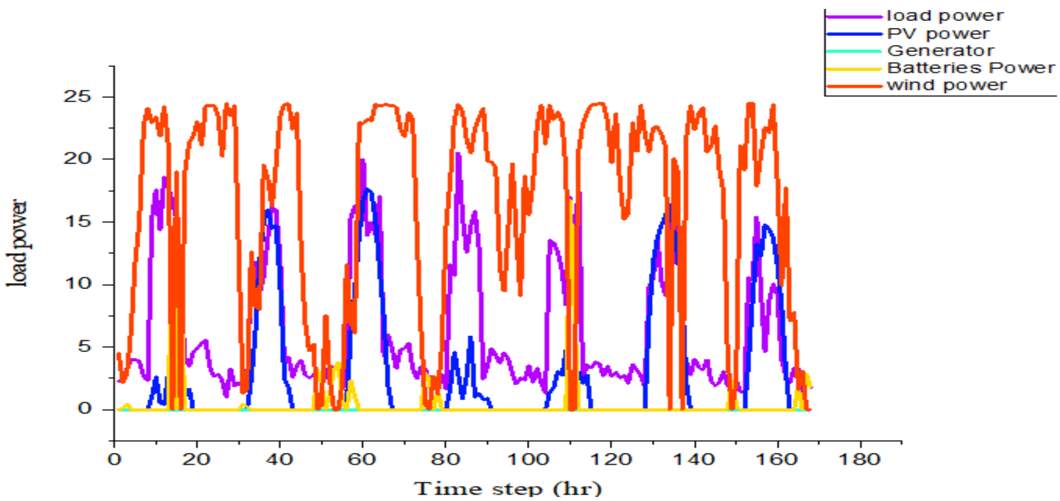

Figure 10 Electricity Produced by System

3.3 Optimized System (PV), Wind Turbine, and battery Storage

The fully renewable system consists of a wind turbine, PV panels, and storage batteries. These components can produce the load required in the village which is calculated as (165.59 kW/d). Figure 11 illustrates the main components used in this configuration. The system needs 220 PV panels to generate power output calculated as 146,063 kW/yr. The capacity factor used in this system for PV panels is 21.9%. The PV solar panels can operate 4,391 hr/yr. This system is supplied with a wind turbine generator which produces total energy calculated as 105,831 kW/yr with a capacity factor of 48.3%. The wind turbine system operates for 7,339 hr/yr to meet the load required for this village. Furthermore, the system contains storage batteries to be used in critical times when renewable sources are not sufficient to generate power. The number of batteries in this configuration has risen compared to the previous two systems, where 48 batteries are used in two strings to generate energy estimated by 4889 kWh/yr. The simulation calculated the losses as 1,222 kWh/yr from batteries. A converter is installed between the AC bus and DC bus to convert the DC that comes from renewable sources machines and the storage batteries (Yamashita et al., 2019). A 24.4 kW inverter is appropriate to this system as the simulation showed. The operational hours of the converter are calculated as 3280 hrs/yr

TrinTallM+ (kW)	SWP25-16TV20	CAT-20 (kW)	Surr6CS25P	Sinexcel 30 (kW)	Dispatch	NPC (د.ل)	COE (د.ل)	Operating cost (د.ل/yr)	Initial capital (د.ل)
44.4		16.0	22	21.2	LF	98,942د.ل	0.127د.ل	3,235د.ل	57,116د.ل
17.3	1	16.0	28	28.3	LF	105,276د.ل	0.135د.ل	1,883د.ل	80,939د.ل
70.1			32	24.4	CC	109,061د.ل	0.140د.ل	3,217د.ل	67,414د.ل
	1	16.0	12	10.7	CC	109,839د.ل	0.141د.ل	3,741د.ل	61,472د.ل
76.1	1		48	24.4	CC	142,091د.ل	0.182د.ل	3,642د.ل	95,014د.ل

Figure 11 Components for System 3

3.3.1 Cost Summary of System 3

The net present cost (NPC) of this configuration is determined as 142,090.70 LYD. The system is costive compared to the previous systems. The advantage of this system is that no production of green gases which affects the environment negatively. The cost of energy is the highest among the optimized systems where the value is calculated as 0.1819 LYD. Table 8 demonstrates the summary cost of the system.

Table 8 The Summary Cost of System 3

S/No	Component/Parameter	Quantity	Unit of scale
1	PV panels	220	KW
2	Batteries	48	-
3	Inverter	1	Kw
4	Total NPC	142,090.70	LD
5	Cost of energy	0.1819	LD

From Table 9 the total net present cost (NPC) is evaluated as 142,090.70 LYD. The system is more expensive than the other two systems. The capital cost of wind turbine system SWP25-16TV20 is 30,000 LYD, while 5% of this number is allocated for the maintenance set as 1,292.75 LYD. The portion of purchase the batteries is evaluated as 28,800 LYD and 12,410 LYD is allocated for maintenance and operation expenses. The least cost of this system is determined for installing the inverter and the value is calculated as 9,750 LYD. This system needs 2,100 LYD for operating and maintaining the converter for 25 years which is the lifetime of the system. The number of solar panels dramatically increased in this configuration due to the massive dependence on renewable resources where 220 PV solar panels are installed in this system with a cost of 26,463.77 LD for capital cost and 14,254.62 LD for operation and maintenance costs. The evaluation shows the capacity shortage as 0.00320% which gives 1.91 kWh/yr. Figure 12 shows the cost summary chart for this system.

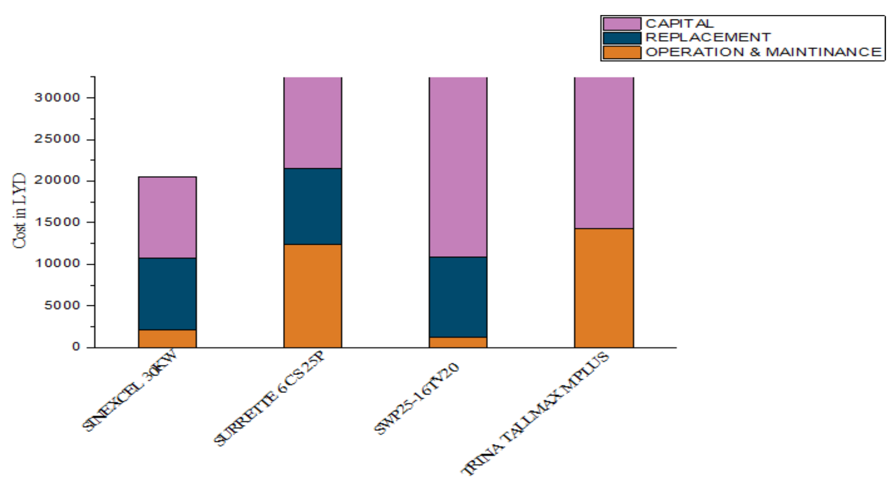

Figure 12 Capital Cost of System 3

3.3.2 *Electric Production for System 3*

In this system, the output power of solar PV panels is considered as the highest output, where the total power extracted is 146,063 kWh/yr which is 58% of the total output of 251,894. The hybrid system uses a wind turbine to generate a power of 105,894 kWh/yr, which means 42% of the output power. The electricity accessed in this system is measured as 189,729 kWhr/yr with max renewable penetration of 13.845%. The unmet power of this system is calculated as 0% which makes the system viable and acceptable. Figure 13 demonstrates the comparison between the power output from each system and the load consumption in 7 days' time step.

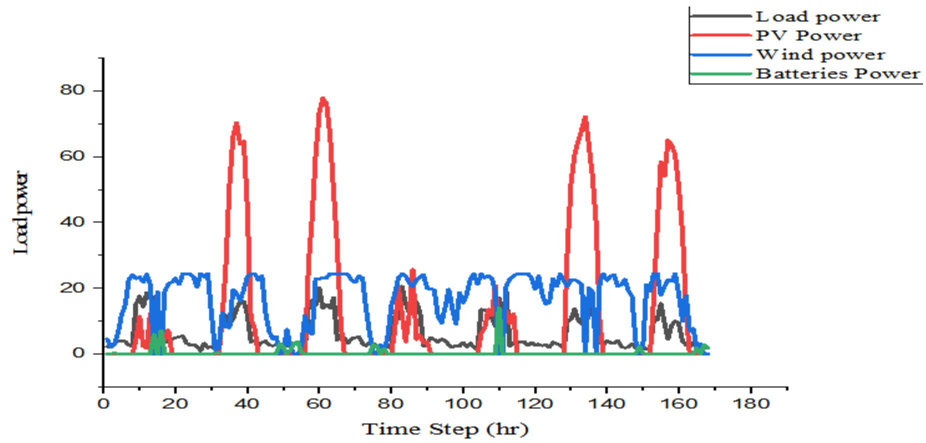

Figure 13 Electricity Produced by System 3 Components

3.4 Cost Summary of Three Systems

Table 9 illustrates the three systems with the cost of the configuration. The least cost is the hybrid system contains diesel generator and solar PV panels, the output power meets the load requirements, and the cost is not high compared to the two other systems. Comparing the three systems with grid extension, the three projects are lower. The gride extension costs 15,000 LYD per 1KM and the village is located 45 KM from the nearest city. The total cost for extending the national grid to the village cost 675,000 LYD.

Table 9 Comparison of Three Systems

System	PV, Diesel generator, Batteries	PV, Wind Turbine, Diesel generator, Batteries	PV, Wind Turbine, Batteries
Total net present cost (NPC)	98,942 LYD	103,884 LYD	140,699 LYD
Levelized cost of energy (COE)	0.1266 LYD	0.1330 LYD	0.1801 LYD
Operating cost	3,235.37 LYD	1,774.89 LYD	3,533.98 LYD
Initial capital cost	57,116 LYD	80,939 LYD	95,014 LYD

5. Conclusion

The simulation result using HOMER software was successfully achieved and presented based on the scope of the project and objectives mentioned in chapter 1. The design and economic evaluation of electrifying 70 residential homes in rural Entellat were given in this research. When comparing the three systems, the hybrid system PV solar panels-wind turbine is the viable system to be considered in this project, because it has low cost, low-capacity shortage, and low emissions. Due to the power production rate and significant economic prospects in energy investment, the design, optimization, and sensitivity findings revealed that renewable energy technology is a feasible way of electrifying Entellat with a COE of 0.1801 LYD. The hybrid PV-diesel generator system, on the other hand, is not recommended since it has a drawback: it has a 0.0680 percent annual capacity shortfall while being the cheapest of the three systems. Because the NPC of a hybrid PV-wind system is much greater than that of a hybrid PV-Wind-Diesel generator and the benefit of a 0.00320 percent annual capacity shortfall, it was chosen as the best system to be deployed in the region.

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