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Design and Analysis of an Islanded Green Energy Station for Highways Emergency Hospitals at Different Locations in Egypt

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A B S T R A C T

The aim of this study is to evaluate the optimum combination of stand-alone hybrid renewable energy systems to match the load demand in a maintainable and cost-effective way. (HOMER) program has been analyzed for three Egyptian key highways. The configuration of the project has been equated and investigated based on the performance of their technical constraints, costs, and the electrical power generation of each source. The results have estimated that the off-grid solar-wind-diesel-battery configuration is the most economical for all the sites amongst other system configurations, with the greatest reliable and resilient solution in terms of net present cost and cost of energy. The study investigates that the average cost of electricity for three sites is 0.322 $/kWh, and the average net present cost of electricity for those sites is 487539 $/Yr, which is not only economical associated to a stand-alone diesel system where the obtained average cost of electricity is 0.727 $ and the net present cost is 1.10 $, but also reasonable carbon dioxide emissions than any used renewable energy systems since they produce 10,663 kg/yr at their optimum, whereas the stand-alone diesel system produces 146978 kg/yr.

1. Introduction

High population growth and dependence on non-renewable fossil energy sources in the Middle East and North Africa are causing energy demand to double by 2020 [1]. Rising global temperatures and melting glaciers are causing sea level rise, threatening coastal cities and low-lying islands. Global renewable generation capacity reached 3,064 GW in 2021, with hydropower being the largest source. Other renewable sources include marine, bioenergy, and geothermal energy[2].

At the COP27 Conference, all countries reaffirmed their commitment to preserve global temperatures rising to 1.5 °C above pre-industrial levels [3]. Egypt targets using this challenge to improve the percentage of green electricity in the country's energy supply to 42% of the grid's supply from renewable power stations by 2035 [4]. Egypt has an abundance of renewable resources, which could make for an interesting solution. In fact, the government has prioritized the usage of renewable energy to meet the rising demand for energy supplies. In Egypt, PV and wind technologies are the primary options for the mix of electricity generation [5]. Even though highways have been extremely developed and enormously extended in Egypt after many years of traffic congestion, there is no doubt that road accidents remain a major source of death and injury around the world. Therefore, prompt healthcare facilities have been critical for saving lives on the road in the first hour after the injury, which is the most vital period that determines the patient's outcome and has been termed the "Golden Hour." Accordingly, building an emergency hospital on the highways has been one of the keys to solving the road's accident problem [6]. By considering that highways are in remote areas Besides that, Egypt has a high level of solar radiation sufficient to allow growing the share of solar power stations in the energy subdivision of the country and a premium average yearly wind speed in the east and north of the country, reaching 8–10 m/s to allow utilizing economic benefits for wind power plants. Therefore, hybrid renewable energy sources are the most effective solution available to face the power source of electricity in healthcare facilities. [7]. A hybrid renewable energy system (HRES) can be considered a convenient solution to achieve a sustainable power output for the system. Several revisions have been conducted on the sizing, operation, and optimization of HRES as a response to rising demands. [8].

Recent years have seen an increase in the number of studies published on hybrid renewable energy systems. A study [9] presents an overview of the literature on rural electrification proves that expanding the grid to remote communities can lead to energy poverty and poor return-on-investment, causing many interventions to focus on urban centres for cheaper and more profitable capacity expansion, A study [10] indicates that the village medical system in Bhubaneswar, Odisha, is proposed to use a hybrid power system with 100% renewable energy, including solar and wind, and 1% battery power, with a 25-year lifespan and minimal upkeep, to meet energy needs, A study [11] describes a green energy system for an island in New Cairo, Egypt, uses photovoltaic solar panels, wind turbines, fuel cells, and batteries. Lead-acid batteries perform best, with FC adding 3.6% energy reduction and 0.2% decrease in unmet demand and capacity shortfalls. The study [12] examines a hybrid power system using a PV/Wind/Diesel system, revealing a 0.36 renewable fraction. However, reliability is uncertain due to solar radiation availability and winter wind speed issues. The least expensive solution is a solar generator and batteries. But study [13] shows that Li-ion batteries are more efficient, longer-lasting, faster, and cost-effective than lead acid batteries for off-grid communities in tropical and semi-tropical developing countries. The study [14] explores the use of combining diesel and PV solar energy in an Abuja hospital, revealing that PV energy is more frequently used than diesel. The system is more environmentally friendly, reducing C02 emissions by over 80% compared to diesel-only systems. A simulation was conducted in study [15] in four regions of Indonesia using different wind turbine capacities. The first region used 20 KW turbines with a 7% wind-energy contribution and fuel diesel cost of $0.47. The second region used 3 KW turbines with a 9% wind-energy contribution and fuel diesel cost of $0.52. The third region used 1 KW turbines with a 4% wind-energy contribution and fuel diesel cost of $0.53. The study [16] evaluates case studies and evaluates their environmental impact on Najaf town, A grid-on system with 81 kW PV, 58 kW Converter, and 108 kW Grid is found suitable for Najaf, costing 186729 over 15 years. This system reduces CO_2 by 174.38%. where in study [17] HOMER Pro off-grid renewable energy solution is used to power a specific load at the KhshU Site in Iran, Where Three fully renewable energy options are used batteries, wind, and solar panels. The PV-battery system has a total NPC of $8,173 and a COE of 0.546 $/kWh.

Design and analysis of the station have been done by HOMER software, created by UL, which is a worldwide standard for energy modelling tools for solar-plus-storage, microgrids, and distributed energy projects. It aids engineers in designing affordable, reliable microgrids using conventional and renewable energy sources. The company offers two platforms: HOMER Grid for solar-plus-storage systems and HOMER Pro for hybrid microgrids. Over 200,000 users have created energy cost savings and feasibility studies using HOMER Pro [18], [19].

This study is done to simulate and get experimental results of a solar-wind hybrid renewable energy system by the following goals.

1. Design an off-grid hybrid renewable energy system for the highway emergency hospital

with the best size and cost-effectiveness with the aid of the HOMER program.

2. The performance of three different locations is estimated based on the minimum value of net present cost (NPC) and levelized cost of energy (LCOE).

3. The proposed system must accomplish reasonable environmental benefits with fewer emissions of CO_2 and more renewable fractions.

- Location's Description

Three separate locations have been selected according to the Egyptian highway network: the International Coastal Road (location A), the EL Galala Road (location B), and the Suez-Sharm El-Sheikh Road (location C). These locations have been chosen in the middle of the road to be easy to arrive at. Table.1 shows location coordinates according to the ATLAS map. Table.2 indicates the location's average solar radiation, wind speed, and temperature profile, respectively.

Table.1 Location's Coordination

SITE NAME	COORDINATE
location A	30º 50′ 26.53″ N 28º 53′ 38.74 ″ E
location B	29º 31′ 57.73″ N 32º 05′ 51.00 ″ E
location C	28º 17′ 55.36″ N 33º 15′ 39.99 ″ E

Table .2 Location's Average Solar Radiation, Wind Speed and Temperature Profile

Location's Data	Location A	Location B	Location C
Road annual average daily solar radiation (kWh.m2/day)	5.44	5.69	5.74
Annual average wind speed (m/s)	5.85	5.81	6.01
Annual average temperature (ºC)	20.23	20.50	22.17

- System Configeration
  - *Electric Load Profile*

A crucial hospital is designed with definite departments to provide safe and effective patient health care, such as a casualty department to deal with emergency conditions, an operating room to deal with urgent surgical operations, an intensive care unit to deal with severe injuries, and moreover, a sterilization department to keep clean and sterile all the used instruments of the hospital to prevent infection from spreading, an obstetrics department to care for women during pregnancy, and a radiology department (X-rays and ultrasound) to provide medical imaging services. In addition, some service units such as a pharmacy, laboratory, control room, laundry, and water pump are also utilized. Table.3 indicates total energy consumption for each department, including lighting, sockets, water heaters, air conditioning, and other equipment's [20], [21].

  - *Design's Tool*

The HOMER program Pro® from HOMER Energy is used to optimize microgrid designs in all fields, whether they are off-grid or linked to the grid. It explores system configurations that are cost-efficiently optimized, simulates energy systems, and offers sensitivity evaluations. In order to simulate how a system will operate, HOMER compares energy stability calculations for each time step of the year, compares the electric and thermal demand loads for that time step to the energy that the system can supply, and furthermore calculates the flow of energy to and from each element of the system[22], [23], [24].

A "dispatch strategy" is a set of guidelines designed to regulate generator and storage bank process whenever there is not enough renewable energy to supply the load, is used by HOMER to make decisions about how to run batteries or generators in systems that have them. HOMER also determines how to operate generators and whether to charge or discharge batteries at each time step. Algorithms for optimization are provided by HOMER Pro. All of the described system configurations are simulated by the original grid search technique. using a unique, derivative-free technique to look for the most affordable system. Following that, HOMER provides a list of configurations arranged by net present cost that can be used to assess various system design options. (also known as life-cycle cost)[25]–[27].

Table.3 Hospital Energy Consumption

Load	**Power Rating (W)**	**Quantity**	**Total Power (W)**	**Total hr/day**	**Total KWhr/day**
Casualty Department	600	1	600	6	3.6
Operation Room	2500	4	10000	2	20
ICU Room	1750	12	21000	6	126
Sterilization Department	1000	2	2000	2	4
Obstetrics Delivery	1100	1	1100	2	2.2
Radiology department	3500	1	3500	3	10.5
Administrative Department	500	1	500	6	3
inpatient rooms	1600	8	12800	6	76.8
Vaccine fridge	60	2	120	24	2.88
Laboratory	1000	1	1000	3	3
Pharmacy	300	1	300	12	3.6
Control Room	1200	1	1200	24	28.8
Laundry	2000	2	4000	3	12
Water Pump	1500	2	3000	4	12
Waiting areas and Corridors	500	1	500	24	12
Total Energy Consumed 320.38					

- *Power Station Component*

Generator

A generic 50 kW fixed capacity generator has been used to meet the peak load, which is 46 kW in our case. In Homer's calculation, the costs are 25000 $ for initial capital, 25000 $ for replacement, 1.500 $/hr for operation and maintenance, and 1 $/L for fuel. The following formula is used by HOMER to determine the fuel consumption rate for a given time step when the generator is operating [28]:

$$F = (F_0) * (Y_{gen}) + (F1) * (P_{gen}) \qquad (1)$$

Where:

F Full consumption rate for each time step in L/hr.

F_0 Fuel curve intercept coefficient for generator in L/hr/kWrated.

Y_{gen} Generator rated capacity in kW.

F1 Fuel curve slope for generator in L/hr/kWoutput.

P_{gen} Generator time step output in kW.

When the generator is not operating within a specific time interval, there is no fuel usage.The proposed generator has been configured and modelled to match the desired peak load demand when there is no power output from the renewable resources under three different dispatch strategies[29].

The load-following strategy (LF) is frequently best in systems that use a lot of renewable energy when the load is occasionally exceeded by the output of renewable energy. A generator only generates as much energy as is required at any one time.

The cycle charging strategy (CC) seems to be most effective in systems with little or no renewable energy since, if a generator must run, it does so at maximum capacity with any excess power being sent to recharge the battery bank.

Combined dispatch strategy (CD) depending on the current net load, choose whether to use the generator to charge the battery. Cycle charging dispatch is used when the net load is low, while load following dispatch is used when the net load is high. In energy access situations, combined dispatch, which is flexible based on high and low demands, can outperform load following or cycle charging and allow for continued use of the generator[30].

PhotoVoltaic Panels

A generic flat-plate photovoltaic (PV) system has been used with a derating factor of 80%, an efficiency of 13%, and a life time of 25 years. It costs 2500 $/KW for initial capital and replacement, and it has been sized according to some variables such as ground reflection, panel slop, and tracking systems. The output power of the PV array is calculated by HOMER using the following equation[31]:

$$P_{pv} = P_{stc} * df * [R/R_{stc}] * [1 + \alpha * (T_c - T_{stc})] \qquad (2)$$

Where:

P_{stc} PV array output power under standard test conditions in KW.

df PV derating factor.

R Current time step's solar radiation incident on the PV array in kW/m2.

R_{stc} Incident radiation at standard test conditions in kW/m2.

α Power temperature coefficient in % °C.

T_c PV cell temperature in the current time step in°C.

T_{stc} PV cell temperature under standard test conditions in 25°C.

Wind Turbine

A generic 10KW with a hub height of 24 m and a life span of 20 years costs $50,000 for initial capital and replacement and $500 per year for operation and maintenance. The power output of a wind turbine is calculated by HOMER using the following equation [32]:

$$P_{wtg} = [\rho/\rho_0] \times P_{wtg,\ stp} \qquad (3)$$

Where:

P_{wtg} Maximum output power for turbine in kW

ρ air definite density in kg/m3

ρ_0 Wind density of the at standard temperature and Pressure.

$P_{wtg,stp}$ Wind turbine power output in kW at standard temperature and pressure.

Storage

A generic 24-volt lithium-ion battery with 1 KW of energy stored has a throughput of 3000 kWh and a lifetime of 15 years; it costs 550 $/KW for initial capital and replacement and 10 $/year for operation and maintenance.

For every time step, HOMER determines how much electricity the storage bank can hold at maximum capacity. When deciding how much extra power a cycle charging generator should supply, or if the storage bank can absorb all of the excess renewable energy that is available, factors like this maximum charge power are taken into account. The maximum charge power changes from one time step to the next based on its current state of charge and recent history of charge and discharge [33].

HOMER imposes three equations to calculate the maximum charge power[34], [35]

$$P_{cb,max1} = \frac{k * Q1 * e^{-k\Delta t} + Qkc * (1 - e^{-k\Delta t})}{1 - e^{-k\Delta t} + c * (k\Delta t - 1 + e^{-k\Delta t})} \qquad (4)$$

Where:

$P_{cb,max1}$ Maximum amount of power that can be absorbed by the two-tank system.

Q1 Available energy in kWh in the storage at the beginning of the time step.

Q Total amount of energy in kWh in the storage at the beginning of the time step.

c Storage capacity ratio.

k Storage rate constant [h-1].

Δt Length of the time step in h.

$$P_{cb,max2} = \frac{(1-e^{-\alpha\Delta t})*(Q2-Q)}{\Delta t} \quad (5)$$

Where:

$P_{cb,max2}$ Storage maximum charge rate.

Q2 storage bank total capacity in kWh.

α Storage's maximum charge rate in A/Ah.

$$P_{cb,max3} = \frac{N*I*V}{1000} \quad (6)$$

Where:

$P_{cb,max3}$ Maximum storage bank charge power corresponding to this maximum charge current

N Number of batteries in the storage bank.

I Storage's maximum charge current in A.

V Storage's nominal voltage in V.

HOMER sets the maximum storage charge power equal to the least of the values of 4,5,6 . Assuming each applies after charging losses, hence:

$$P_{cb.cmax} = MIN\ (P_{b.max1}, P_{b.max2}, P_{b.max3})/\eta_{b,c} \quad (7)$$

Where:

$P_{cb.cmax}$ Maximum storage charge power.

$\eta_{b,c}$ Battery charge efficiency.

The following equation determines the maximum power that the storage bank may discharge over a certain period of time:

$$P_{dcb,max1} = \frac{-k*c*Qm+k*Q1*e^{-k\Delta t}+Q*k*c*(1-e^{-k\Delta t})}{1-e^{-k\Delta t}+c*(k\Delta t-1+e^{-k\Delta t})} \quad (8)$$

Where:

Q1 Available energyin kWh in the Storage Component at the beginning of the time step.

Q Total amount of energy in kWh in the Storage Component at the beginning of the time step.

Qm Storage bank total capacity in kWh.

The maximum discharge power of the storage bank is determined by the following equation because HOMER considers that the discharging losses happen after the energy exits the two-tank system:

$$P_{dcb.cmax} = P_{dcb,max1} * \eta_{b,c} \quad (9)$$

(5) Converter

A generic system converter has an efficiency of 95%, a lifetime of 15 years, and costs $300/KW for initial capital and replacement, with no operation or maintenance costs.

In relation to the input power (P_{input}) and output power (P_{output}), the efficiency of the converter (η_{con}) may be roughly calculated using the following equation [36]:

$$\eta_{con} = P_{output} / P_{input} \quad (10)$$

- *Economic calculations*

HOMER Pro® has performed many calculations to obtain the results of the economics of the proposed system and the cases compared with it. The optimum economic metrics which draws attention are:

Simple payback (SP)

The amount of years at which the overall cash flow difference between the current system and the base case system turns positive. The payback gives an idea of how long it would take to make up the investment cost variance between the current system and the best-case scenario[37].

Internal Rate of Return (IRR)

the discount rate at which the net present costs of the current system and the base case are equal. The discount rate that brings the present value of the difference between the two cash flow sequences to zero is used by HOMER to compute the internal rate of return [38].

Return on Investment (ROI)

The difference between the capital cost and the nominal cash flow difference on an annualized basis over the project's lifetime[39].

Levelized Cost of Energy (LCOE)

The promising key parameter to evaluate the production of energy for any systems including wind and solar-PV. LCOE is the system's average cost per kWh ($/kWh) of beneficial electricity generated and can be represented by the following equation[40]:

$$LCOE = \frac{\textbf{Total Life Cycle Cost}}{\textbf{Annual energy output of the system } (\frac{KWh}{yr})} \quad (11)$$

Where total life cycle cost is the total of the annual operation and maintenance costs, the annual cost of replacing system components, and the annual capital cost of the system components.

Net Present Cost (NPC)

the discrepancy between the lifetime present value of all earnings and expenses for the system. Expenses include fuel expenses, fuel-related fines for emissions, replacement costs, operations and maintenance costs, and the cost of grid power. There are two sources of income: salvage value and grid sales money. The total NPC is calculated by adding the total discounted cash flows for each year of the project's lifespan [41].

$$NPC = \frac{\textbf{Total Life Cycle Cost}}{\textbf{CRF}} \quad (12)$$

$$CRF = [r(1+r) n] / [(1+r) n -1] \quad (13)$$

Where:

r Rate of interest in %.

n Lifetime of the project.

CRF Capital recovery factor has been used to convert the initial investment cost to annual capital cost.

Salvage value (SV)

The value that a power system component still has at the end of the project's lifecycle. The salvage value of a component is directly proportional to its enduring life because HOMER assumes linear depreciation of its components. Additionally, it is predicated that the salvage value is determined by replacement costs as opposed to initial capital expenditures. HOMER uses the following equation to determine salvage value[42].

$$S = Crep * (R_{rem} / R_{comp}) \quad (14)$$

Where:

C_{rep} cost of replacement in $.

R_{rem} Maximum amount of power that can be absorbed by

the two-tank system.

R_{comp} Component lifetime in yr.

$$R_{rem} = R_{comp} - (R_{proj} - R_{rep}) \quad (15)$$

Where:

R_{proj} Project lifetime in yr.

$$R_{rep} = R_{comp} * INT (R_{proj} / R_{comp}) \quad (16)$$

Where:

INT () a function that returns the integer amount of a real number.

- *Emissions and Renewable Fraction Assessments*

The renewable fraction (RF) is the percentage of energy from renewable sources that was used to power the load. And whenever RF increases the CO2 emissions decrease and vice versa [43], [44].

$$RF = 1- [E_{nonren} + H_{nonren}]/[E_{serv} + H_{serv}] \quad (17)$$

Where:

E_{nonren} Nonrenewable electrical production in kWh/yr.

H_{nonren} Nonrenewable thermal production in kWh/yr.

E_{serv} Total electrical load served in kWh/yr.

H_{serv} Total thermal load served in kWh/yr.

2. Results and Discussion

Homer has run many feasible complex simulations of a hybrid electrical system's energy data and system components to control the best size of every component to trade-off between cost and emission and achieve the least-cost solution and most effective risk-moderation strategies [45]. The power station component of the proposed system is seen in fig.1 [46].

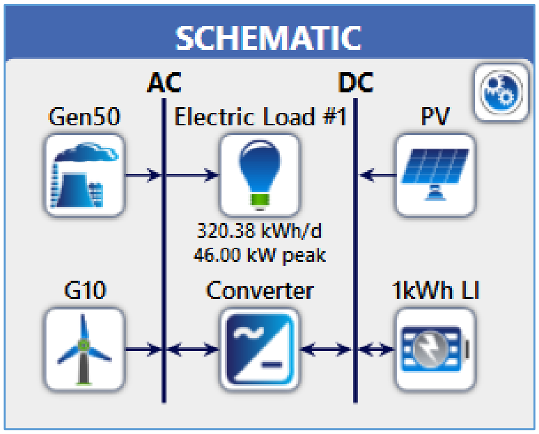


Fig.1 power station component.

The proposed system consists of solar panels, wind turbines, battery storage, and a diesel generator used as a backup system to supply electricity continuously at night or during periods of low wind. The proposed off grid is intended to supply the hospital for the three locations on the highway as a solution to the electricity shortage issue brought on by dependence on expensive diesel and expensive transportation[41]. Using HOMER software, the proposed system's optimal sizing and operation are carried out [47]. The economic optimization of several configurations has been completed using the HOMER software package. It aims to identify the ideal configuration (i.e., the proposed system) for producing electrical power in each location The analysis's goal is to evaluate the proposed configurations' technical and financial viability with respect to another cases [48]. Simulations were performed with Homer software for all components using two scenarios for all locations.[49].

1) **First Scenario**

This scenario has been done with two strategy controllers (LF and CC). Table.4 and Table.5 show the component details of Location A, Location B, and Location C for the proposed system (1) and the base case (1), respectively.

2) **Second Scenario**

This scenario has been done with all strategy controllers (LF, CC, and CD). Table.6 and Table.7 show the component details of Location A, Location B, and Location C for the proposed system (2) and the base case (2), respectively.

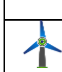
The scenarios have been analyzed and discussed in economic parameters and emissions as follows:

A. Economic Comparitive

Table.8 indicates that for the first scenario, by adding 1.0 kW of PV, 132 kWh of battery capacity, and 10 kW of wind generation capacity, this would reduce the operating costs for location A to $13320 per year. The investment has a payback of 2.0 years and an IRR of 48%. Furthermore, NPC was reduced from $1.15 million to $494901, initial capital was reduced from $197000 to $322700, and LCOE was reduced from $0.763/kWh to $0.327/kWh for the same location. Likewise, for location B, the operating costs were reduced to $12887/yr., the investment had a payback of 2.4 years and an IRR of 41%, the NPC was reduced to $511602, the initial capital was reduced to $345000, and the LCOE was reduced to $0.338/kWh for the same location. For location C, the operating costs were reduced to $11810/yr., the investment had a payback of 2.2 years and an IRR of 45%, the NPC was reduced to $487273, the initial capital was reduced to $334600, and the LCOE was reduced to $0.322/kWh for the same location.

In the second scenario, as shown in Table.9, by adding 56.2 kW of PV, 68 kWh of battery capacity, and 10 kW of wind generation capacity. This would reduce the operating costs to $17282/year for location A. The investment has a payback of 3.6 years and an IRR of 28 %. Furthermore, NPC decreased from $1.10 million to $489.538, initial capital increased from $25000 to $266.129, and LCOE decreased from $0.727/kWh to $0.324/kWh for the same location. Likewise, for location B, the operating costs were reduced to $17617/year. The investment has a payback of 3.5 years and an IRR of 28%. Furthermore, NPC decreased from $1.10 million to $491589, initial capital increased from $25000 to $263840, and LCOE decreased from $0.727/kWh to $0.325/kWh for the same location. For location C, the operating costs were reduced to $12850/yr. The investment has a payback of 3.8 years and an IRR of 26%. Furthermore, NPC decreased from $1.10 million to $468242, initial capital increased from $25000 to $302117, and LCOE decreased from $0.727/kWh to $0.310/kWh.

Table.4 Locations components detail for the first scenario proposed system

Component	location A	location B	location C
	65 KW	66 KW	66 KW
	10 KW	10 KW	10 KW
	50 KW	50 KW	50 KW

	132 KWh	168 KWh	148 KWh
	42 KW	42 KW	44 KW
	LF	CC	LF

Table.5 Locations components detail for the first scenario base case

Component	location A	location B	location C
	64 KW	64 KW	64 KW
	50 KW	50 KW	50 KW
	40 KW	41 KW	43 KW
	CC	CC	CC

Table.6 Locations components detail for the second scenario proposed system

Component	location A	location B	location C
	56.2 KW	56 KW	57.7 KW
	10 KW	10 KW	10 KW
	50 KW	50 KW	50 KW
	68 KWh	64 KWh	128 KWh
	44.3 KW	45.3 KW	41.6 KW
	CD	CD	CD

Table.7 Locations components detail for the second scenario base case

Component	location A	location B	location C
	50 KW	50 KW	50 KW
	CC	CC	CC

Table.8 First Scenario Economic Metric

Economic Metric	location A	location B	location C
IRR	48%	41%	45%
ROI	44%	37%	41%
SP	2 yr	2.4 yr	2.2 yr

Table.9 Second Scenario Economic Metric

Economic Metric	location A	location B	location C
IRR	28%	28%	26%
ROI	23%	23%	21%
SP	3.6 yr	3.5 yr	3.8 yr

The Simulation Results window provides information on the system's yearly electrical energy production and consumption.

. **For the first scenario** at location A, the total energy production is 149939 kWh/yr, with excess electricity of 17.1%, zero unmet electric load, and zero shortage capacity in renewables. Most of the energy production comes from photovoltaic power, with 74.5%, while the generator contributes 9.48% and the wind turbine 16%, with a renewable fraction of 87.9%. The fuel costs $72730.37, and the salvage value is $16676.86. but the total energy production for location B is 145953 kWh/yr, with excess electricity of 13.6%, zero unmet electric load, and zero shortage capacity renewable part. Most of the energy production comes from photovoltaic power, with 73.6%, while the generator contributes 13.5% and the wind turbine 12.9%, with a renewable fraction of 83.2%. The fuel costs $78322.37, and the salvage value is $18036.30. And the total energy production for location C is 150816 kWh/yr, with excess electricity of 17.2%, zero unmet electric load, and zero shortage capacity renewable part. Most of the energy production comes from photovoltaic power, with 79.3%, while the generator contributes 7.35% and the wind turbine 13.3%, with a renewable fraction of 90.5%. The fuel costs $56952.36, and the salvage value is $19903.39.

For the second scenario at location A, the total energy production is 149645 KWh/yr with excess electricity 16.4%, zero unmet electric load and zero shortage capacity renewable part. Most of the energy production comes from photovoltaic power with 64.6%, while the generator contributes 19.4% and the wind turbine 16% with renewable fraction 75.1%. The fuel costs $120574.76 and the salvage value is $18492.65.

while the total energy production for location B is 144637 kWh/yr with excess electricity 13.4%, zero unmet electric load and zero shortage capacity renewable part. Most of the energy production comes from photovoltaic power with 63.1%, while the generator contributes 20.7% and the wind turbine 16.3% with renewable fraction 74.4%. The fuel cost $123663.65 and the salvage value is $16288.96.

but the total energy production for location C is 148949 KWh/yr with excess electricity 15.7%, zero unmet electric load and zero shortage capacity renewable part. Most of the energy production comes from photovoltaic power with 70.2%, while the generator contributes 13% and the wind turbine 16.8% with renewable fraction 83.4%. The fuel cost $79552.78 and the salvage value is $27190.72.

The study of three locations according to Scenario's analyses 1 and 2 cleared that, despite the high initial cost of proposed system 1 (Scenario 1 proposed system) and proposed system 2 (Scenario 2 proposed system), with respect to base case 1 (Scenario 1 base case) and base case 2 (Scenario 2 base case), see figure.5 but the operating, maintenance, and NPC are low; see Figures.2,3. LCOE is approximately similar in the two scenarios and lower than the base case in two scenarios too; see figure.4 The use of a CDS controller reduces the capacity of the solar panel from 65 KW, 66 KW, and 66 KW for locations A, B, and C, respectively, in scenario 1 to 56.2 KW, 56 KW, and 57.7 KW for locations A, B, and C, respectively, in scenario 2, and minimizes the storage capacity from 132 kWh, 168 kWh, and 148 kWh for locations A, B, and C, respectively, in scenario 1 to 68 kWh, 64 kWh, and 128 kWh for locations A, B, and C, respectively, in scenario 2. This has an effect directly on ICC reduction; see Figure.5.

B. Emissions and Renewable Fraction Assessments

The study developed a proposed system 1 at location A, location B, and location C was 87.9%, 83.2%, and 90.5%, respectively, which is more than base case 1 for the same site (1.03%, 0.876%, and 1.12%, respectively) and a proposed system 2 at location A, location B, and location C was 75.1%, 89.7%, and 91.2%, respectively, which is more than base case 2 for the same site (zero renewable fraction).

This result points to the CO2 emissions, which are 14728 kg/yr, 15861 kg/yr, and 11533 kg/yr, respectively, for the three locations for the proposed system 1. and 24417 kg/yr, 12578 kg/yr, and 10663 kg/yr, respectively for the proposed system 2. That is less than base case 1, which is 120536 kg/yr for location A, 120671 kg/yr for location B, and 120459 kg/yr for location C, and less than base case2 which is 224417 kg/yr for all locations.

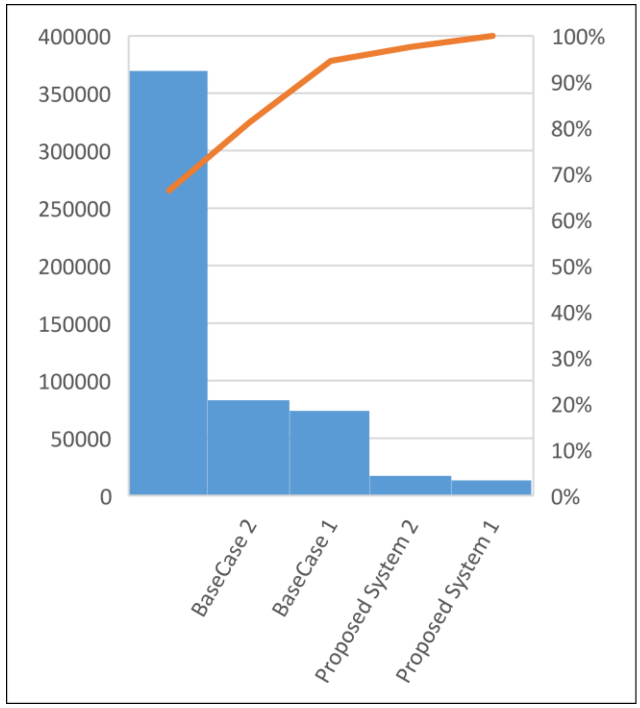


Fig.2 Operations and Maintenance Cost Comparative

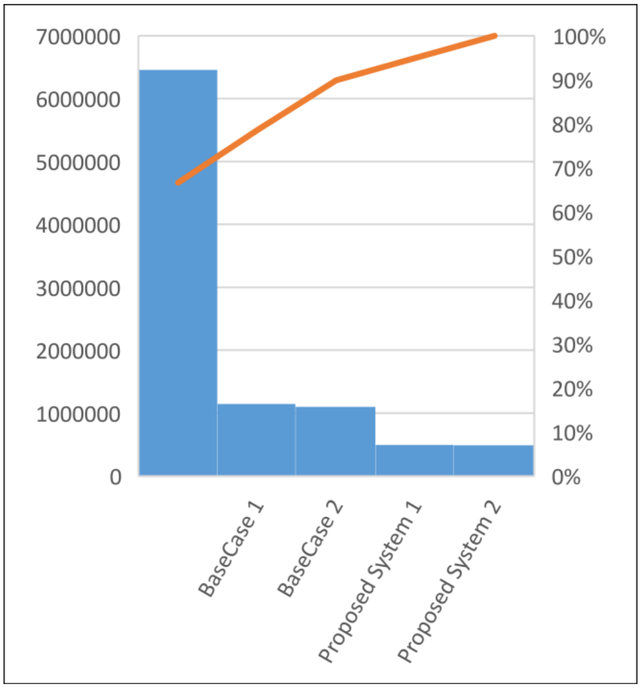


Fig.3 Net Present Cost Comparative

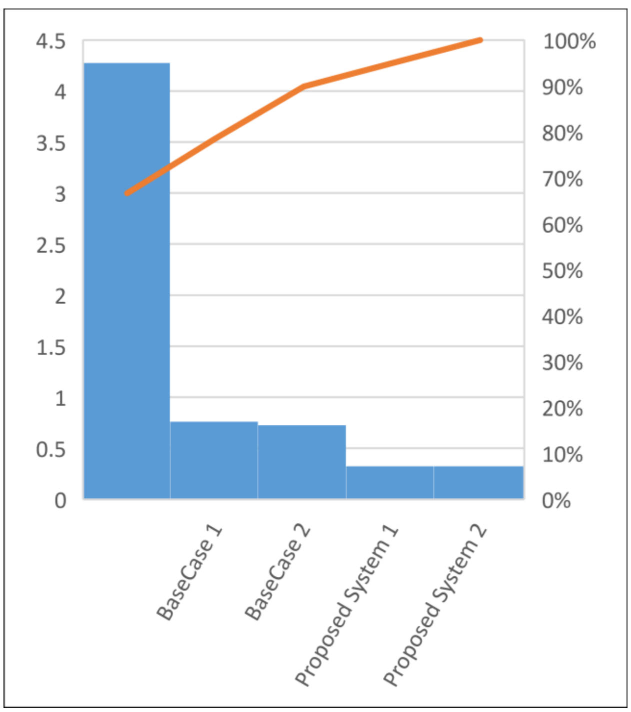


Fig.4 Levelized Cost of Energy Comparative

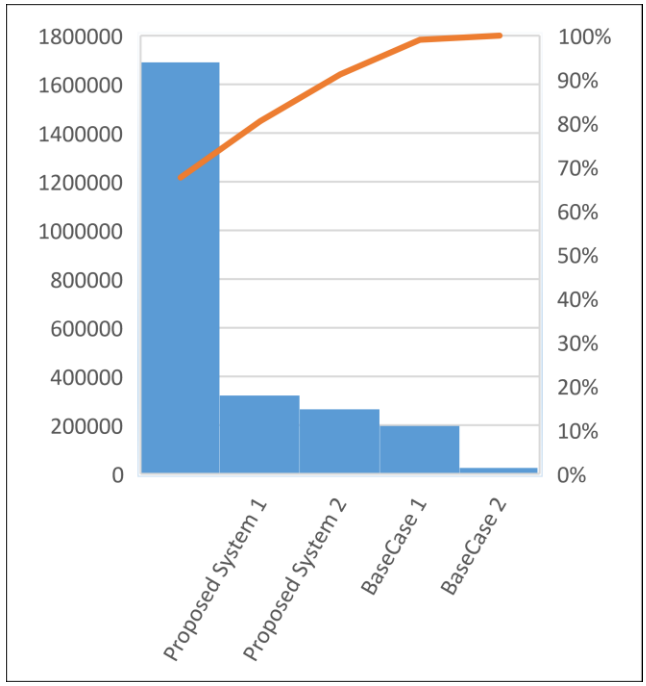


Fig.5 Initial Capital Cost Comparative

3. Conclusion

In this study, three distinct locations on Egyptian key highways have been selected for the design and analysis of an off-grid station for an emergency hospital. The International Coastal Road (location A), ELGalala Road (location B), and Suez-Sharm El-Sheikh Road (location C) Because of simulation and optimization by HOMER Pro®, it has been concluded that the configuration of hybrid PV/wind/diesel/battery is an optimum effective selection and extra cost-efficient than the case of diesel only (base case 1) or hybrid PV/diesel (base case 2). It is concluded that all locations‘stations for the proposed system are qualified to meet the load demand because of the average solar, wind, and temperature resources, and despite the high initial capital cost (ICC) of an average of 329267 $. It has a low net present cost (NPC) of an average 487539 $/Yr, a low operations and maintenance cost (O&M) of an average 12243 $/Yr, and a levelized cost of energy (LCOE) of an average 0.322 $/KWh compared with other cases. The implementation of this station with hybrid PV, wind, diesel, and batteries will decrease CO2 emissions to 91.32% on average compared with diesel only, which has zero RF, and 89.41% on average compared with hybrid PV, diesel, and 1.15% RF. Moreover, the use of a CDS controller decreases the solar panel's capacity by an average of 13.6% and storage capacity by an average of 41.9%, directly impacting the reduction of ICC.

References

[1] K. Abdeladim, S. Bouchakour, A. Hadj Arab, S. Ould Amrouche, and N. Yassaa, ‘Promotion of renewable energy in some MENA region countries’, in IOP Conference Series: Earth and Environmental Science, Institute of Physics Publishing, May 2018. doi: 10.1088/1755-1315/154/1/012003.

[2] I. Renewable Energy Agency, ‘Renewable capacity highlights 2022’, 2022. [Online]. Available: www.irena.org/publications.

[3] G. dos Santos Ferreira et al., ‘Short- and long-term forecasting for building energy consumption considering IPMVP recommendations, WEO and COP27 scenarios’, Appl Energy, vol. 339, Jun. 2023, doi: 10.1016/j.apenergy.2023.120980.

[4] S. I. Salah, M. Eltaweel, and C. Abeykoon, ‘Towards a sustainable energy future for Egypt: A systematic review of renewable energy sources, technologies, challenges, and recommendations’, Cleaner Engineering and Technology, vol. 8. Elsevier Ltd, Jun. 01, 2022. doi: 10.1016/j.clet.2022.100497.

[5] M. A. H. Mondal, C. Ringler, P. Al-Riffai, H. Eldidi, C. Breisinger, and M. Wiebelt, ‘Long-term optimization of Egypt’s power sector: Policy implications’, Energy, vol. 166, pp. 1063–1073, Jan. 2019, doi: 10.1016/j.energy.2018.10.158.

[6] A. Karthick, V. K. Chinnaiyan, J. Karpagam, V. S. Chandrika, and P. Ravi Kumar, ‘Optimization of PV-Wind Hybrid Renewable Energy System for Health Care Buildings in Smart City’, in Hybrid Renewable Energy Systems, wiley, 2021, pp. 213–228. doi: 10.1002/9781119555667.ch8.

[7] G. H. Allam, B. E. Elnaghi, M. N. Abdelwahab, and R. H. Mohammed, ‘Using Machine Learning to forecast Solar Power in Ismailia’, International Journal of Scientific and Research Publications (IJSRP), vol. 11, no. 12, pp. 238–244, Dec. 2021, doi: 10.29322/ijsrp.11.12.2021.p12033.

[8] F. Pande, H. Thakre, S. Ladukar, and D. Radke, ‘Designing and Optimizing a Hybrid Renewable System Using Homer for Site Selected’, vol. 2, no. 2, pp. 165–170, 2017.

[9] O. M. Babatunde, O. S. Adedoja, D. E. Babatunde, and I. H. Denwigwe, ‘Off-grid hybrid renewable energy system for rural healthcare centers: A case study in Nigeria’, Energy Sci Eng, vol. 7, no. 3, pp. 676–693, Jun. 2019, doi: 10.1002/ese3.314.

[10] A. K. Pradhan, S. K. Kar, M. K. Mohanty, and C. Author, ‘Off-Grid Renewable Hybrid Power Generation System for a Public Health Centre in Rural Village’, 2016.

[11] 2022 23rd International Middle East Power Systems Conference (MEPCON) 13-15 Dec. 2022.

[12] Q. Hassan, M. Jaszczur, and J. Abdulateef, ‘Optimization of PV/WIND/DIESEL Hybrid Power System in HOMER for Rural Electrification’, in Journal of Physics: Conference Series, Institute of Physics Publishing, Oct. 2016. doi: 10.1088/1742-6596/745/3/032006.

[13] H. Keshan, J. Thornburg, and T. Selim Ustun, ‘Comparison of Lead-Acid and Lithium Ion Batteries for Stationary Storage in Off-Grid Energy Systems’, 2016.

[14] R. Usman, | Page, and M. Barivuresigalo, ‘Analysis and Simulation of Electrical Load in aHospital Using Hybrid (Diesel/Solar) System as aBack Up 1*’, 2017. [Online]. Available: www.questjournals.org

[15] G. Tjahjono and T. Setiawaty, ‘Analysis providing diesel-wind hybrid electrical energy system in timor Island Indonesia’, in IOP Conference Series: Materials Science and Engineering, Institute of Physics Publishing, Mar. 2017. doi: 10.1088/1757-899X/180/1/012268.

[16] A. H. Al-Hamdani et al., ‘Potential of Renewable Energy in Al-Fourat Al-Awsat: Al Najaf City Case Study’, in Journal of Physics: Conference Series, Institute of Physics Publishing, Jun. 2018. doi: 10.1088/1742-6596/1032/1/012014.

[17] M. Haratian, P. Tabibi, M. Sadeghi, B. Vaseghi, and A. Poustdouz, ‘A renewable energy solution for stand-alone power generation: A case study of KhshU Site-Iran’, Renew Energy, vol. 125, pp. 926–935, Sep. 2018, doi: 10.1016/j.renene.2018.02.078.

[18] W. H. Beitelmal et al., ‘Renewable energy as a source of electricity for Murzuq health clinic during COVID-19’, MRS Energy and Sustainability, vol. 9, no. 1, pp. 79–93, Mar. 2022, doi: 10.1557/s43581-021-00020-w.

[19] N. M. Ali and H. Ammari, ‘Design of a hybrid wind-solar street lighting system to power LED lights on highway poles’, AIMS Energy, vol. 10, no. 2, pp. 177–190, 2022, doi: 10.3934/ENERGY.2022010.

[20] P. Ahmed et al., ‘Feasibility and Techno-Economic Evaluation of Hybrid Photovoltaic System: A Rural Healthcare Center in Bangladesh’, Sustainability, vol. 15, no. 2, p. 1362, Jan. 2023, doi: 10.3390/su15021362.

[21] N. Mat Isa, C. Wei Tan, and A. H. M. Yatim, ‘A techno-economic assessment of grid connected photovoltaic system for hospital building in Malaysia’, in IOP Conference Series: Materials Science and Engineering, Institute of Physics Publishing, Jul. 2017. doi: 10.1088/1757-899X/217/1/012016.

[22] D. Suchitra, R. Rajarajeswari, and J. Dasgupta, ‘Optimization of hybrid renewable energy system using homer’, International Journal of Recent Technology and Engineering, vol. 8, no. 2 Special Issue 11, pp. 2542–2550, Sep. 2019, doi: 10.35940/ijrte.B1301.0982S1119.

[23] D. Gospodinova, P. Dineff, and K. Milanov, ‘Greenhouse Gas Emissions Assessment after Renewable Energy Sources Implementation in Bulgarian Grid-Connected Single-Family Houses by HOMER Pro Software’, in 2020 12th Electrical Engineering Faculty Conference, BulEF 2020, Institute of Electrical and Electronics Engineers Inc., Sep. 2020. doi: 10.1109/BulEF51036.2020.9326082.

[24] M. K. Shahzad, A. Zahid, T. Rashid, M. A. Rehan, M. Ali, and M. Ahmad, ‘Techno-economic feasibility analysis of a solar-biomass off grid system for the electrification of remote rural areas in Pakistan using HOMER software’, Renew Energy, vol. 106, pp. 264–273, 2017, doi: 10.1016/j.renene.2017.01.033.

[25] Z. Gu and Y. Zhou, ‘Economic verification of hybrid energy utilizations with HOMER pro’, in IOP Conference Series:

Earth and Environmental Science, IOP Publishing Ltd, Oct. 2020. doi: 10.1088/1755-1315/582/1/012009.

[26] C. Sanjay Kumar, M. Karthikeyan, K. M. Prasannakumaran, and V. Kirubakaran, 'Techno Commercial Study of Hybrid Systems for the Agriculture Farm Using Homer Software', in Hybrid Renewable Energy Systems, wiley, 2021, pp. 115–133. doi: 10.1002/9781119555667.ch5.

[27] M. Ku. Babu and P. Ray, 'Sensitivity analysis, optimal design, cost and energy efficiency study of a hybrid forecast model using HOMER pro', Journal of Engineering Research, vol. 11, no. 2, p. 100033, Jun. 2023, doi: 10.1016/j.jer.2023.100033.

[28] A. M. K. See, K. Mehranzamir, S. Rezania, N. Rahimi, H. N. Afrouzi, and A. Hassan, 'Techno-economic analysis of an off-grid hybrid system for a remote island in Malaysia: Malawali island, Sabah', Renewable and Sustainable Energy Transition, vol. 2, p. 100040, Aug. 2022, doi: 10.1016/j.rset.2022.100040.

[29] S. A. Mousavi, A. Toopshekan, M. Mehrpooya, and M. Delpisheh, 'Comprehensive exergetic performance assessment and techno-financial optimization of off-grid hybrid renewable configurations with various dispatch strategies and solar tracking systems', Renew Energy, vol. 210, pp. 40–63, Jul. 2023, doi: 10.1016/j.renene.2023.04.018.

[30] A. S. Aziz, M. F. N. Tajuddin, T. E. K. Zidane, C. L. Su, A. J. K. Alrubaie, and M. J. Alwazzan, 'Techno-economic and environmental evaluation of PV/diesel/battery hybrid energy system using improved dispatch strategy', Energy Reports, vol. 8, pp. 6794–6814, Nov. 2022, doi: 10.1016/J.EGYR.2022.05.021.

[31] J. Ma and X. Yuan, 'Techno-economic optimization of hybrid solar system with energy storage for increasing the energy independence in green buildings', J Energy Storage, vol. 61, May 2023, doi: 10.1016/j.est.2023.106642.

[32] S. Suriadi, W. I. Daru, S. R Halid, M. Syukri, and M. Gapy, 'The optimization of hybrid power generator system (PV-Wind turbine) using Homer software', IOP Conf Ser Mater Sci Eng, vol. 1087, no. 1, p. 012080, Feb. 2021, doi: 10.1088/1757-899x/1087/1/012080.

[33] J. Peng et al., 'A comprehensive overview and comparison of parameter benchmark methods for lithium-ion battery application', J Energy Storage, vol. 71, p. 108197, Nov. 2023, doi: 10.1016/J.EST.2023.108197.

[34] M. S. Javed, A. Song, and T. Ma, 'Techno-economic assessment of a stand-alone hybrid solar-wind-battery system for a remote island using genetic algorithm', Energy, vol. 176, pp. 704–717, Jun. 2019, doi: 10.1016/j.energy.2019.03.131.

[35] E. Rosales-Asensio, M. de Simón-Martín, A. E. Rosales, and A. Colmenar-Santos, 'Solar-plus-storage benefits for end-users placed at radial and meshed grids: An economic and resiliency analysis', International Journal of Electrical Power and Energy Systems, vol. 128, Jun. 2021, doi: 10.1016/j.ijepes.2020.106675.

[36] J. Barsana Banu, M. Balasingh Moses, and S. Rajarajacholan, 'Simulation and Control of MPPT Based Hybrid System with Boost Converter', in IOP Conference Series: Materials Science and Engineering, Institute of Physics Publishing, Aug. 2018. doi: 10.1088/1757-899X/396/1/012046.

[37] A. AL-SARRAJ, H. T.Salloom, K. K.Mohammad, and S. M.Mohammadghareeb, 'Simulation Design of hybrid System (Grid/PV/Wind Turbine/ battery /diesel) with applying HOMER: A case study in Baghdad, Iraq', International Journal of Electronics and Communication Engineering, vol. 7, no. 5, pp. 10–18, May 2020, doi: 10.14445/23488549/ijece-v7i5p103.

[38] S. Podder, R. S. Khan, and S. M. A. Alam Mohon, 'The Technical and Economic Study of Solar-Wind Hybrid Energy System in Coastal Area of Chittagong, Bangladesh', Journal of Renewable Energy, vol. 2015, pp. 1–10, 2015, doi: 10.1155/2015/482543.

[39] C. Mokhtara, B. Negrou, N. Settou, B. Settou, and M. M. Samy, 'Design optimization of off-grid Hybrid Renewable Energy Systems considering the effects of building energy performance and climate change: Case study of Algeria', Energy, vol. 219, Mar. 2021, doi: 10.1016/j.energy.2020.119605.

[40] A. F. Tazay, M. M. Samy, and S. Barakat, 'A Techno-Economic Feasibility Analysis of an Autonomous Hybrid Renewable Energy Sources for University Building at Saudi Arabia', Journal of Electrical Engineering and Technology, vol. 15, no. 6, pp. 2519–2527, Nov. 2020, doi: 10.1007/s42835-020-00539-x.

[41] S. Shaposhnikov, Sankt-Peterburgskiĭ gosudarstvennyĭ ėlektrotekhnicheskiĭ universitet 'LĖTI', Natsionalʹnyĭ issledovatelʹskiĭ universitet 'MIĖT' (Russia), Institute of Electrical and Electronics Engineers. Russia North West Section., Institute of Electrical and Electronics Engineers. Russia Section., and Institute of Electrical and Electronics Engineers., Economic Feasibility Analysis of PV/Wind/Diesel/Battery Isolated Microgrid for Rural Electrification in South Egypt. 2019.

[42] E. Kelly, B. A. Medjo Nouadje, R. H. Tonsie Djiela, P. T. Kapen, G. Tchuen, and R. Tchinda, 'Off grid PV/Diesel/Wind/Batteries energy system options for the electrification of isolated regions of Chad', Heliyon, vol. 9, no. 3, Mar. 2023, doi: 10.1016/j.heliyon.2023.e13906.

[43] H. A. Alkhwaildi, 'ATRADE-OFF BETWEEN COST AND CO2 EMISSION IN OPTIMIZATION OF HYBRID RENEWABLE ENERGY SYSTEMS: A CASE STUDY IN SAUDI ARABIA', 2020.

[44] H. A. Alkhwaildi, 'ATRADE-OFF BETWEEN COST AND CO2 EMISSION IN OPTIMIZATION OF HYBRID RENEWABLE ENERGY SYSTEMS: A CASE STUDY IN SAUDI ARABIA', 2020.

[45] K. Balachander, G. Suresh Kumaar, M. Mathankumar, A. Manjunathan, and S. Chinnapparaj, 'Optimization in design of hybrid electric power network using HOMER', in Materials Today: Proceedings, Elsevier Ltd, 2021, pp. 1563–1567. doi: 10.1016/j.matpr.2020.08.318.

[46] L. Khalil, K. Liaquat Bhatti, M. Arslan Iqbal Awan, M. Riaz, K. Khalil, and N. Alwaz, 'Optimization and designing of hybrid power system using HOMER pro', in Materials Today: Proceedings, Elsevier Ltd, 2020, pp. S110–S115. doi: 10.1016/j.matpr.2020.06.054.

[47] D. Pelupessy and F. Manuhutu, 'Hybrid solar-wind-diesel power plant for small islands in Maluku Province', in IOP Conference Series: Earth and Environmental Science, Institute of Physics Publishing, Oct. 2019. doi: 10.1088/1755-1315/339/1/012046.

[48] N. Alshammari, M. M. Samy, and J. Asumadu, 'Optimal Economic Analysis Study for Renewable Energy Systems to Electrify Remote Region in Kingdom of Saudi Arabia', in 2018 20th International Middle East Power Systems Conference, MEPCON 2018 - Proceedings, Institute of Electrical and Electronics Engineers Inc., Feb. 2019, pp. 1040–1045. doi: 10.1109/MEPCON.2018.8635287.

[49] East-West University, Institute of Electrical and Electronics Engineers, Institute of Electrical and Electronics Engineers. Bangladesh Section, and IEEE Robotics and Automation Society. Bangladesh Chapter, HOMER Optimized Off-grid *Hybrid Energy System: ACase Study on RohingyaRelocation Center in Bangladesh*. 2019.