Techno-economic environmental assessment of hybrid renewable energy system in India

K. M. Venkatachalam[1], V. Saravanan[2]
[1]Research Scholar, Faculty of Electrical Engineering, Arunai Engineering College, Anna University, Tamil Nadu, India
[2]Department of Electrical and Electronics Engineering, Arunai Engineering College, Anna University, Tamil Nadu, India

Article Info	ABSTRACT
	The co-ordination of non-conventional energy technologies such as solar, wind, geothermal, biomass and ocean are gaining significance in India due to more energy requirements and high greenhouse gas emission. In this assessment, the sustainability of emerging the gird isolated hybrid solar photovoltaic (PV)/wind turbine (WT)/diesel generator (DG)/battery system for Arunai Engineering College, India building is evaluated. The techno-economic and environmental research was inspected by HOMER Pro software by choosing the optimal combination depends on size of the components, renewable fraction, net present cost (NPC), cost of energy (COE) and greenhouse gas (GHG) emission of the hybrid system. From the acquired outcomes and sensitivity investigation, the optimal PV-WT-DG-battery combination has a NPC of \$28.944.800 and COE \$0.1266/kWh, with an operating cost of \$256.761/year. The grid isolated hybrid system is environmentally pleasant with a greenhouse gas emission of 2.692 kg/year with renewable fraction of 99.9%.

Corresponding Author:

K M. Venkatachalam
Research Scholar
Faculty of Electrical Engineering
Arunai Engineering College, Anna University
Tiruvannamalai 606 603, Tamil Nadu, India
Email: kmvpeee@gmail.com

1. INTRODUCTION

Growth of population, globalization and the progression in innovation, builds the utilization in energy and the emission of a significant greenhouse gas (GHG), carbon dioxide (CO_2) in the environment. In present days, the electric energy is mostly generated by conventional energy sources, for example, lignite, diesel and nuclear based energy sources. The fossil fuel based electric energy generation system derivatives drives two major issues, their consumption in nature and CO_2 level in air prompting an unnatural weather change. Over the nation the non-renewable sources based electricity generation and consumer lines are integrated in a single grid. This structure of action ends up being advantageous for different spots, though, remote spaces suffer from restricted accessibility of electricity or no accessibility by any means, where the energy demand is less and the accessibility of petroleum products is far away from the heap request. The augmentation of grid such places bring about high establishment costs, less energy demand for most of the time. This is the place renewable energy sources (RES) coming to picture given their preferences, for example, accessibility at remote zones, unimportant contamination to the earth and less operating cost. International energy agency (IEA) forecasts that practically 30% of the electricity will produce from renewable sources by year 2020 [1].

According to Satsangi *et al.* [2] India has an average solar radiation (SR) is 4.9 kWh/m2/day with an average sunshine of 7.0 hours in a day. In India the SR is ranges from 3.9 to 5.6 kWh/m2/day depending upon climatic condition and locations [3]-[7], with the north-western borders facing grater solar radiation. It is additionally evaluated that India has average wind speed (WS) of 6.58 m/s and the WS ranges from 3.5 to 9.75 m/s from northern border to southern border, with southern coastal region experienced the highest wind speed of 9.75 m/s [8]-[10]. Different investigations have recommended the arrangement of solar photovoltaic, wind turbine, fuel cell and other renewable energy sources for electric energy generation in different places in India [11]-[14]. These renewable energy sources are without contamination sources with zero natural effect. They are unreservedly accessible also, liberated from GHG emission [15]-[17]. While several works utilized the single renewable energy source based power generation system, other thought about the utilization of hybrid electric system by connecting solar photovoltaic (PV), wind turbine, fuel cell, biomass and utility grid. Some places the diesel generator (DG) and batteries were utilized as a backup generator and storage device for provide reliable and efficient energy to the load demands [18]-[22]. Whereas the grid supply is not accessible places like villages and remote areas, the diesel generator integrated hybrid system is preferred. The hybrid renewable energy system is chosen for reason that increase the overall reliability, reduce the components of electric system which may reduce the initial investment price of the system [23]-[26]. There is likewise the impact of climate condition because of variances in wind speed and solar radiation. Wind and solar based renewable system is established in various pieces of the world have required the growth and uses of a few optimization models and simulation tools for techno-economic and environmental feasibility investigation of various hybrid structures [27]-[32]. In India, many of the investigation were done in different pieces of the nation on grid isolated hybrid system for power optimization by using HOMER Pro simulation tool [12], [14]. The vast majority of the examinations concentrated on the utilization of hybrid RES for increase the productivity, while adjusting the impact of instability in the renewable energy sources [33], [34].

A few examinations have been done in different pieces of the world to survey the techno-economic and environmental analysis of different hybrid electric system. Ghenai and Bettayeb [16] examined the various combination of hybrid PV/fuel cell/DG energy system. They show that standalone system is a high renewable fraction, feasible economic with environmental friendly system for university building in Sharjah. Al-Hamadani [35] analyzed the hybrid diesel/PV/wind/battery systems under Iran climate conditions for non-residential consumers. The hybrid system was analyzed on the basis of size of the PV panels and wind turbine, cost of energy and renewable fraction under with and without battery connected conditions. Hossain *et al.* [21] identified three rural places in Colombia, estimated the load demands and optimized the off-grid hybrid renewable energy system using HOMER. They demonstration that combination of hybrid PV/wind turbine (WT)/diesel is a capital cost, net present cost (NPC), and cost of energy (COE). In another study, Fodhil *et al.* [36] explored the optimal power and analysis the sensitivity of hybrid PV-DG-battery electric system by applying particle swarm optimization (PSO) techniques and HOMER software for rural electrification in Algeria. In Bangladesh, techno-economic feasibility assessment was proposed to fulfill the 248 kWh/day energy demand for remote community using standalone hybrid photovoltaic/wind turbine/diesel generator/biogas generator/battery system by Das *et al.* [37]. In this standalone hybrid system greenhouse gas emission was compared with diesel based and grid connected system. Duman and Güler [38] developed an off-grid solar photovoltaic system for the application of light-emitting diode (LED) road light. They declared that the proposed model is acceptable decision for both financially and environmentally. Al-Hamadani [35] implemented a comparative feasibility investigation of grid integrated and isolated systems under southern Iran climate conditions. The optimal sizing of photovoltaic module, wind and batteries and also annual load growth by using HOMER simulation tool. Li *et al.* [39] estimated the housing estate loads in china and locate the optimal design of hybrid system utilizing HOMER. The results shows cost optimal, emission of pollution for hybrid solar PV/DG/battery system.

The techno-economic and feasibility analysis was completed in Dongola by Elkadeem *et al.* [40] to analyze the techno-economic of a hybrid PV/WT/DG/converter/battery system in providing power for agriculture and irrigation area. The examination uncovered the optimal design and economically reasonable with levelized COE and NPC of 0.387 $/kWh and 24.16 M$ respectively. The greenhouse gas emission is 95% is reduced to equate with only diesel system. A techno-economic examination of grid isolated hybrid photovoltaic/DG/battery system was analyzed in place of household load demand in Urunqi, China by Li and Yu [41]. A numerous models which incorporates fixed axis, one axis and two axis solar tracking systems, were dissected in the investigation. The optimal arrangement as far as cost of energy was the fixed axis solar tracking system ranges between 1.319 $/kWh and 2.847 $/kWh. A technical and relative investigation of grid connected hybrid renewable energy system was carried out by Islam [42] for a large office building in Southeastern in France. The hybrid PV/utility grid system was seen as the 43% energy consumption is reduced from utility grid and also minimized the 90% of greenhouse gas emission. Shahzad *et al* [43] also

assessed off grid hybrid solar-biomass system for provide electricity for rural areas in Pakistan. In this report the system initial capital cost and NPC are calculated as PKR 2.64 M and PKR 4.48 M respectively and also electricity provide at COE 5.51 PKR/kWh for the application of agricultural purposes. The performance of hybrid solar photovoltaic/DG/battery in Sabah, Malaysia by Halabi *et al*. [44] using HOMER simulation tool. The outcomes shows the hybrid photovoltaic/DG/battery system configuration is the best optimal design compared to overall configuration. Renewable fraction of the system values varied like 0%, 39.89%, 42.38%, 59.21%, 86.90% and 100% depends upon different configuration of the hybrid system.

The related investigations talked about give a good foundation to the current examination by introducing different techno-economic contextual investigations carried out in many countries. For the examinations reported in India, the gotten cost of energy is more because wrong selection of equipment and components for the feasibility investigation. A large portion of the investigations concentrated on NPC particularly in India contextual analyses. Accordingly, in this examination, HOMER Pro simulation software was used to define the optimal design of hybrid solar photovoltaic/wind/diesel/battery in southern region of India, Tiruvannamalai. It is evaluates the techno-economic analysis depends on the minimal NPC and COE with less environmental pollution effects. The various configuration were simulated and the optimal configuration for the investigation place is the hybrid PV/WT/DG-battery with a NPC and COE are $28.944.800 and 0.1266 $/kWh in that order.

2.   STUDY AREA AND LOAD PROFILE DESCRIPTION

The grid isolated hybrid PV/WT/DG-battery is designed to make available electricity for Arunai Engineering College (Educational Institution) in Velu Nagar village, Tiruvannamalai with latitude $12^0$11.6' N and longitude $79^0$5.0' E. The Institution is located in North-West region of Tamilnadu and located in western mountainous hills, which has huge amount of solar potential and wind potential.

The Arunai Engineering College was established in the year of 1993, total area of around 105.50 sq.m. Spanning area for academic, hostels, playground and amenities purposes. The institution consists of several buildings and each building consists of three to four floors. The most of the buildings are used for the academics purpose and few buildings are used for the hostel and administrative purposes. The electricity is needs for academics, administrative and hostel buildings for various electrical appliances at different time duration. The academics and administrative buildings energy consumption is relatively high due to more number of lights, air conditioner, lifts, computers and electrical motors at time duration between from 8.00 am to 5.30 pm. In hostel buildings mostly light loads, air coolers and water heater are consuming electrical energy at time duration between from 5.00 pm to 9.00 am.

The total load and energy consumption of the administrative building is 19.8794 kW and energy consumption 158.873 kWh/day, while the total load and energy consumption for academic and hostel buildings are 355.8785 kW and 1490.9312 kW, 2649.719 kWh/day and 8527.0108 kWh/day as presented in Table 1. The overall three buildings total energy consumption per day, peak load and average energy consumption are 11335.5128 kW/day, 1,769.87 kW and 472.31 kW/day with a load factor of 0.27, 15% hour-hour and 10% day to day random variable were used to enable the load data to have some degree of variability at different times of the year. The load data is served into the HOMER software for the graphical representation of the hourly and monthly load profiles as illustrated in Figure 1.
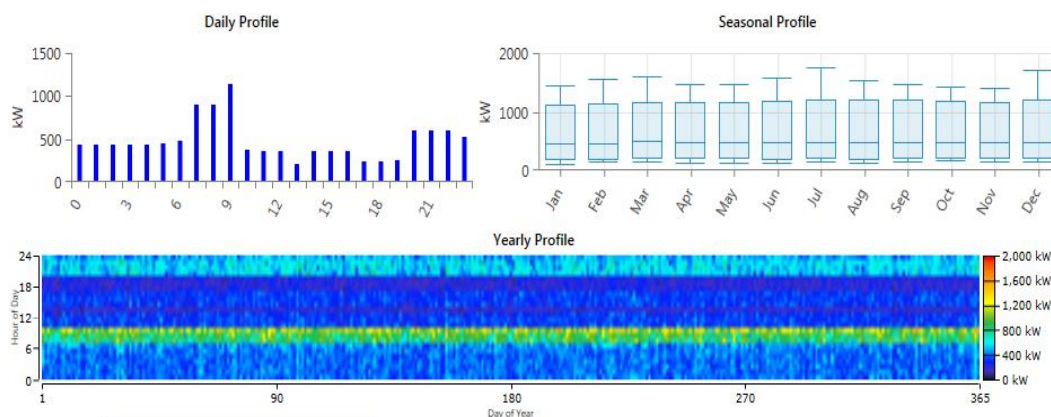

Figure 1. The daily and monthly electric load profile of Arunai Engineering College

Table 1. The estimated electric load demand profile for Arunai Engineering College

Buildings	Type of Loads	Rating of loads (W)	No. of Loads	Total Loads Power (kW)	Operating time (h/day)	Energy Consumption (kWh/day)	Total energy consumption (kWh/day)
Administrative building	Light (Building inside)	40	35	1.40	9	12.60	158.783
	Light (Street)	40	8	0.32	13	4.16	
	Fan	60	24	1.44	9	1.296	
	Computer	110	16	1.76	9	15.84	
	Printer	250	4	1.00	9	9.00	
	Scanner	12	4	0.048	9	0.432	
	Xerox machine	930	1	0.930	6	5.58	
	Air conditioner	1740	6	10.44	8	83.52	
	Water purifier	700	1	0.70	9	6.30	
	Water pump	1491.4	1	1.4914	1	1.4914	
	Refrigerator	250	1	0.25	24	6.00	
	Other socket loads			0.10	9	0.90	
Academic building	Light (Building inside)	40	478	19.12	9	172.08	2649.719
	Light (Street)	40	108	4.32	13	56.16	
	Fan	60	497	29.82	9	268.38	
	Computer	110	428	47.08	9	423.72	
	Printer	250	43	10.75	9	96.75	
	Scanner	12	43	0.516	9	4.644	
	Xerox machine	930	2	1.86	6	11.16	
	Projector	282	72	20.304	4.5	91.368	
	Air conditioner	1740	36	62.64	9	563.76	
	Water purifier	700	9	6.30	9	56.70	
	Water pump	3728.5	1	3.7285	2	7.457	
	Laboratory Loads			149.14	6	894.84	
	Other socket Loads			0.30	9	2.70	
Hostel building	Light	40	1940	77.60	7.5	582.00	8527.0108
	Fan	60	900	54.00	15	810.00	
	Laptop	65	1400	91.00	7	637.00	
	Printer	250	20	5.00	2	10.00	
	Scanner	12	20	0.240	2	0.48	
	Xerox machine	930	2	1.860	2	3.72	
	Air conditioner	1740	200	348.00	11	3828.00	
	Water purifier	700	24	16.80	10	168.00	
	Water pump	3728.5	2	7.457	2	14.914	
	Water heater	4000	60	240.00	1.5	360.00	
	Washing Machine	1300	10	13.00	13	169.00	
	Iron box	700	900	630.00	3	1890.00	
	Refrigerator	250	4	1.00	24	24.00	
	GYM machinery	372.85	12	4.4742	4	17.8968	
	Other socket loads			0.50	24	12.00	
					Overall total		11335.5128

3. SOLAR AND WIND POTENTIAL ASSESSMENT

To design a solar PV system, the information on the SR and clearness index of the particular site is required. The openness of this solar potential is dictated by the accessibility of enough daylight hours in the zone [45]. For this evaluation, [46] the information utilized for the investigation was acquired from national aeronautics and space administration (NASA) utilizing the latitude and longitude of the area.

The chose area is in Tiruvannamalai arranged at latitude $12^011.6'$ N and longitude $79^05.0'$ E with the forecast daily average SR is 5.14 kW/m^2/day. The twenty two years the average value of the solar data was gained from NASA by means of HOMER Pro software, the solar data information comprising of the

clearness index and solar radiation ranges from 0.454 to 0.634 and 3.99 kW/m^2/day to 6.43 kW/m^2/day respectively as introduced in Figure 2. The long stretch of November has the least SR is 3.99 kW/m^2/day and the period of March has the most elevated SR estimation of 6.43 kW/m^2/day. In any case, the month having least SR is still the solar system can be used to generate electricity.

Wind is another renewable resource that can be tackled for power generation. Wind turbines are combined with inbuilt generators which transforms the wind energy into electrical energy [9]. To generate effective electrical energy from the wind system, the evaluation place must have the essential wind speed to be driving the wind turbine. The non-identical wind turbines are exist for electric power generation and can work at different wind speed be decided by manufacturers, the wind speed for wind turbine activity may differ between 2.5 m/s cut-in WS and 25 m/s cut-out WS [10]. In this evaluation, the average wind speed of the Assam Engineering College (AEC) campus location 3.29 m/s at 50 m height. The WS changes between 2.65 and 3.95 m/s for the whole year in this location [46]. The information utilized for this investigation was acquired from NASA by means of HOMER Pro software, twenty two years average wind speed information changes between 2.65 and 3.95 m/s as introduced in Figure 3. There is lower WS the month of November having an average WS of 2.65 m/s and higher WS of 3.95 m/s during the period of May. However, the average wind speed of the investigation place falls inside the necessary wind speed that can be utilized to exploit energy to generate electricity.
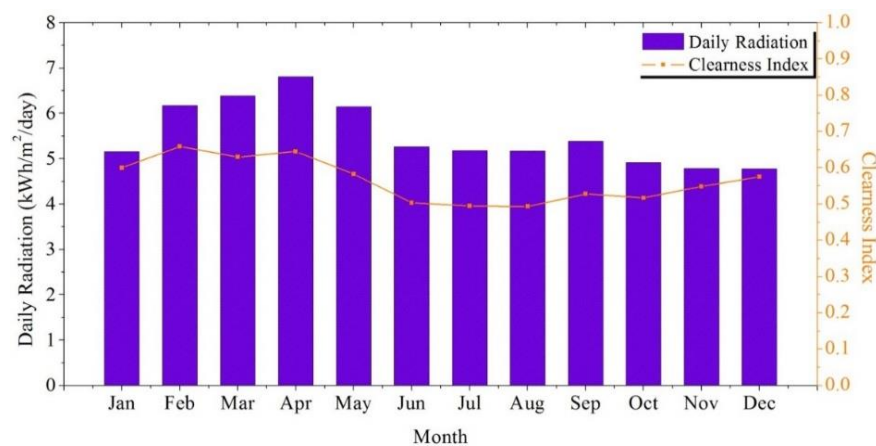

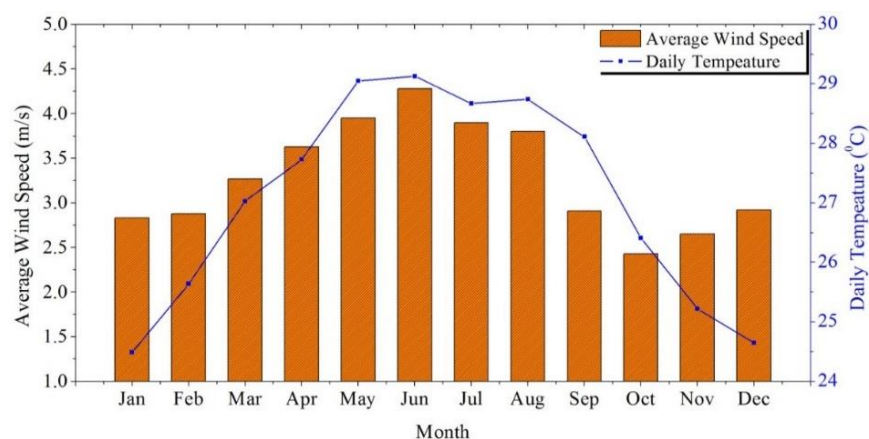Figure 2. Monthly average solar radiation and clearness index in Arunai Engineering College

Figure 3. Monthly average wind speed and temperature in Arunai Engineering College

4. DESIGN AND SPECIFICATION DESCRIPTION OF HYBRID SYSTEM

The grid isolated hybrid electric energy system comprising of photovoltaic arrays, wind generator, diesel generator, battery, a converter, DC bus, AC bus and electric load as appeared in Figure 4. The batteries are used to store the surplus energy that can utilized while the solar photovoltaic and wind generator systems

are not capable to encounter the load demand, while the diesel generator fills in as a reinforcement power flexibly when the solar, wind and the batteries also not capable to encounter load requirements. Various combination of hybrid frameworks have been proposed in various pieces of the globe dependent on the accessible renewable resources in those regions [47], [48]. In India, a few investigations have likewise been completed utilizing the accessible renewable resources [1], [11], [12], [27]. In this assessment HOMER Pro is utilized to design the hybrid PV-WT-DG-battery system and analysis the techno-economic feasibilities, optimization of power and sensitivity. It simulates various framework designs utilizing sources of info, for example, climate information for the chose location, component technical specifications, cost of the components and load information. HOMER Pro software simulates the wide range of framework arrangements and chooses optimal design with the less NPC and levelized COE. Figure 5 presents the architecture of the HOMER Pro software for techno-economic assessment.
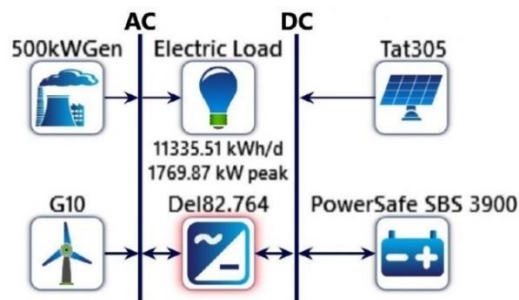

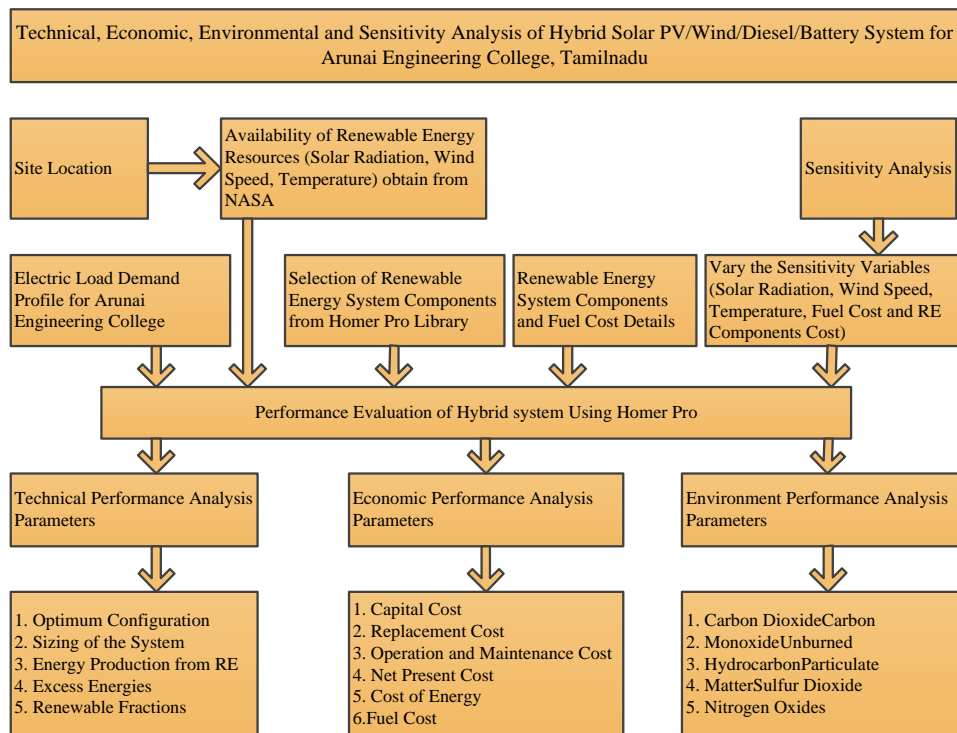Figure 4. Schematic diagram of hybrid PV-WT-DG-battery system

Figure 5. Architecture of the HOMER Pro operation for Arunai Engineering College

4.1. Output power of the solar photovoltaic array
The output power of the solar photovoltaic array is calculated by (1) [12], [35] in HOMER Pro.

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{G_T}{G_{T,STC}} \right) \left[1 + \alpha_p (T_c - T_{c,STC}) \right] \tag{1}$$

Where Y_{PV}, f_{PV}, G_T and $G_{T,STC}$ are the PV array rated capacity, derating factor, actual SR and test condition SR respectively. T_c and $T_{c,STC}$, α_p, are the actual and standard test condition cell temperature and temperature coefficient respectively.

In this assessment, Tat305TP305LBZ, rating of 0.305 kW_p flat plate photovoltaic panel is selected and its capital cost, operation and maintenance cost (O & M), replacement cost (RC) and other technical parameters details are introduced in Table 2. The maximum capacity of the photovoltaic system considered for this assessment is 3500 kW.

Table. 2. Technical and economic parameters details of solar photovoltaic system

Parameter	Specification
Model	Tat305TP305LBZ (Tat305)
Manufacturer	Tata Power Solar Systems
Panel Type	Flat Plate
Rated Capacity (kW)	0.305
Operating Temperature (°C)	48.8
Temperature Coefficient	-0.438300
Efficiency (%)	13
Capital cost ($/kWp)	1,500
Replacement cost ($/kWp)	1,200
O&M cost ($/kWp/year)	25
Derating Factor (%)	85
Life time (years)	25

4.2. Output power of the wind generator
The WS in wind turbine hub was assessed by HOMER Pro as (2) [12], [35].

$$U_{hub} = U_{anem} \frac{ln(Z_{hub}/Z_0)}{ln(Z_{anem}/Z_0)} \tag{2}$$

Where U_{anem} is a WS, Z_{anem} is a height of the anemometer, Z_{hub} is a height of the hub and Z_0 is a length of the surface. The wind system output power is determined as (3).

$$P_{WTG} = \left(\frac{\rho}{\rho_0} \right) P_{WTG,STP} \tag{3}$$

Where $P_{WTG,STP}$ is a output power of the wind turbine at standard conditions are determined utilizing the wind turbines output power curve, ρ is actual air density and ρ_0 is air density at standard conditions.

In this assessment selected a generic 10 kW wind turbine framework which is chosen dependent on the cut-in and cut-out WS of the wind turbine, height of WT and cost of the WT. Figure 6 represents the characteristic curve of the WT. The technical parameters of the WT, CC, RC, O & M cost are introduced in Table 3.
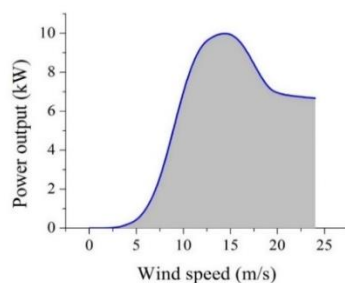

Figure 6. Characteristic curve of the 10 kW generic wind turbine

Table 3. Technical and economic parameters details of wind turbine

Parameter	Specification
Model	Generic 10 kW (G10)
Manufacturer	Generic
Rated Capacity (kW)	10
Capital cost ($)	45.000
Replacement cost ($)	45.000
O&M cost ($/year)	150
Hub Height (m)	24
Life time (years)	20

4.3. Diesel generator

The essential back-up power source, diesel generators have been generally utilized in hybrid power generation system so as to improve the reliability of the system. In this assessment, 500 kW diesel generators were chosen to fulfill a peak load demand of 1769.87 kW with 10% of operating reserve capacity. The fuel utilization of the DG is identified with the rated power and output powers, which can be determined as (4) [35].

$$F_{DG} = a_{P_{DG-rated}} + b_{PDG-out} \tag{4}$$

Here, $P_{DG\text{-rated}}$, $P_{DG\text{-out}}$ are the generator rated power and generator output power. Efficiency of the diesel generator is determined by utilizing the derived equation [35].

$$\eta_{DG} = \frac{3.6P_{DG-out}}{\rho_{fue}F_{DG}H_{L-fue}} \tag{5}$$

Here, ρ_{fue} is the density of the fuel (kg/m^3) and $H_{L\text{-fue}}$ (MJ/kg) is the lower warming of the fuel. The DG efficiency curve as presented in Figure 7 and technical parameters of the diesel generator, CC, RC, O & M cost, fuel consumption and other parameters are introduced in Table 4.
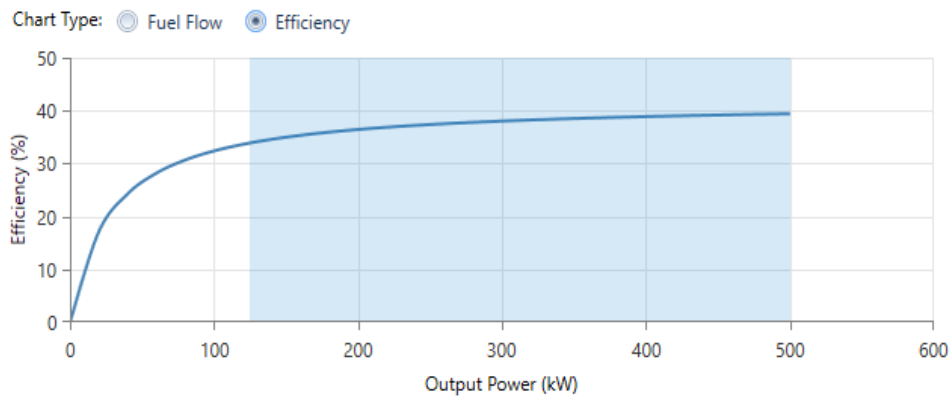

Figure 7. Efficiency curve of 500 kW diesel generator

Table 4. Technical and economic parameters details of diesel generator

Parameter	Specification
Model	Generic 500 kW Fixed Capacity Genset
Capacity (kW)	500
Fuel	Diesel
Fuel curve intercept (L/hr)	7
Fuel curve slop (L/hr/kW)	0.244
CO (g/L fuel)	13.566
Unburned HC (g/L fuel)	0.72
Particulate (g/L fuel)	0.116
Fuel sulfur converted to PM (%)	2.2
NOx (g/L fuel)	2.60
Lower heating value (MJ/kg)	43.2
Density (kg/m^3)	820
Carbon content (%)	88
Sulfur content (%)	0.4
Capital cost ($)	200.000
Replacement cost ($)	200.000
O&M cost ($/op.hour)	5
Minimum load ratio (%)	25
Fuel Price ($/L)	0.86
Life time (hours)	15.000

4.4. Battery charge and discharge power

A battery maximum charge power ($P_{batt, cmax}$) is measured using HOMER Pro is the base of three distinct limits on the batteries $P_{batt, cmax}$, to be specific [12], [35].

$$P \frac{MIN(P_{batt,cmax,kbm}, P_{batt,cmax,mcr}, P_{batt,cmax,mcc})}{\eta_{batt,c}} \qquad _{batt,cmax} \tag{6}$$

Where,

$$P_{batt,cmax,kbm} = \frac{kQ_1 e^{-k\Delta t} + Qkc(1-e^{-k\Delta t})}{1-e^{-k\Delta t} + c(k\Delta t - 1 + e^{-k\Delta t})} \tag{7}$$

$$P_{batt,cmax,mcr} = \frac{(1-e^{-k\Delta t})(Q_{max}}{\Delta t} \tag{8}$$

$$P_{batt,cmax,mcc} = \frac{N_{batt} I_{max} V_{max}}{1000} \tag{9}$$

$$\eta_{batt,c} = \sqrt{\eta_{batt,rt}} \tag{10}$$

Where, Q_1, Q and Q_{max} are the accessible energy, sum of energy and capacity of the battery bank respectively. c, k and α_c are the capacity ratio, constant rate and maximum rate of charge. Additionally, t, N_{batt}, I_{max}, V_{nom}, $g_{batt, c}$, $g_{batt, rt}$ are step time, battery quantity, battery nominal voltage, battery charge efficiency and round-trip efficiency respectively. The maximum discharge power ($P_{batt, dmax}$) of the battery banks as calculated as (11), (12) and (13).

$$Pbatt, d_{batt,dmax,kbm}{}_{batt,dmax} \tag{11}$$

Where,

$$P_{batt,dmax,kbm} = \frac{-kQ1^{-k\Delta t}{}^{-k\Delta t}{}_{max}}{1-e^{-k\Delta t} + c(k\Delta t - 1 + e^{-k\Delta t})} \tag{12}$$

$$\eta_{batt,d} = \eta_{batt,d} \tag{13}$$

In this assessment, a PowerSafe SBS 3900 lead-acid battery with 12 V, maximum capacity is 4300 Ah and nominal capacity of 51.6 kWh is selected for simulation. The round-trip efficiency of this battery is 97% with minimum state of charge (SOC) value is 30%. The technical and economic parameters details are introduced in Table 5. Figure 8 shows the capital and replacement cost variation curve.
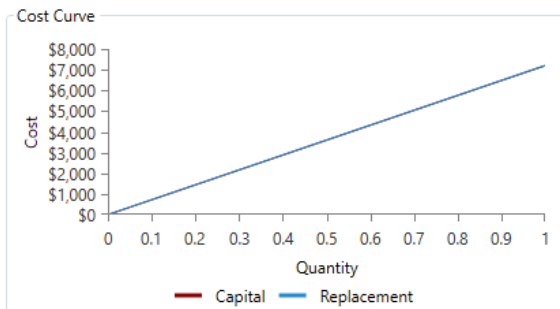

Figure 8. Cost curve of the PowerSafe SBS 3900 lead-acid battery

Table 5. Technical and economic parameters details of battery

Parameter	Specification
Nominal voltage (V)	12
Nominal capacity (kWh)	51.6
Maximum Capacity (Ah)	$4.3E^{+03}$
Capacity ratio	0.298
Rated constant (1/hr)	1.95
Roundtrip efficiency (%)	97
Maximum charge current (A)	$3.9 E^{+03}$
Maximum discharge current (A)	$4.6 E^{+03}$
Maximum charge rate (A/Ah)	1
Capital cost ($)	7200
Replacement cost ($)	7200
O&M cost ($/year)	0
Throughput (kWh)	55.134.60
Minimum SOC (%)	30
Life time (years)	15

4.5. Converter

There are two energy conversion in the electric system such as DC-AC and AC-DC conversion. Consequently, an inverter and rectifier are fundamental. In this assessment a Del82.764 converter, the

rectifier had 100% limit comparative with the inverter and its efficiency was 98.5% and converter lifetime was 15 years. The converter technical and economical parameters are introduced in Table 6.

Table 6. Technical and economic parameters details of converter

Parameter	Specification
Model	Del82.764
Manufacturer	Delta Electronics
Capital cost ($/kW)	220
Replacement cost ($/kW)	220
O&M cost ($/year)	10
Efficiency (%)	98.50
Life time (years)	15

4.6. Economic evaluation of the system

The NPC includes transformation of every single yearly advantage and costs stream happening at various focuses in the existence time of the project to their current value counterparts and including them to get the overall worth everything being equal and expenses of the project which is mathematically composed as (14) [35].

$$NPV = \sum_{t=1}^{N} \frac{R_t - C_t}{(1+i)^t} - I_0 \tag{14}$$

Here R_t, C_t, I, I_0 and N are the income, expense, rate of interest, initial cost and project life time respectively. The COE is acquired by including up the net costs a yearly premise and partitions it by the yearly provided energy as (15).

$$COE = \frac{ACC + ARC + AMC + AGC}{ASE} \tag{15}$$

Where,

$$ACC = \frac{i(1+i)^N}{(1+i)^N - 1} I_0 \tag{16}$$

It is an annual capital cost and replacement cost.

$$ARC = \frac{i(1+i)^N}{(1+i)^N - 1} I_0 \sum_{n_R} \frac{C_R}{(1+i)^{t_R}} \tag{17}$$

Where, C_R is a replacement of the components, t_R is a time of the replacement and n_R is the no.of replacements during the existence time of the project. Likewise AGC and AMC are yearly net grid charge and maintenance cost, independently.

4.7. Environmental evaluation of the system

The GHG emission in hybrid PV-WT-DG-battery system results from the generation of electric power by the renewable resources and generators. For the diesel generator yearly CO_2 emission is determined by using emission factor and yearly fuel utilization. For the grid integrated system, the emission level is calculated by using purchased net power from grid and its emission factor [35].

5. OPERATION STRATEGY

The grid isolated hybrid PV-WT-DG-battery system works in two principle techniques, specifically the cycle charging (CC) and load following (LF). The CC technique, the DG joined is utilized to supply power to the load and charge the battery bank simultaneously. While LF technique, the solar and wind turbines are serving demand simultaneously the battery bank charged by surplus power. In the occasion where the renewable power generation is not capable to encounter or inaccessible, the DG is arranged to attend the load. Figure 9 represents the operational flowchart for grid isolated hybrid PV/wind/diesel/battery system. The flow chart expresses the expresses overall power management of the system that is directs the flow of the energy in the hybrid system. For this assessment, the LF technique is implemented where just the renewable energy sources are utilized in charging the battery bank.

The charged battery storage system attends to serve the load demand in the occasion where the renewable sources can't serve the load requirements. The diesel generator can possibly serve the load demand when both renewable sources and battery storage systems are couldn't meet the loads. This decreases helps in decreasing the surplus power generation and furthermore helps in reduce NPC of the framework. There are circumstances that the load can't be given by the RES because of weather conditions. For instance, when there is accessible SR, the solar photovoltaic supplies power to the load and surplus power is a charge to the battery bank, similarly goes to the wind system when there is accessible WS to drive the WT. At the point when the photovoltaic and wind generator sources are not capable to encounter the demand, the batteries which fill in as the capacity will flexibly the load demand until battery discharged to 30% of the minimum SOC. When battery is going to under 30% of SOC the generator consequently goes on to serve the load demand.
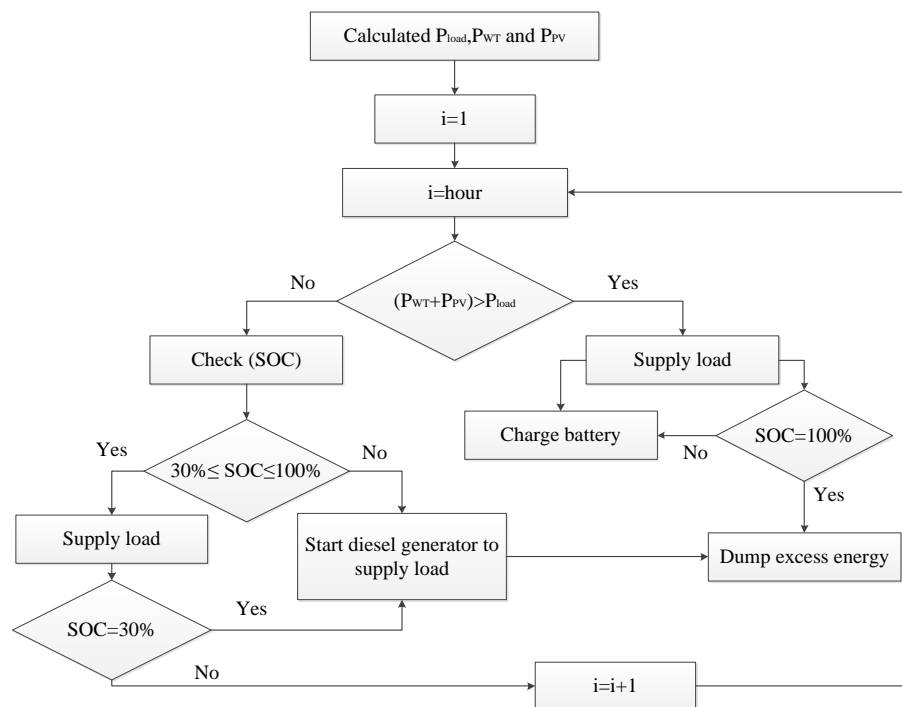

Figure 9. Operational flowchart for grid isolated hybrid PV/wind/diesel/battery system

6.   SIMULATION RESULTS AND DISCUSSION

In this assessment designs a hybrid PV/WT/DG-battery electric system to attend the electric load requirements of Arunai Engineering College in Tiruvannamalai, Tamil Nadu, India. HOMER Pro simulation tool was employed to model the hybrid renewable energy system by determining the optimal system configuration using the Arunai Engineering College electric load profile, weather data and component details.

6.1. Optimization analysis of the hybrid electric system

HOMER Pro software categorized all the possible framework arrangements for the Arunai Engineering College. The classified optimal configuration for Arunai Engineering College with an annual average SR of 5.14 kWh/m^2/day and a fuel cost of 0.86 $/L are appeared in Table 7 and Figure 10. The optimization configurations are classified four kinds of power system with minimum NPC and COE as PV-WT-DG-Battery, PV-DG-battery, PV-WT-battery and PV-battery.

For the optimal PV-WT-DG-battery design contains 3500 kW photovoltaic panels, 1 kW wind turbine, 500 kW DG, 1.222 quantity of batteries with 2.090 kW converters. It has the total NPC of $28.944.800 and COE of $0.1266/kWh. For this design, the solar system has the higher capital expense followed by the batteries and the converter, the diesel generator has the least capital expense. In view of the NPC, the batteries have the higher NPC because of replacement cost followed by the solar photovoltaic and fuel cost of DG, the converter of the system has the minimum NPC. Table 8 presents the overview of the cash flow of the optimal setup investigated by various cost types. Table 8 presents the capital and

replacement expenses are main cost of the system which includes for the most part the batteries and the solar system, followed by the diesel cost. The operating and maintenance cost is extremely minimum due to considered the system is mainly supplied by the solar and wind sources, which has the less operating expenses.

Table 7. Optimal configurations of the hybrid electric system

Configuration	PV (kW)	WT (kW)	DG (kW)	Battery	Converter (kW)	DS	NPC ($)	COE ($/kWh)	Initial cost ($)	Operating cost ($/year)	RF (%)	Total fuel (L/year)
PV-WT-DG-Battery	3.500	1	500	1.222	2.090	LF	28.944.800	0.1266	14.753.114.69	256.761.50	99.9	1027
PV-DG-Battery	3.500		500	1.239	1.946	LF	28.981.140	0.1268	14.798.939.66	256.590.00	99.9	898
PV-WT-Battery	3.500	1		1.321	1.800	CC	30.589.540	0.1338	15.202.123.72	278.395.30	100	0
PV-Battery	3.500			1.325	1.811	CC	30.601.110	0.1338	15.187.660.64	278.866.30	100	0

Table 8. Cash flow summary of PV-WT-DG-battery configuration

| Component	Capital ($)	Replacement ($)	O & M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	5.250.000	0	4.836.286.48	0	0	10.086.286.48
WT	45.000	135.349.19	8.290.78	0	-133.683.47	54.956.50
DG	200.000	0	2.210.87	48.802.59	-781.635.70	530.622.23
Battery	8.798.400	20.094.909.91	0	0	-11.616.796.53	17.276.513.37
Converter	459.714.69	1.049.955.14	1.154.967.24	0	-606.975.36	2.057.661.71
System	14.753.114.69	21.280.214.23	6.001.755.38	48.802.59	-13.139.091.06	28.944.795.83
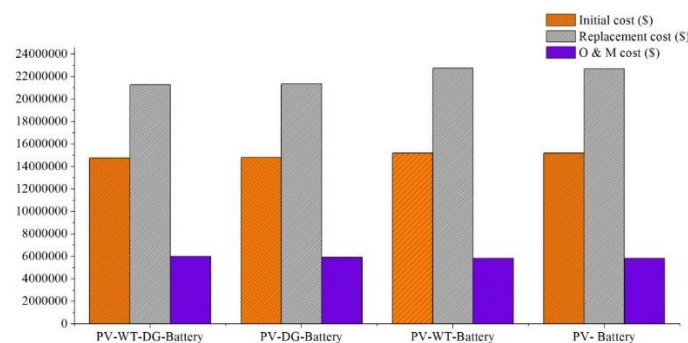
Figure 10. Optimal configurations of the hybrid system

6.2. Economic analysis of the hybrid electric system

HOMER Pro simulates various economic details. Table 7 introduced a correlation of the financial boundaries for every one of the classified configurations. The financial details are divided into initial cost, NPC, RC, and O & M cost. The grid isolated PV-WT-DG-battery configuration has the minimum initial cost of $14.753.114.69.

The hybrid PV-DG-battery has the second least initial cost of $14.798.939.66. The other two PV-WT-battery and PV-battery configurations have the highest initial cost of $15.202.123.72 and $15.187.660.64 respectively. The hybrid PV-DG-battery has the second minimum cost of $14.798.939.66. Remaining two PV-WT-battery and PV-battery configurations have the maximum initial cost of $15.202.123.72 and $15.187.660.64 respectively. The configuration with the minimum O & M cost is the hybrid PV-WT-DG-battery system with operating cost of $6.001.755.38. The following is the PV-DG-battery framework with O & M cost of $5.913.860.51 and happens to be the setup with the higher O & M cost. The PV-WT-battery and PV-battery frameworks have the O & M cost of $5.839.278.84 and $5.836.721.84 correspondingly. The hybrid PV-WT-battery arrangement has the higher replacement cost of $22.762.503.97 which is because of more number of batteries and photovoltaic panels utilized in the design. PV-battery setup

has the second higher replacement cost, followed by PV-DG-battery and PV-WT-DG-battery configurations with replacement cost of \$22.698.865.40, \$21.352.302.72 and \$21.280.214.23 correspondingly as shown in Table 7 and Figure 10. It is noticed that the design with the more number of batteries has the higher replacement cost because of more battery cost, it is in this way decided the quantity of batteries influences the expense of a framework. Furthermore, the total NPC and COE of all the feasible framework designs examined in Arunai Engineering College are demonstrated in Figure 11.
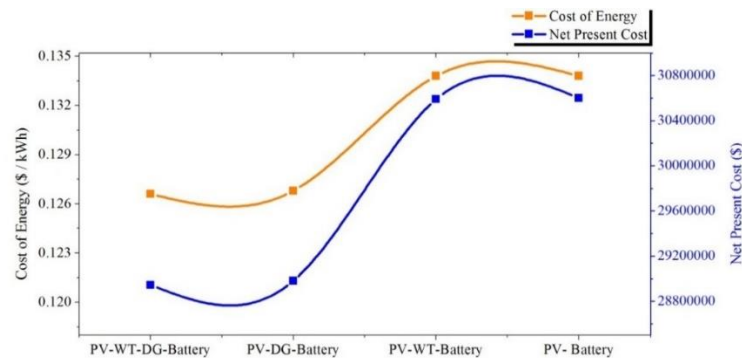

Figure 11. NPC and COE of all the feasible system configurations in Arunai Engineering College

6.3. Output energy analysis of the hybrid electric system

Various electric energy parameters of the hybrid renewable system were also analyzed. From the outcomes acquired from HOMER Pro, the hybrid PV-WT-DG-battery design has the maximum energy generation is 5.103.072 kWh/year with annual utilization of 4.136.751 kWh/year and surplus energy of 847.231 kWh/year. The hybrid PV-DG-battery setup has the second higher energy generation is 5.100.836 kWh/year with annual utilization of 4,136,735 kWh/year and surplus energy of 844,944 kWh/year that is utilized to charge the batteries. The energy of 99% is generated from the photovoltaic system with 1.01% generated from the diesel generator. The PV-WT-battery and PV-battery arrangements have power generation of 5.099.094 kWh/year and 5.096.520 kWh/year surplus energy of 843.106 kWh/year and 840.486 kWh/year correspondingly. These two setups have the minimum energy generation and they fulfill the annual energy utilization of 4.136.728 kWh/year and 4.136.734 kWh/year as introduced in Table 9. Moreover, Figure 12 and Figure 13 shows the month average energy generation, surplus energy from the optimal hybrid PV-WT-DG-Battery system in Arunai Engineering College.

Table 9. Comparison of output energy in hybrid electric system

Configuration	Energy Production (kWh/year)	Energy Consumption (kWh/year)	Excess Energy (kWh/year)
PV-WT-DG-battery	5.103.072	4.136.751	847.231
PV-DG-battery	5.100.836	4.136.735	844.944
PV-WT-battery	5.099.094	4.136.728	843.106
PV-battery	5.096.520	4.136.734	840.486
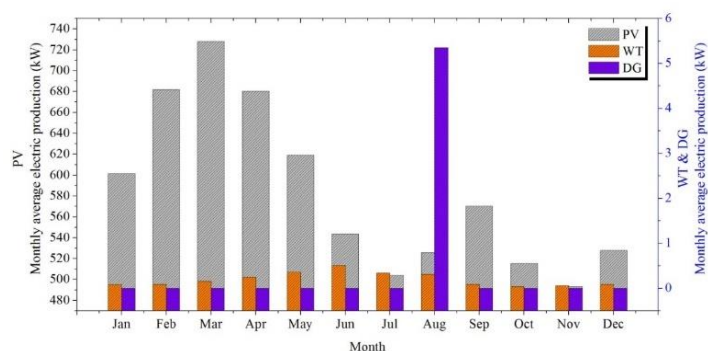
Figure 12. Monthly average electric production in the PV-WT-DG-battery system

Techno-economic environmental assessment of hybrid renewable energy system in … (Venkatachalam K M)
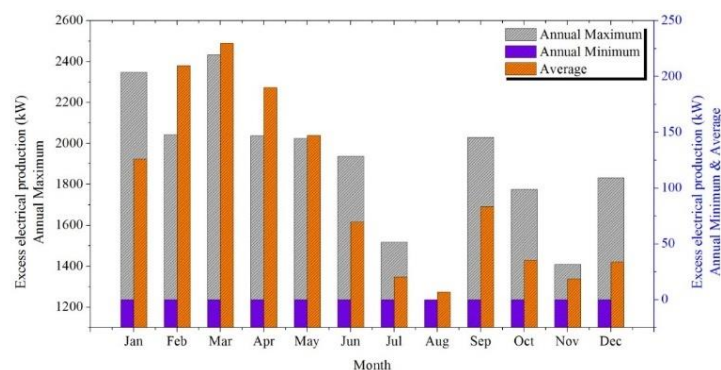
Figure 13. Monthly average excess electric energy in the PV-WT-DG-battery system

6.4. Environmental analysis of the hybrid system

From the design simulated by HOMER Pro, the hybrid PV-WT-DG-battery system has the more carbon dioxide emission of 2.692 kg/year, followed by hybrid PV-DG-Battery setup with CO_2 of 2.355 kg/year. The PV-WT-battery and PV-battery arrangements have zero greenhouse gas emission due to the 100% renewable fraction of the system. This shows that the hybrid PV-WT-battery and PV-battery systems are the most environmentally friendly configurations with zero emission, but unfortunately not economically viable because they have the highest NPC and COE compared to the optimum configuration system. It shows the hybrid PV-WT-battery and PV-battery systems are the most environmentally friendly setups with zero emission, but not economically feasible due to higher value of NPC and COE compared to the other optimal design. The hybrid system with the optimal design dependent on the less NPC and COE is still environmentally friendly due to less amount of greenhouse gas emission with 99.9% of energy generated from renewable sources compared other setup. Table 10 represents the greenhouse gas emission of the various configurations simulated by HOMER Pro.

Table 10. Comparison of GHG emission in hybrid electric system

Quantity	PV-WT-DG-battery (kg/year)	PV-DG-battery (kg/year)	PV-WT-battery (kg/year)	PV-battery (kg/year)
Carbon Dioxide	2.692	2.355	0	0
Carbon Monoxide	13.9	12.2	0	0
Unburned Hydrocarbon	0.739	0.647	0	0
Particulate Matter	0.119	0.104	0	0
Sulfur Dioxide	6.58	5.76	0	0
Nitrogen Oxides	2.67	2.33	0	0

6.5. Sensitivity analysis of the hybrid electric system

Certain sensitivity factors were providing into HOMER Pro software to decide the optimal system arrangement and corresponding techno-economic assessments for such system. By performing the sensitivity assessment for this hybrid system, a different value of yearly average solar radiation, average temperature, oscillation in average WS, rise and fall of the fuel price and changing the multiplication value of the capital cost, RC and O & M cost of the photovoltaic and wind system were conducted.

6.5.1. Sensitivity analysis with the variation of average SR

When the hybrid PV-WT-DG-battery system model in HOMER Pro, the yearly average solar radiation ranges from 4.5 kWh/m²/day to 5.5 kWh/m²/day. As saw in Table 11, with the other design factors of the system are undisturbed, during the system is operating at yearly average SR was 4.5 kWh/m²/day, optimum size of the photovoltaic and wind turbine required were setup 3500 kW and 406 kW, which are 20 kW photovoltaic and 403 kW wind turbine more than when the system is operating at yearly average SR was 5.5 kWh/m2/day. Therefore, the capital cost, operating cost, NPC and COE was rises by around 62.2%, 38.37%, 53.46%, and 53.44% correspondingly as compared with the system is operating at average SR was 5.5 kWh/m²/day appeared in Figure 14.

Table 11. Sensitivity analysis results for hybrid electric system

| Sensitivity Variables	Configuration	PV (kW)	WT (kW)	DG (kW)	Battery	Converter (kW)	NPC ($)	COE ($/kWh)	Initial Cost ($)	Operating Cost ($/year)	RF (%)	Total Fuel (L/year)
Solar radiation variation at Fuel cost of 0.86 $/L, Temperature of 27.07 °C, Wind speed of 3.29 m/s												
4.5 kWh/m²/day	PV-WT-DG-battery	3500	406	500	1577	1851	56.051.220	0.2452	35.481.570.27	372.154.20	99.8	1.997
4.8 kWh/m²/day	PV-WT-DG-battery	3497	1	500	1773	1807	36.428.900	0.1593	18.653.257.57	321.603.90	99.9	709
5.5 kWh/m²/day	PV-WT-DG-battery	3480	3	500	1035	1838	26.089.320	0.1141	13.411.010.17	229.381.00	99.9	769
Temperature variation at Fuel cost of 0.86 $/L, Solar radiation of 5.14 kWh/m²/day, Wind speed of 3.29 m/s												
20 °C	PV-WT-DG-battery	3500	1	500	1068	2069	26.754.730	0.1170	13.639.721.07	237.281.90	99.9	1.156
35 °C	PV-WT-DG-battery	3482	5	500	1412	1867	31.594.280	0.1382	16.224.751.56	278.071.60	99.9	1.283
45 °C	PV-WT-DG-battery	3500	145	500	1359	3528	40.241.830	0.1760	22.535.976.91	320.341.30	99.9	1.489
Wind speed variation at Fuel cost of 0.86 $/L, Temperature 27.07 °C, Solar radiation of 5.14 kWh/m²/day												
2.5 m/s	PV-WT-DG-battery	3500	3	500	1.212	1.964	28.797.300	0.1259	14.743.465.43	254.267.60	99.9	1.156
4 m/s	PV-WT-DG-battery	3500	1	500	1.222	2.090	28.944.800	0.1266	14.753.120.52	256.761.50	99.9	1.026
5 m/s	PV-WT-DG-battery	3500	43	500	906	1801	26.508.510	0.1159	14.304.391.87	220.801.70	99.9	1.150
Fuel cost variation at Solar radiation of 5.14 kWh/m²/day, Temperature of 27.07 °C, Wind speed of 3.29 m/s												
0.5 $/L	PV-WT-DG-battery	3500	1	500	1.222	2090	28.924.370	0.1265	14.753.114.69	256.391.90	99.9	1027
1.0 $/L	PV-WT-DG-battery	3500	1	500	1.222	2090	28.952.740	0.1266	14.753.114.69	256.905.20	99.9	1027
1.5 $/L	PV-WT-DG-battery	3500	1	500	1.222	2.090	28.981.110	0.1268	14.753.114.69	257.418.60	99.9	1027
Solar PV capital, Replacement and O&M cost multiplier variations at Solar radiation of 5.14 kWh/m²/day, Fuel cost of 0.86 $/L, Temperature of 27.07 °C, Wind speed of 3.29 m/s												
0.6 %	PV-WT-DG-battery	3500	1	500	1.222	2.090	24.910.280	0.1089	12.653.114.69	221.761.50	99.9	1.027
1.4 %	PV-WT-DG-battery	3500	1	500	1.222	2.090	32.979.310	0.1442	16.853.114.69	291.761.50	99.9	1.027
WT capital, Replacement and O&M cost multiplier variations at Solar radiation of 5.14 kWh/m²/day, Fuel cost of 0.86 $/L, Temperature of 27.07 °C, Wind speed of 3.29 m/s												
0.6 %	PV-WT-DG-battery	3500	1	500	1.215	2.007	28.750.590	0.1257	14.666.621.74	254.712.80	99.9	1.156
1.4 %	PV-WT-DG-battery	3500	1	500	1.222	2.090	28.966.780	0.1267	14.771.114.69	256.833.50	99.9	1.027
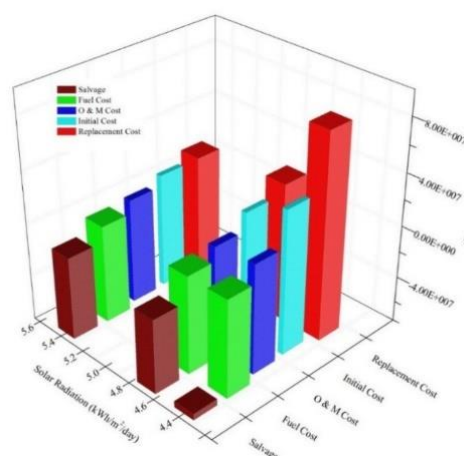
Figure 14. Cash flow summary of PV-WT-DG-battery system at different solar radiation

6.5.2. Sensitivity analysis with the variation of average temperature

By keeping the yearly average solar radiation, wind speed and other design factors are constant for this optimal hybrid system, the yearly average temperature were ranges from 20 °C to 45 °C. When the hybrid system is operating at average temperature was 20 °C, the quantity of the photovoltaic and wind turbine required were setup 3500 kW and 1 kW, the wind turbine quantity is 403 kW less than when the system is operating at yearly average temperature were 45 °C as shown in Table 11. Accordingly, the capital cost, operating cost, NPC and COE was drops by almost 39.48%, 25.93%, 33.51% and 33.52% in that order as related to when the system is operating at temperature was 45 °C as displayed in Figure 15.

6.5.3. Sensitivity analysis with the variation of average wind speed

The average WS of the WT changes between 2.5-5 m/s with fuel cost of 0.86 $/L, Temperature 27.07 °C, Solar radiation of 5.14 kWh/m²/day. As observed in Table 11 when the system is operate at average WS was 2.5 m/s, the size of PV and WT wanted were found to be 3500 kW and 3 kW, the size of the WT is 40 kW greater than when the system is operates average WS was 5 m/s. Therefore, the capital cost, operating cost, NPC and COE was rises by roughly 2.99%, 13.16%, 7.95% and 7.94% respectively as associated to when the average WS was 5 m/s as presented in Figure 16.
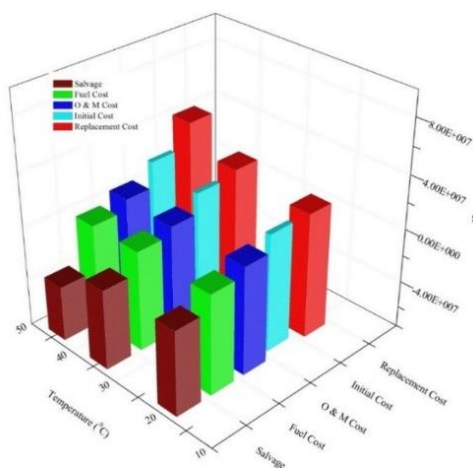

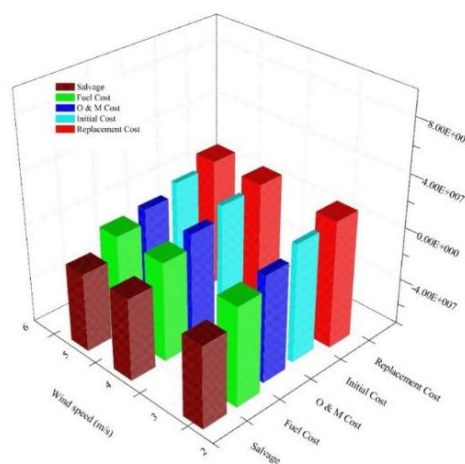| Figure 15. Cash flow summary of PV-WT-DG-battery system at different temperatures	Figure 16. Cash flow summary of PV-WT-DG-battery system at different wind speed

6.5.4. Sensitivity analysis with the variation of fuel price

The universal oil and gas area encounters changes in the costs of prepared raw petroleum items, among the few reasons for these value fluctuations are governmental strategies and complexities emerging from the extraction and handling of unrefined petroleum into items, for example, diesel fuel. Therefore, a sensitivity assessment of variation in diesel prices comes to be essential.

Here, when the cost of fuel were differed between $0.5/L, $1.0/L and $1.5/L at SR of 5.14 kWh/m²/day, Temperature of 27.07 °C, WS of 3.29 m/s, it was seen that costs of diesel impacted the total NPC and COE as found in Table 11. NPC observed at $0.5/L, $1.0/L and $1.5/L expanded in extent by 0.098%, 0.099% and 0.12% in that order. The cost of energy saw at $0.5/L, $1.0/L and $1.5/L expanded by 0.078%, 0.15%, and 0.24% correspondingly.

6.5.5. Sensitivity analysis with variations of PV and WT capital, RC and O&M costs

In this assessment, the photovoltaic and wind system initial cost, RC and O&M costs were given for the period of hybrid system model in HOMER Pro, hereafter an adjustment in the initial, replacement and O & M costs. At an yearly average SR of 5.14 kWh/m²/day, fuel cost of 0.86 $/L, average temperature of 27.07 °C, average WS of 3.29 m/s, varying the initial cost, replacement cost, operation and O & M costs of the photovoltaic and WT was multiplied by 0.6 % and 1.4 % of the original cost. During the photovoltaic system costs are multiplied by 0.6 % and 1.4 %, the net present cost vary from $24,910,280 to $32,979,310 and COE from 0.1089 $/kWh to 0.1442 $/kWh as presented in Table 11. When the wind turbine costs are multiplied by 0.6 % and 1.4 %, the net present cost vary from $28,750,590 to $28,966,780 and COE from 0.1257 $/kWh to 0.1267 $/kWh as presented in Table 11.

6.5.6. Sensitivity analysis with variations of fuel price and average solar radiation

For this assessment, the average solar radiation and fuel cost considered for sensitivity analysis ignoring the wind speed. The solar radiation and fuel costs were both fluctuated to get the impact of variation on the hybrid system economy. In spite of the fact that the diesel cost is selected at \$0.86/L, it ranges between \$0.5/L-\$1.5/L and the average solar radiation as well fluctuates between 4.5 and 5.5 kW/m²/day. Table 12 shows observed sensitivity results, due to the fuel cost and solar radiation fluctuations with corresponding NPC and COE. When solar radiation is increases and fuel cost decreases the system NPC and COE are decreases. Whereas a decrease the solar radiation and increases the fuel cost the system NPC and COE are increases. Figure 17 and Figure 18 exposed the total fuel cost per year and COE respectively for the hybrid PV-WT-DG-battery system.

Table 12. Sensitivity analysis results for optimal hybrid PV-WT-DG-battery system

| Fuel Cost (\$/L)	Solar Radiation (kWh/m²/day)	PV (kW)	WT (kW)	DG (kW)	Battery	Converter (kW)	DS	NPC (\$)	COE (\$/kWh)	Initial Cost (\$)	CO_2 emission
0.5	4.5	3500	452	500	1.477	1.911	LF	57.178.810	0.2501	36.844.784.40	4.967
0.5	4.8	3497	1	500	1.773	1.807	LF	36.414.790	0.1592	18.653.257.57	1.860
0.5	5.5	3480	3	500	1.035	1.838	LF	26.074.030	0.1140	13.411.010.17	2.016
1	4.5	3500	452	500	1.477	1.911	LF	57.231.150	0.2503	36.844.784.40	4.967
1	4.8	3497	1	500	1.773	1.807	LF	36.434.390	0.1593	18.653.257.57	1.860
1	5.5	3480	3	500	1.035	1.838	LF	26.095.270	0.1141	13.411.010.17	2.016
1.5	4.5	3500	452	500	1.477	1.911	LF	57.283.490	0.2506	36.844.784.4	4.967
1.5	4.8	3497	1	500	1.773	1.807	LF	36.453.990	0.1594	18.653.257.57	1.860
1.5	5.5	3480	3	500	1.035	1.838	LF	26.116.520	0.1142	13.411.010.17	2.016
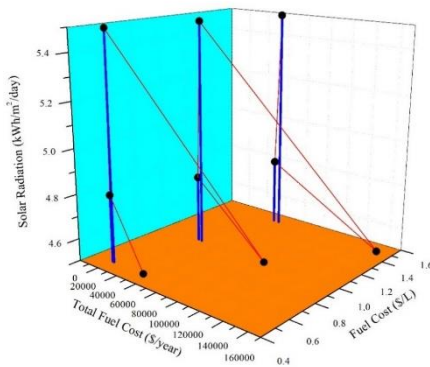
Figure 17. Effect of solar radiation (kWh/m²/day) and fuel price (\$/L) on the total fuel price (\$/year) of the optimal configuration system
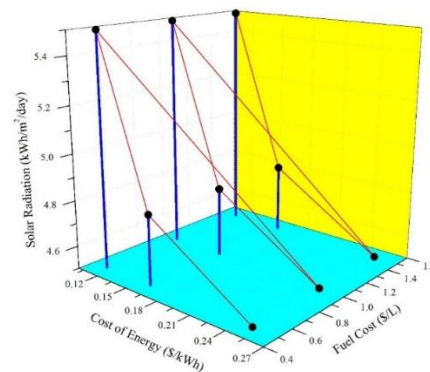

Figure 18. Effect of solar radiation (kWh/m²/day) and fuel price (\$/L) on the COE of the optimal configuration system

7. CONCLUSION

In this assessment, a gird isolated hybrid solar photovoltaic/wind turbine/diesel generator/battery system for electricity generation for Arunai Engineering College in Tiruvannamalai, Tamil Nadu, Southern India. The HOMER Pro software is used to design a hybrid electric system. The proposed system simulation results were determined based on the minimum NPC and COE. In this system were found the four categorized optimal design configuration which take account of PV-WT-DG-battery, PV-DG-battery, PV-WT-battery and PV-battery systems. The acquired results from this hybrid system, it very well be determined that the combination of the energy sources with less NPC of \$28.944.800 and COE of \$0.1266 is the PV-WT-DG-battery and is the optimal combination for all the sensitivity results. a) The optimal PV-WT-DG-battery combination of the system has a renewable fraction of 99.9% with delivered yearly greenhouse gas emission of 2.692 kg; b) The fourth optimal PV-battery combination of the system has a zero-greenhouse gas emission due to the 100% renewable fraction. Unfortunately, the combination has the highest NPC of \$30.601.110 and COE of \$0.1338 because of the huge amount of costs need to spend for converter and storage batteries; c) The economic and environmental analysis has demonstrated that the optimal PV-WT-DG-battery combination system is economically and environmentally feasible for the reason that of less capital cost, operating cost, NPC and COE with less amount of greenhouse gas emission for electric power

generation in Arunai Engineering College in southern India; d) [For] the sensitivity variables, which are average SR, average temperature, average WS, fuel price, multiplication factor of capital cost, RC and O & M cost of the photovoltaic and wind system. It can be found that with a higher value of average SR, average WS with lower value of multiplication factor, fuel price and temperature, the NPC and COE decreases. Due to the higher value of multiplication factor, fuel price and temperature with lower value of SR and WS, the NPC and COE increases; and e) In this techno-economic research of harnessing RE generation for institutional and rural area electrification purpose can be functional to developing countries.

ACKNOWLEDGMENT

REFERENCES

[1] J. Kumar, B.V. Suryakiran, A. Verma and T. S. Bhatti, "Analysis of techno-economic viability with demand response strategy of a grid-connected microgrid model for enhanced rural electrification in Uttar Pradesh state, India," *Energy*, vol. 178, pp. 176-185, 2019, doi: 10.1016/j.energy.2019.04.105.

[2] K. P. Satsangi, D. B. Das, G.S. S. Babu, and A.K. Saxena, "Performance analysis of grid interactive solar photovoltaic plant in India," *Energy for Sustainable Development*, vol. 47, pp. 9-16, 2018, doi: 10.1016/j.esd.2018.08.003.

[3] R. Sharma and S. Goel, "Performance analysis of a 11.2 kWp roof top grid-connected PV system in Eastern Indi," *Energy Reports*, vol. 3, pp. 76-84, 2017, doi: 10.1016/j.egyr.2017.05.001.

[4] S. Bhakta and V. Mukherjee, "Solar potential assessment and performance indices analysis of photovoltaic generator for isolated Lakshadweep Island of India," *Sustainable Energy Technologies and Assessments*, vol. 17, pp. 1-10, 2016, doi: 10.1016/j.seta.2016.07.002.

[5] S. K. Yadav and U. Bajpai, "Performance evaluation of a rooftop solar photovoltaic power plant in Northern India," *Energy for Sustainable Development*, vol. 43, pp. 130-138, 2018, doi: 10.1016/j.esd.2018.01.006.

[6] S. Sundaram and J. S. C. Babu, "Performance evaluation and validation of 5 MWp grid connected solar photovoltaic plant in South India," *Energy Conversion and Management*, vol. 100, pp. 429-439, 2015, doi: 10.1016/j.enconman.2015.04.069.

[7] B. Dobaria, M. Pandya and M. Aware, "Analytical assessment of 5.05 kWp grid tied photovoltaic plant performance on the system level in a composite climate of western India," *Energy*, vol. 111, pp. 47-51, 2016, doi: 10.1016/j.energy.2016.05.082.

[8] S. H. Kulkarni, T. R. Anil and R. D. Gowdar, "Wind Energy Development in India and a Methodology for Evaluating Performance of Wind Farm Clusters, " *Journal of Renewable Energy*, vol. 2016, p. 6769405, 2016, doi: 10.1155/2016/6769405.

[9] M. M. R. Singaravel and S. A. Daniel, "MPPT With Single DC–DC Converter and Inverter for Grid-Connected Hybrid Wind-Driven PMSG–PV System," in *IEEE Transactions on Industrial Electronics*, vol. 62, no. 8, pp. 4849-4857, Aug. 2015, doi: 10.1109/TIE.2015.2399277.

[10] Miloud Benmedjahed, Rachid Maouedj, Samir Mouhadjer, "Wind energy resource assessment of desert sites in Algeria: energy and reduction of CO2 emissions," *International Journal ofApplied Power Engineering (IJAPE)*, vol. 9, no. 1, pp. 22-28, 2020, doi: 10.11591/ijape.v9.i1.pp22-28.

[11] A. Chauhan, R. P. Saini, "Techno-economic feasibility study on Integrated Renewable Energy System for an isolated community of India, " *Renewable and Sustainable Energy Reviews*, vol. 59, pp. 388-405, 2016, doi: 10.1016/j.rser.2015.12.290.

[12] A. Chauhan, R. P. Saini, "Techno-economic optimization based approach for energy management of a stand-alone integrated renewable energy system for remote areas of India," *Energy*, vol. 94, pp. 138-156, 2016, doi: 10.1016/j.energy.2015.10.136.

[13] W. M. Amutha and V. Rajini, "Cost benefit and technical analysis of rural electrification alternatives in southern India using HOMER," *Renewable and Sustainable Energy Reviews*, vol. 62, pp. 236-246, 2016, doi: 10.1016/j.rser.2016.04.042.

[14] M. J. Khan, A. K. Yadav and L. Mathew, "Techno economic feasibility analysis of different combinations of PV-Wind- Diesel-Battery hybrid system for telecommunication applications in different cities of Punjab, India," *Renewable and Sustainable Energy Reviews*, vol. 76, pp. 577-607, 2017, doi: 10.1016/j.rser.2017.03.076.

[15] M. Jahangiri *at al*., "Techno-econo-environmental optimal operation of grid-wind-solar electricity generation with hydrogen storage system for domestic scale, case study in Chad," *International journal of hydrogen energy*, vol. 44, pp. 28613-28628, 2019, doi: 10.1016/j.ijhydene.2019.09.130.

[16] C. Ghenai and M. Bettayeb, "Modelling and performance analysis of a stand-alone hybrid solar PV/Fuel Cell/Diesel Generator power system for university building," *Energy*, vol. 171, pp. 180-189, 2019, doi: 10.1016/j.energy.2019.01.019.

[17] F. Khalid, I. Dincer and Marc A. Rosen, "Techno-economic assessment of a renewable energy based integrated multi generation system for green buildings," *Applied Thermal Engineering*, vol. 99, pp. 1286-1294, 2016, doi: 10.1016/j.applthermaleng.2016.01.055.

[18] A. Yasin and M. Alsayed, "Optimization with excess electricity management of a PV, energy storage and diesel generatorhybrid system using HOMER Pro software," *International Journal ofApplied Power Engineering (IJAPE)*, vol. 9, vol. 3, pp. 267-283, 2020, doi: 10.11591/ijape.v9.i3.pp267-283.

[19] S. Salisu, M. W. Mustafa, L. Olatomiwa and O. O. Mohammed, "Assessment of technical and economic feasibility for a hybrid PV-wind-diesel-battery energy system in a remote community of north central Nigeria," *Alexandria Engineering Journal*, vol. 58, no. 4, pp. 1103-1118, 2019, doi: 10.1016/j.aej.2019.09.013.

[20] M. Usman, M. T. Khan, A. S. Rana and S. Ali, "Techno-economic analysis of hybrid solar-diesel-grid connected power generation system," *Journal of Electrical Systems and Information Technology*, vol. 5, no. 3, pp. 653-662,2018, doi: 10.1016/j.jesit.2017.06.002.

[21] F. C. Amanze and D. J. Amanze, "Off-grid rural electrification using integrated renewable energy sources," *International Journal of Advances in Applied Sciences (IJAAS)*, vol. 10, no. 1, pp. 1-12, 2021, doi: 10.11591/ijaas.v10.i1.pp1-12.

[22] M. Hossain, S. Mekhilef, L. Olatimiwa, "Performance evaluation of a stand-alone PV-wind-diesel-battery hybrid system feasible for a large resort center in South China Sea, Malaysia," *Sustainable Cities and Society*, vol. 28, pp. 358-366, 2017, doi: 10.1016/j.scs.2016.10.008.

[23] M. Nurunnabi, N. K. Roy, E. Hossain and H. R. Pota, "Size Optimization and Sensitivity Analysis of Hybrid Wind/PV Micro-Grids- A Case Study for Bangladesh," in *IEEE Access*, vol. 7, pp. 150120-150140, 2019, doi: 10.1109/ACCESS.2019.2945937.

[24] M. R. Elkadeem, S. Wang, A. M. Azmy, E. G. Atiya, Z. Ullah and S. W. Sharshir, "A systematic approach for planning and design of hybrid renewable energy-based microgrid with techno-economic optimization: A case study on an urban community in Egypt," *Sustainable Cites and Society*, vol. 54, p. 102013, 2020, doi: 10.1016/j.scs.2019.102013.

[25] T. M. Azerefegn, R. Bhandari and A. V. Ramayya, "Techno-economic analysis of grid-integrated PV/wind systems for electricity reliability enhancement in Ethiopian industrial park," *Sustainable Cites and Society*, vol. 53, p. 101915, 2020, doi: 10.1016/j.scs.2019.101915.

[26] L. Lozano, E. M. Querikiol, M. L. S. Abundo and L. M. Bellotindos, "Techno-economic analysis of a cost-effective power generation system for off-grid island communities: A case study of Gilutongan Island, Cordova, Cebu, Philippines," *Renewable Energy*, vol. 140, pp. 905-911, 2019, doi: 10.1016/j.renene.2019.03.124.

[27] S. Bhakta and V. Mukherjee, "Performance indices evaluation and techno economic analysis of photovoltaic power plant for the application of isolated India's island," *Sustainable Energy Technologies and Assessments*, vol. 20, pp. 9-24, 2017, doi: 10.1016/j.seta.2017.02.002.

[28] A. Singh, P. Baredar and B. Gupta, "Techno-economic feasibility analysis of hydrogen fuel cell and solar photovoltaic hybrid renewable energy system for academic research building," *Energy Conversion and Management*, vol. 145, pp. 398-414, 2017, doi: 10.1016/j.enconman.2017.05.014.

[29] J. Ahmad, *et al*., "Techno economic analysis of a wind-photovoltaic-biomass hybrid renewable energy system for rural electrification: A case study of Kallar Kahar," *Energy*, vol. 148, pp. 208-234, 2018, doi: 10.1016/j.energy.2018.01.133.

[30] M.A. Baseer, A. Alqahtani and S. Rehman, "Techno-economic design and evaluation of hybrid energy systems for residential communities: Case study of Jubail industrial city," *Journal of Cleaner Production*, vol. 237, p. 117806, 2019, doi: 10.1016/j.jclepro.2019.117806.

[31] A. S. K. Dalabeeh, "Techno-economic analysis of wind power generation for selected locations in Jordan," *Renewable Energy*, vol. 101, pp. 1369-1378, 2017, doi: 10.1016/j.renene.2016.10.003.

[32] W. Ma, J. Fan, S. Fang and G. Liu, "Techno-economic potential evaluation of small-scale grid-connected renewable power systems in China," *Energy Conversion and Management*, vol. 196, pp. 430-442, 2019, doi: 10.1016/j.enconman.2019.06.013.

[33] D. Thomas, O. Deblecker and C. S. Ioakimidis, "Optimal design and techno-economic analysis of an autonomous small isolated microgrid aiming at high RES penetration," *Energy*, vol. 116, pp. 364-379, 2016, doi: 10.1016/j.energy.2016.09.119.

[34] W. Ma, X. Xue, Gang Liu and R. Zhou, "Techno-economic evaluation of a community-based hybrid renewable energy system considering site-specific nature," *Energy Conversion and Management*, vol. 171, pp. 1737-1748, 2018, doi: 10.1016/j.enconman.2018.06.109.

[35] S. Al-Hamadani, "Solar energy as a potential contributor to help bridge the gap between electricity supply and growing demand in Iraq: A review," *International Journal of Advances in Applied Sciences (IJAAS)*, vol. 9, no. 4, pp. 302-312, 2020, doi: 10.11591/ijaas.v9.i4.pp302-312.

[36] F. Fodhil, A. Hamidat and O. Nadjemi, "Potential, optimization and sensitivity analysis of photovoltaic-diesel-battery hybrid energy system for rural electrification in Algeria," *Energy*, vol. 169, pp. 613-624, 2019, doi: 10.1016/j.energy.2018.12.049.

[37] B. K. Das, N. Hoque, S. Mandal, T. K. Pal, M. A. Raihan, "A techno-economic feasibility of a stand-alone hybrid power generation for remote area application in Bangladesh," *Energy*, vol. 134, pp. 775-788, 2017, doi: 10.1016/j.energy.2017.06.024.

[38] A. C. Duman and Ö. Güler, "Techno-economic analysis of off-grid photovoltaic LED road lighting systems: A case study for northern, central and southern regions of Turkey," *Building and Environment*, 2019, vol. 156, pp. 89-98, doi: 10.1016/j.buildenv.2019.04.005.

[39] C. Li, D. Zhou, H. Wang, H. Cheng and D. Li, "Feasibility assessment of a hybrid PV/diesel/battery power system for a housing estate in the severe cold zoned A case study of Harbin, China," *Energy* 2019, vol. 185, pp. 671-681, doi: 10.1016/j.energy.2019.07.079.

[40] M. R. Elkadeem, S. Wang, S. W. Sharshir and E. G. Atia, "Feasibility analysis and techno-economic design of grid-isolated hybrid renewable energy system for electrification of agriculture and irrigation area: A case study in Dongola, Sudan," *Energy Conversion and Management*, vol. 196, pp. 1453-1478, 2019, doi: 10.1016/j.enconman.2019.06.085.

[41] C. Li and W. Yu, "Techno-economic comparative analysis of off-grid hybrid photovoltaic/diesel/battery and photovoltaic/battery power systems for a household in Urumqi, China," *Journal of Cleaner Production*, vol. 124, pp. 258-265, 2016, doi: 10.1016/j.jclepro.2016.03.002.

[42] M. S. Islam, "A Techno-Economic Feasibility Analysis of Hybrid Renewable Energy Supply Options for a Grid-Connected Large Office Building in Southeastern part of France," *Sustainable Cities and Society*, 2018, vol. 38, pp. 492-508, doi: 10.1016/j.scs.2018.01.022.

[43] M. K. Shahzad, A. Zahid, T. ur 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," *Renewable Energy*, vol. 106, pp. 264-273, 2017, doi: 10.1016/j.renene.2017.01.033.

[44] L. M. Halabi, S. Mekhilef, L. Olatomiwa and J. Hazelton, "Performance analysis of hybrid PV/diesel/battery system using HOMER: A case study Sabah, Malaysia," *Energy Conversion and Management*, vol. 144, pp. 322-339, 2017, doi: 10.1016/j.enconman.2017.04.070.

[45] U. S. Kumar and P. S. Manoharan, "Economic analysis of hybrid power systems (PV/diesel) in different climatic zones of Tamil Nadu," *Energy Conversion and Management*, vol. 80, pp. 469-476, 2014, doi: 10.1016/j.enconman.2014.01.046.

[46] NASA, Surface Meteorology and Solar Radiation, 2019. [Online]. Available: https://eosweb.larc.nasa.gov/sse/.

[47] G. Pillai and H. A. Y. Naser, "Techno-economic potential of large scale photovoltaics in Bahrain," *Sustainable Energy Technologies and Assessments*, vol. 27, pp. 40-45, 2018, doi: 10.1016/j.seta.2018.03.003.

[48] M. Qolipour, A. Mostafaeipour and O. M. Tousi, "Techno-economic feasibility of a photovoltaic-wind power plant construction for electric and hydrogen production: A case study," *Renewable and Sustainable Energy Reviews*, vol. 78, pp. 113-123, 2017, doi: 10.1016/j.rser.2017.04.088.