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A Feasibility Study of Solar-Wind-Diesel Hybrid System in Rural and Remote Areas of Bangladesh

Molla Shahadat Hossain Lipu*‡, Md. Shazib Uddin**, Muhammad Ahad Rahman Miah*

*Department of Electrical and Electronic Engineering, University of Asia Pacific, Bangladesh

**Department of Mechanical Engineering, Rajshahi University of Engineering and Technology, Bangladesh

(lipuhossain@gmail.com, msu0397@yahoo.com, topuuap09@yahoo.com)

‡Corresponding Author; Molla Shahadat Hossain Lipu, University of Asia Pacific, Department of Electrical and Electronic Engineering, Block I , House 54/1 & 53/1, Road 4A ,Dhanmondi R/A, Dhaka 1209, lipuhossain@gmail.com

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Abstract- A feasibility study of a hybrid renewable energy system considering a combined use of solar-wind-diesel has been performed for rural and remote areas of Bangladesh using a software called HOMER (Hybrid Optimization Model for Electric Renewable). The predicted monthly average daily radiation in Bangladesh is 4.36 kWh/m2. The wind speed varies seasonally from 3 m/s to 5 m/s. The hybrid system analysis has showed that the electricity is generated in a year is 330,886 kWh in which 45% electricity comes from wind, 36% electricity comes from diesel generator and the remaining from solar energy. The optimized PV-wind-diesel system reduces the Net Present Cost (NPC) about 13% and 7% compared to PV-diesel generator-battery and wind-diesel generator-battery respectively, which has a similar effect on cost of energy (COE). The hybrid system will reduce CO2 emission by 37% in the local atmosphere compared to electricity draw from national grid.

Keywords- Solar energy, wind energy, hybrid renewable energy system, CO2 emission, socio-economic benefits

1. Introduction

Fossil energy is the major share of world energy consumption. Oil, natural gas and coal together constitute 80% of global energy consumption [1]. But the development of fossil energy is significantly dominated by the concern of global air pollution, water pollution, coastal pollution, deforestation and global climate deterioration. In response to control the global consequences, it is difficult to engage the large-scale energy development activities in a short term policies in developing countries. Over the last few decades, a decline of fossil fuels reserves has been observed world-wide. Alternately, fossil fuels are limited findings and not form in a significant rate compared with consumption. Based on current reserves and consumption rate of fossil resources the world will sustain 122 years for coal, 42 years for oil and 60 years for natural gas [2,3]. World Bank reported that 2.4 billion people rely on traditional energy sources, while 1.6 billion people do not have access to electricity [4]. With an estimated world average growth rate of 2.8%, the electricity demand is expected to be doubled in 2020. During this period, the electricity demand in developing countries is projected to increase by 4.6% annually [5].

Bangladesh is a developing country. Presently, 60% of the total population (including renewable energy) has access to electricity [6]. The installed electricity generation capacity is about 8,100 MW in 2012 [7]. The annual per capita electricity consumption in Bangladesh is only 292 kWh which was much below the world average of 2800 kWh [8]. Due to the shortage of natural gas, weak policies, inefficient power plants and high system losses, the country was unable to meet the growing demand of electricity [9]. There was 15-25 percent shortage of electricity generation which means the country was able to generate only 5,600-6,350 MW against the high demand of 7,500 MW [8]. Natural gas is the major and available energy sources in Bangladesh and most of the power generation unit greatly depends on natural gas. About 73.95% (3685 MW) energy comes from natural gas followed by diesel (13.61%, 678 MW), furnace oil (7.83%, 390 MW) and hydro (4.62%, 230 MW) [10]. The present share of renewable energy in Bangladesh is only 1% [11].

The Government of Bangladesh has its vision and policy to bring the entire country under electricity service by the year 2020 [12]. To eradicate the country from the acute energy crisis, several energy policies have been introduced since 1990. A draft Renewable Energy Policy was released in 2004 [12]. This draft policy provided modalities and procedures for financing arrangements, tariff regulations, fiscal and other incentives for implementation of renewables and guidelines for establishment of an independent renewable energy institution [13, 14]. This draft renewable energy policy has not been finalized or implemented to date. However, a 'Draft Renewable Energy Policy, 2008' was prepared by the Power Cell of Ministry of Power, Energy and Mineral Resources, Bangladesh to promote rural energy programs where emphasize has been given to solar PV and solar thermal technologies [12]. The application of renewable energy sources like solar, wind, biomass, geothermal is still limited in the power generation sector. But the potential of solar, biogas and wind resources is significant [15].

The government is investing substantially in renewable energy, particularly solar power and biogas for rural households and enterprises. Though there are several technologies to get energy from solar, but power generation from solar is dominated by PV in Bangladesh. The current electricity generation from Solar Home Systems (SHSs) in the country amount to 65 MW. The target is to install 2.5 million SHSs by 2014 [15]. There are several government and private organizations (i.e IDCOL, BRAC, Grameen Shakti, REB, BPDB, LGED) in Bangladesh these are in charge to disseminate solar home system. Infrastructure Development Company Limited (IDCOL) has installed a total of 1.4 million SHSs which save 100,000 tonnes of fuel a year and provide livelihood to 70,000 people. The SHS has generated a US$ 200 million market in Bangladesh through an innovative financing mechanism by making it easier for the poor to pay back the credit in installments over 3 years with interest [16]. In 2011, the government made it mandatory for developers to install solar power to meet 3% of the total electricity requirement of any new building before getting electricity connection. This will not only reduce the load on conventional power but also force developers to plan for green buildings. Although the country saw some progress in the area of solar and biogas energies, hardly any progress has been made in respect of wind energy. The few wind turbines that were set up as pilots have not been sustainable. Absence of wind mapping in the country remains a constraint [16].

The electrification rate in rural areas of Bangladesh is only 30% [17]. The lower electrification rate as well as the irregular supply of electricity not only hamper the daily life of rural people but also hinder socioeconomic development. As most of the rural areas in Bangladesh are located far from the national grid, so a sufficient amount of time and money are required for grid extension. In that scenario, renewable energy sources like sun, wind which is quiet affluent in Bangladesh can act as a stand-alone system. As sun is not available during the night time and wind speed is fluctuated throughout the day, so a diesel generator can be used as a backup considering a combined use of solar-wind-diesel hybrid system to avoid intermittent supply of electricity.

Hybrid renewable energy systems (HRES) are becoming popular for power generation applications due to its advances in renewable energy technologies. HRES combined the types of renewable energy sources like solar, wind, and others to deliver useful energy to meet the demands. Balance, reliability and stability are the advantages of using a combination of various renewable energy sources. The balanced system can provide stable outputs from sources and minimizes the dependence of the output upon seasonal changes; furthermore, it optimizes utilization of the different renewable sources of energy available [18]. In addition, if multiple energy storage devices with complementary performance characteristics are used together, the resulting hybrid system can dramatically decrease the cost and investment of energy storage over single storage systems [19]. Large scale solar photovoltaic and wind system is popular over the world in the context of energy supply shortage. Reliable supply is the major problem of these systems as the sources are seasonal. Therefore, energy storage system is required for each of these systems in order to get continuous supply of energy. Usually storage system is expensive and hence the cost effective size of storage system is important. Hybrid power systems can be used to reduce energy storage requirements.

The purpose of the study is to evaluate the feasibility of PV-wind-diesel hybrid system in rural and remote areas of Bangladesh through optimization using HOMER. Besides, the study estimates CO2 emission and assesses its effectiveness in reducing CO2 emission. Furthermore, the study brings out the advantages on social and economic life of rural people.

The organization of this paper is as follows. Section 2 provides a brief description of solar and wind energy resource assessment at different locations in Bangladesh using Geospatial toolkit and Ret screen software. Section 3 presents system description and assumptions. The electric load demand profile of the selected location is presented in section 4. Section 5 describes the model and simulation using HOMER software. Section 6 presents results and discussions. Section 7 concludes.

2. Solar and wind energy potential in Bangladesh

Bangladesh is situated between 20.30° and 26.38° north latitude and 88.04° and 92.44° east longitude with an area of 147,500 km2, which is an ideal location for solar energy utilization. Bangladesh has 724 km long coastline and number of small islands namely, Saint Martin, Kutubdia, Swandip and Hatia in the Bay of Bengal are suitable for wind energy.

2.1. Solar Energy Potential

The average annual power density of solar radiation is typically in the range of 100-300 W/m2 [20]. A solar PV efficiency of 10%, an area of 3-10 km2 is required to establish an average power output of 100 MW, which is about 10% of a large coal or nuclear power plant [20]. Solar energy conversion technologies do not produce noise, pollution etc. and can be installed near consumers to reduce construction costs. Application of solar energy technologies required unused land or it can be installed on rooftops. A study suggested that 6.8% (10,000 km2) of Bangladesh's total land is required for power generation from solar PV to meet electricity demand of 3000 kWh/capita/year [21]. The total household roofs area in Bangladesh is about 4670 km2 [22] which is 3.2% of total land area of the country. In urban area (Dhaka city), about 7.86% of total land is suitable for rooftop solar PV electricity generation [23]. Considering the grid availability, only 1.7% of the land in Bangladesh is assumed to be suitable for generating electricity from solar PV [24]. The capacity of grid-connected solar PV is derived using the annual mean value of solar radiation (200 W/m2) and a 10% efficiency of the solar PV system. Thus, the potential of grid-connected solar PV in Bangladesh is calculated as about 50,174 MW [25]. Table 1 shows the average daily solar radiation at different locations in Bangladesh.

Table 1. Average daily solar radiation at 14 locations in Bangladesh [26, 27]

Station Name	Elevation (m)	Latitude (degrees)	Longitude (degrees)	Radiation (RERC) (kWh/m2/day)	Radiation (NASA) (kWh/m2/day)
Dhaka	50	23.7	90.4	4.73	4.65
Rajshahi	56	24.4	88.6	5.00	4.87
Sylhet	225	24.9	91.9	4.54	4.57
Khulna	11	22.8	89.6	-	4.55
Rangpur	230	25.7	89.3	-	4.86
Cox's Bazar	76	21.4	92	-	4.77
Dinajpur	194	25.6	88.6	-	4.99
Kaptai	345	22.5	92.2	-	4.71
Chittagong	118	22.3	91.8	-	4.55
Bogra	59	24.8	89.4	4.85	4.74
Barisal	31	22.7	90.4	4.71	4.51
Jessore	23	23.2	89.2	4.85	4.67
Mymensingh	114	24.8	90.4	-	4.64
Sherpur	308	25	90	-	4.67

Table 1 shows that Bangladesh receives average 4.64 kWh/m2 solar radiation per day which is a very good number for generating electricity. Considering an average standard 50 Wp solar panel for each household, the total capacity will be equivalent to 200 MW (200 MWp) [28]. The same capacity is applicable for the hybrid system, as this system is suitable only for rural non- electrified remote areas. Economic viability of SHSs in Bangladesh was evaluated in [29] and techno-economic viability of hybrid systems was described in [30].

2.2. Wind energy potential

Bangladesh Center of Advance Studies (BCAS) project in collaboration with Local Government Engineering Department (LGED) and the UK's Energy Technology Support Unit (ETSU) found that the coastal areas of Bangladesh have the potential to utilize the wind velocity for power generation in both summer and winter season over the year [31]. The study showed that the average annual wind speed measured in the seven coastal stations ranged from 2.94 m/s to 4.52 m/s which is shown in Table 2.

Table 2. Monthly average wind speeds at 25 meter height at seven coastal stations measured by WEST [29].

Year	Month	Monthly average wind speed (m/s) at the monitoring stations stated						
		Patnga	Cox's Bazar	Teknaf	Noakhali	Char Fasion	Kuakata	Kutubdia
2009	June	8.75						
	July	5.87	5.42	5.77				
	August	5.32	5.33	4.9	4.7	5.2	5.7	
	September	3.36	3.69	3.46	2.94	3.34	3.77	3.58
	October	3.2	3.74	3.3	2.83	3.7	2.18	3.98
	November	2.61	2.93	2.29	1.91		1.98	3.23
	December	2.97	1.78	1.44	1.35	3.09	3.35	3.38
2010	January	3.25	2.33	1.99	1.31	2.8	3.18	3.67
	February	3.13	1.99	1.9	1.9	2.69	3.37	3.29
	March	2.88	2.42	2.26	2.38	3.54	4.84	3.53
	April	4.96	1.84	1.65	2.25	3.29	4.93	3.1
	May	5.83	3.97	3.09	3.99	4.81	6.28	4.89
	June	5.67	4.64	3.26	5	5.76	7.31	5.9
	July	5.13	4.8	4.33	4.92	5.22	7.34	6.17
	August		4.31	4.03	3.85	5.17		5.34
	September		2.96	1.83	2.77	3.08		3.97
Annual Average		3.95	3.34	2.94	2.96	4.07	4.52	4.21

A 900 kW plan was undertaken by BPDB at Moghnama Ghat in the Cox's Bazar district. Another project of 1000 KW Wind Battery Hybrid Power Plant at Kutubdia Island was completed in 2008 which consists of 50 Wind Turbines of 20 kW capacity each. Small-scale wind turbine generators have been installed by Grameen Shakti (GS) and Bangladesh Rural Advancement Committee (BRAC) in coastal regions of the country. GS installed a 300 W Southeast Air Module (USA) unit and a 1 kW LMW (the Netherlands) unit at Chakoria in the Chittagong district. BRAC installed 11 wind turbine generators in various coastal sites. These systems supply power to some target groups to improve their standard of living [11].

Bangladesh Power Development Board (BPDB) is planning to install a 15 MW grid-connected wind energy farm at Muhuri Dam in the Feni district. BPDB has planned to implement 50-200 MW Wind Power Project at Parky Beach area, Anawara, Chittagong on IPP basis. Power Division and BPDB have primarily identified 22 potential sites for Wind Resource Mapping in Bangladesh. Wind monitoring stations will be installed at these sites for comprehensive Wind Resource Assessment (WRA). BPDB has planned to install Wind monitoring stations at Inani Beach of Cox'sbazar, Parky Beach of Anwara, Sitakundu of Chittagong and at Chandpur under USAID TA project. BPDB has also plan to expand On-shore Wind Power Plants along the coastline of coastal regions of Bangladesh [11].

Seasonal variation of wind speed poses some limitations to wind power generation and its widespread application in Bangladesh. Most of the potential sites in the country are situated in coastal regions and are not connected to the national grid. GS has installed four stations of wind turbines, diesel generator and solar PV hybrid system in the coastal areas of the Barguna district. Three of these have a capacity of 1.5 kW each, while the fourth has a capacity of 10 kW [32]. Local Government Engineering Department, Local Government Engineering Department (LGED) installed 10 kW wind-solar hybrid systems at Saint Martin island in the Chittagong district under the Sustainable Research Excellence (SRE) program with the financial aid of United Nations Development Program (UNDP) [33].

3. System description and assumption

A solar-wind-diesel hybrid system is considered for feasibility study in Bangladesh. The hybrid system will be used to supply electricity to the community living in a remote or rural areas in Bangladesh. The system consist two renewable sources namely solar (50 kWp) and wind (40 kW). A battery bank of 225 Ah capacity and a 50 kW DC/AC converter has been used. A diesel back-up system (50 kW) is also considered for reliability supply of electricity. The system is fully automatic operated by relay switch to ensure reliable supply of electricity. The detailed description of the components of the hybrid system is illustrated in Table 3.

Table 3. Components of the hybrid system analysis [34]

Characteristics	PV module	Wind turbine	Diesel Generator	Battery	Converter
Model	Typical	WES 5 Tulipo	Typical	Trojan T-105	Typical
Power	50 kWp	3 kW	50 kW	Nominal voltage 16 V Nominal capacity 225 Ah	1 kW
Life time	20 years	15 yeas	20 years	Lifetime throughput 845 kWh	20 years
Price	5000 USD/kW	5000 USD/Turbine	15000 USD/kW	225 USD/battery	400 USD/kW
Replacement	2500 USD/kW	4000 USD/Turbine	8000 USD/kW	200 USD/battery	250 USD/kW
Maintenance	3 USD/kW	50 USD/Turbine	0.7 USD/hr/kW	1 USD/battery	1 USD/kW

The following assumptions are considered for the study:

- Project life is assumed to be 30 years and the annual discount rate as 4%.
- Salvage value is taken as 5% of the capital cost.
- Solar panel life is considered 20 years (according to panel manufacturers and SHS installers in Bangladesh). The diesel generator lifetime is also considered 20 years. The lifetime of wind turbine is taken 15 years. The converter is assumed to be replaced after 20 years.
- The total system capacity is around 330,886 kWh annually.
- The energy consumption by a hypothetical community in the proposed site is 850 kWh/day with 104 kW peak demand.
- The cost for the distribution system that would connect the local houses is not considered.
- In the case of proposed hybrid project no such leakages are identified that create indirect emission effects. Emissions occurring during construction period are insignificant.

4. Electric Loads Demand Profile

The daily load profile of the hypothetical community situated in the rural or remote areas in Bangladesh is presented in Fig. 1. The figure shows that consumption is high in the summer (April to September) months than that in winter (October to March) months. In this analysis it is considered that the local houses are closed to each other, so that they could be served by a stand-alone hybrid.

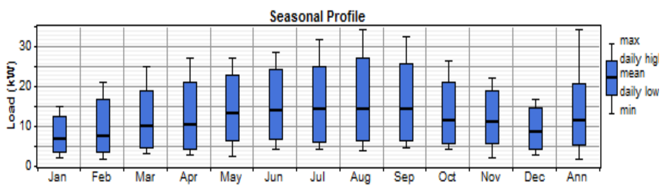

Fig. 1. Daily load demand

5. Design and Simulation

The simulation of the system was done by the software name Hybrid Optimization Model for Electric Renewable (HOMER). The design and simulation procedure is described as follows:

5.1. System Design

The whole system has been designed as a stand-alone system. The system consists of PV Panel, wind turbine, diesel generator, Battery and Converter. There are two buses in the system; AC and DC bus. The output energy of solar PV is stored in a battery which is on the DC bus side. To convert AC from DC, a converter is used. Wind and diesel generator are operating at AC bus. Figure 2 shows the system design.

5.2. Simulation procedure

The visual simulation and analysis has been accomplished by an optimization tool called the Hybrid Optimization Model for Electric Renewable (HOMER, Version 2.68 Beta). It has been originally designed at NREL, USA [35]. HOMER is the software that simplifies the designing of Distributed Generator (DG) systems either off grid or on grid. Its algorithms permit to assess the technical and economic feasibilities of a big system that has lots of technical options and variations. Optimization and the sensitivity analysis are two of its great features. For the analysis, HOMER needs information on system configuration (whether off grid or grid tied), load profile, component specifications including size and numbers, resources data, economics, system control, emissions, constraints etc. The sensitivity analysis is also possible while providing different variables values. The values of different parameters, considered for the modeling and simulation in HOMER is shown in Table 4. Assumptions are made considering the local situation.

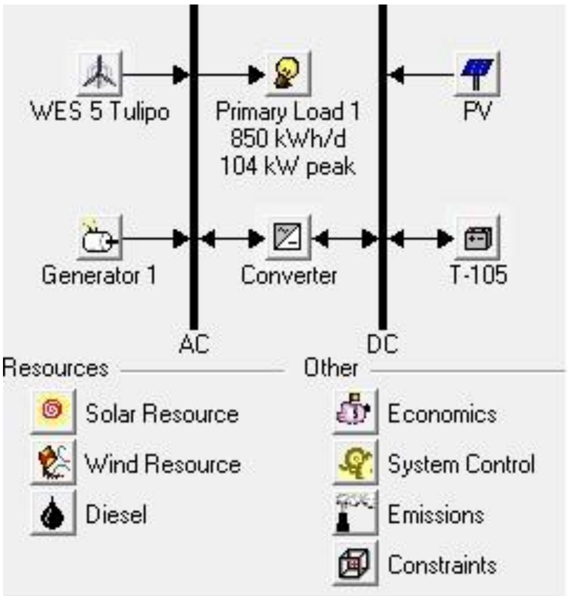

Fig. 2. Configuration of the proposed hybrid system

Table 4. Details of technical and economical parameters used for HOMER

Hybrid system component	Item Parameters	Unit	Value
PV	Derating Factor	%	70
	Slope	Degree	20.43
	Azimuth	Degree west of south	20
	Ground reflectance	%	20
	Tracking	-	No
Wind	Rated power	kW	2.5
	Hub height	Meter	20
	Blade	No.	2
	Diameter	Meter	5
Battery	Nominal Voltage	Volt	2
	Nominal Capacity	Ah	225
	Lifetime Throughput	kWh	845
	Round trip efficiency	%	85
	Min. state of charge	%	30
	Float life	Years	10
	Batteries per string	-	1
Converter	Efficiency	%	95
Rectifier	Efficiency	%	90
	Capacity relative to inverter	%	85
Primary Load	Average	kWh/day	850
	Average	kW	35.4
	Peak	kW	104
	Load Factor	-	34%
	Day to day variability*	%	2.8
Fuel	Diesel	$/L	0.6

HOMER provides a method for finding the least-cost system design on the basis of a given load size, system components and data for energy sources. HOMER simulates thousands of system configurations, optimizes for lifecycle cost, and generates results for sensitivity analyses on most inputs by making energy balance calculations for each of the 8760 hours in a year. For each hour, it compares the electric and thermal load in the hour to energy that the system can supply in that hour. For a system that includes batteries, the software also decides for each hour how to operate the generators and whether to charge or discharge the batteries. If the system meets the loads for the entire year, HOMER estimates the lifecycle cost of the system, accounting for the capital replacement, operation, and maintenance, fuel and interest costs. After simulating all possible system configurations, HOMER displays a list of feasible systems, sorted by lifecycle cost. This simulation tool can perform a sensitivity analysis which shows the variation of results with change in inputs and repeats the optimization process for each of the input so that one can examine the effect of changes in the value on the results.

The study performs the optimization through HOMER software. HOMER implements the energy balance calculations for each system configuration and determines whether a configuration is feasible, i.e., whether it can meet the electric demand under the conditions that are specified, and estimates the cost of installing and operating the system over the lifetime of the project. The system cost calculations account for costs such as capital, replacement, operation and maintenance and interest. HOMER displays all of the possible system configurations, sorted by net present cost (NPC).

6. Results and Discussions

The optimization result of the system, emissions, potential emission reduction and system benefits are presented in this section.

6.1 Optimization

HOMER eliminates all infeasible systems and presents the results in ascending order of net present cost (NPC). Different hybrid options were analyzed to get an optimized hybrid system. The comparison of optimized hybrid system with PV-wind-Diesel generator-battery has been compared with PV-diesel generator-battery and wind-diesel generator-battery is given in Table 5.

Table 5. The comparisons among the optimized hybrid options.

Options	PV (kW)	WES 5 Tulipo (kW)	Diesel generator (kW)	T-105	Converter	Initial cost (USD)	Operating cost (USD/year)	Total NPC (USD)	COE (USD/kWh)
PV-Wind-Diesel Generator-Battery	50	40	50	135	50	515,375	50,115	1,285,761	0.27
PV-Diesel Generator-Battery	50	-	50	135	50	315,375	74,514	1,460,830	0.31
Wind-Diesel Generator-Battery	-	40	50	135	50	378,909	68,598	1,375,780	0.295

Table 5 shows that the optimized PV-wind-diesel generator-battery system which reduces the NPC about 13% and 7% compared with PV-diesel generator-battery and wind-diesel generator-battery respectively, which has a similar effect on cost of energy is defined as the ratio of the annualized cost of producing electricity (the total annualized cost minus the cost of serving the thermal load) and the total useful electric energy production. The cash flow summary of the optimized hybrid system is depicted in Fig. 3.

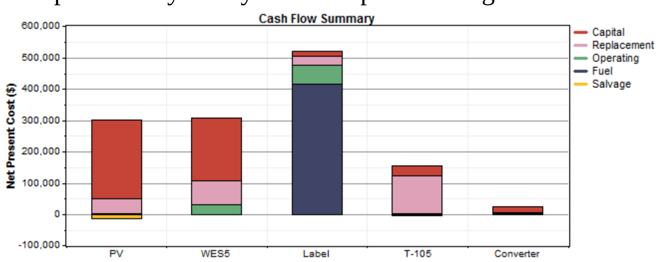

Fig. 3. Cash flow summary of the optimized wind-PV-diesel hybrid system.

The optimization results shows that the optimal PV-wind-diesel generator-battery hybrid system has the lowest NPC (1,285,761 USD) with COE of 0.27 USD/kW. The annual electricity production from the optimal design solution is 303,886 kWh where PV contributes 20% electricity, wind contributes 45% electricity and diesel generator contributes 36% electricity which is depicted in Fig. 4.

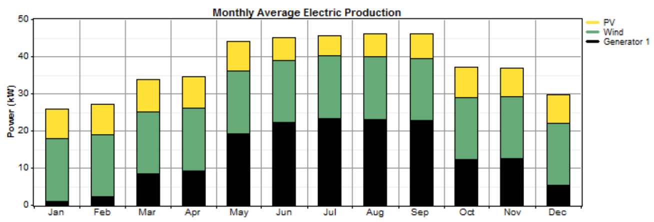

Fig. 4. Annual energy production from the optimized hybrid system.

The total capital cost including solar, wind, diesel generator, converter and battery is 515,375 USD. The source of revenue is only the selling of electricity. Considering 330,886 kWh electricity generated annually and electricity selling price of 15 Tk/kWh (0.19 USD/kWh), the revenue of the hybrid system will be 62,868 USD/year. The estimated payback period is 8.2 years.

6.2. Emissions

Different types of pollutants are emitted during combustion of fossil fuels such as CO2, CO, NOx, SO2 unburned hydrocarbon etc., but in this study, only CO2 emission estimation has been calculated due to its dominant role. The estimation of emissions were calculated using the Eq. (1), (2) and (3) are as follows.

Amount of energy released during diesel burning (GJ/year) = Diesel consumption (liter/year) × calorific value of Diesel (MJ/liter) (1)

CO2 Equivalent (tonne/year) = Amount of energy released during diesel burning (GJ/year) × CO2 emission factor (kg/GJ) (2)

C Equivalent (tonne/year) = 3.67 × CO2 Equivalent (tonne/year) (3)

The amount of diesel consumption in a year is 45,209 liter. The calorific value and emission factor of diesel is 43 MJ/liter and 74.1 kg/GJ respectively [36]. Using the above equations, total CO2 emission is 4356 tonne and Ceq emission is 1187 tonne for the entire project life cycle (30 years) depicted in Table 6.

Table 6. CO_2 and C_{Eq} emission by diesel burning

Consumption (liters/year)	Calorific value of Diesel (MJ/liter)	Energy Released (TJ)	CO_2 Equivalent (tonnes/year)	C Equivalent (tonnes/year)	CO_2 Equivalent (tonne)-30 years	C Equivalent (tonnes)-30 years
45209	43	1.96	145.21	39.57	4356	1187

6.3. Potential Emission Reduction

The main sources of total electricity (330,886 kWh/year) generated from this hybrid project are the Solar PV, wind and diesel. The emission factor for Bangladesh is 0.7 tons CO2/MWh [36]. If same amount of electricity is draw from national grid then the total GHG emission would be 233 tonnes CO2 eq and 63 tonnes Ceq. Considering 30 year period of time, total CO2 and Ceq emission will be 6,949 tonnes and 1893 tonnes respectively, which means, if hybrid system is used, then, 2593 (=6949-4356) tonnes of CO2 and 706 tonnes (=1893 - 1187) of Ceq will be saved. Thus, the hybrid system will reduce CO2 emission by 37%.

6.4. Socio-economic benefits

The study evaluates the performance of the hybrid system which is a combination of 3 independent and globally proven and also regionally and locally tested Technologies (PV, wind and diesel), combined as a hybrid to strike a good balance between environmental benefits as well as socio-economic development. Its success, as mentioned, will lead to its scale-up and dissemination and hence effect a transfer of technology on a larger scale in Bangladesh, where decentralized power plants (50 kW - 10 MW range) are considered to be ideal, being 'Fast Track' plants with a high degree of reliability for continuous electricity supply, minus the current negative experience with huge grid "System Losses" and slow implementation of large Central Plants. The outcome of this hybrid system not only supplies reliable electricity supply to the rural and remote areas of Bangladesh but also makes effective contribution in the social life. The benefits of this hybrid project are discussed below.

- The proposed PV-wind-diesel Hybrid power plant would diversify the source of electricity generation and lead to energy security and sustainable energy supply in the rural and remote areas where there is irregular supply of electricity.
- The implementation of the project will minimize the GHG Emission, resulting in a net reduction of the GHGs, thus bringing a local as well as a global carbon benefit.
- The successful implementation and operation of the hybrid system will lead to further future dissemination and also scale-up of the system to larger capacities, thus displacing more conventional grid where old diesel units are being used presently to produce unreliable and high emission.
- It will promote to capacity building and also contribute to the technology transfer in installation and operational of Renewable Energy - Fossil Hybrid Power Plants which have low emission and cost effective than 100% fossil fuel based plants.
- A number of households currently meeting their lighting needs with kerosene will switch over the electricity, which will also contribute to reduce fire-hazards.
- The project will improve the overall quality of life of people living in the project area that will enjoy reliable electricity supply and related other socio-economic benefits, like longer study hours getting connected to TV and other media/communications with the outside areas, including global exposures.
- Being a central small rural power plant, the direct employment generation will be limited only to a few plant operators and maintenance personnel, including a Plant In-Charge. However, due to the enhancement of quality of life and facilitation of economic activities, the indirect employment generation will increase small rural incomes through Handicrafts, Weaving and other production activities.

7. Conclusion

The hybrid system will bring enormous benefit to the rural and remote areas of Bangladesh where there is severe crisis of reliable supply of electricity. The study clearly shows that the optimized wind-PV-diesel hybrid system is more cost effective in terms of Net Present Cost (NPC) and Cost of Energy (COE) compared to PV-diesel, wind-diesel system. The system will reduce the CO2 emission by 37% thus bringing a local as well as a global carbon benefit. The potential of the system will promote socio-economic development to the local people by getting longer hours of electricity supply after sunset which will help the students to study more as well as local businessman to earn more. Technology transfer and capacity building have also been developed in implementing combined renewable-fossil fuel power plants. However, the effectiveness of the hybrid system is promising enough that further analysis can be made to collect the additional data to perform a more detailed analysis.

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