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ROADMAP OF AN OPTIMIZED HYBRID RENEWABLE ENERGY SYSTEM (HRES) MODEL IN SAINT MARTIN ISLAND, BANGLADESH AND SIMULATION OF IT USING HOMER

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Abstract*-A Hybrid Renewable Energy System (HRES) may be used to reduce dependency on either conventional energy or renewable energy system. Optimization of HRES looks into the process of selecting the best components and its sizing with appropriate operation strategy to provide cheap, efficient, reliable and cost effective alternative energy. In this paper, a methodology will be developed for optimum planning of hybrid system with some battery backup. The hybrid system consists of three energy sources-Wind turbine, PV system and Diesel generator. Among them, two sources are renewable and one is fossil fuel. Solar radiation data, wind speed throughout the year in Saint Martin Island and component database from manufactures will be analyzed and simulated in HOMER to assess the technical and economic viability of the integrated system. To develop this system we have to use load consumption data in Saint Martin Island. Performance of each component will be evaluated and finally sensitivity analysis will be performed to optimize the system at different conditions.*

Keywords: Wind turbine, PV system, Diesel generator, HOMER software, Hybrid Renewable Energy System (HRES).

1. INTRODUCTION

Bangladesh has a large unsatisfied demand for energy, which is growing by 10 percent annually [1]. Currently, it has the lowest per capita consumption of commercial energy in South Asia. Presently total generation capacity is 6727 MW. Of this capacity 3534 MW is from public sector and 3193 MW is from the private sector, which is 53% and 47% respectively of the total generation capacity [2].

To meet the cumulative demand of electricity coal, gas, diesels are being used to produce electricity. But it is also insufficient.

In order to lessen the pressure of power demand on our conventional power plant, renewable energy like wind and solar power can be used. In Bangladesh, the country receives an average daily solar radiation of 4–6.5 kWh/m^2. So, solar energy can be a potential source of power to produce electricity.

Moreover, in Bangladesh, winds are available mainly during the Monsoons and around one to two months before and after the Monsoons. During the months starting from late October to the middle of February, winds either remain calm or are too low to be of any use by a traditional windmill.

Except for the above mentioned period of four months, a windmill if properly designed and located, can supply enough energy to be marketable. So wind power can be used to produce electricity.

The software designs an optimal configuration to serve the desired electric loads. To design the optimum system, HOMER performs thousands of hourly simulations. HOMER also performs sensitivity analysis to see the impact of solar insolation, PV investment cost, Wind speed and Diesel fuel price on the COE [3]. Homer cannot model transient changes which are smaller than 1 hour. Economic analysis is very important before installing the system to generate power. HOMER makes this economic analysis and ranks the systems according to their net present cost.

In this paper, we will show a good optimized combination among solar, wind and diesel for Saint Martin Island using HOMER, software for optimization of renewable based hybrid systems, has been used to find out the finest technically, economically and environmentally viable renewable based energy efficient system.

2. PRESENT CONDITION OF SAINT MARTIN ISLAND

Saint Martin's Island is Located on the southern-most tip of Bangladesh, roughly between 20° 34' - 20° 39' N and 92° 18' - 92° 21' E and 17 km off Teknaf, the most southern main land of Bangladesh . The local name of the island is "Narical Jinjira" translated from Bengali, meaning "Coconut Island" which is the only coral island in Bangladesh. The Island is flat and just only about 3 m high from the sea level. The island is very much resourceful with enormous biological diversity such as existing fauna and flora Coral, Mollusk, Fish, Amphibian, Turtle, Snail, Bird and Mammals. Besides above coconut tree is the important cash crop [4]. Recently Government has taken decision to formulate a master plan for development and protection of bio-diversity of St. Martin's Island and also to build several establishments for the tourism development at St. Martin's Island [5]. An overview of Saint Martin’s Island has given in Fig.1.

A survey was done by the Sustainable Rural Energy (SRE) Program of Local Government Engineering Department (LGED) in 2004 and recorded that the population of the Island is 5196 where most of them are fisherman and they belong to 778 families. The annual electric energy demand was found about 359 MWh [6]. There is a 30 KW diesel generator in St. Martins Island installed by PDB, but it is not running [7]. People meet there energy demand through kerosene, coconut palm or by other biomass plants. Some of the commercial shops and hotels meet their electricity demand by Diesel Generator.

The Island has a good potential of solar and wind energy resources. But till now there has no such activity to use these resources. Therefore HOMER (Hybrid Optimization Model for Electric Renewable) is being used to find out a good optimized solution.

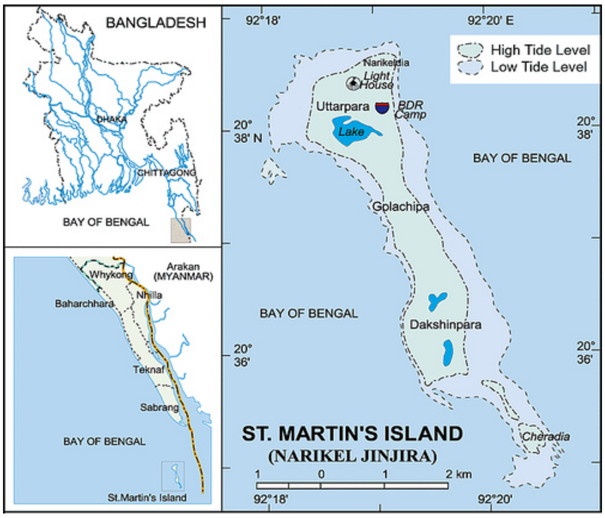

Fig. 1: An Overview of Saint Martin Island.

3. HYBRID RENEWABLE ENERGY SYSTEM

In this study solar and wind energy has been used with a diesel generator. The hybrid system consists of an electric load, renewable energy sources (solar and wind) and other system components such as PV, wind turbines, battery, converter [8]. Fig. 2 shows the complete hybrid renewable energy system and Fig. 3 shows the hybrid system for power generation.

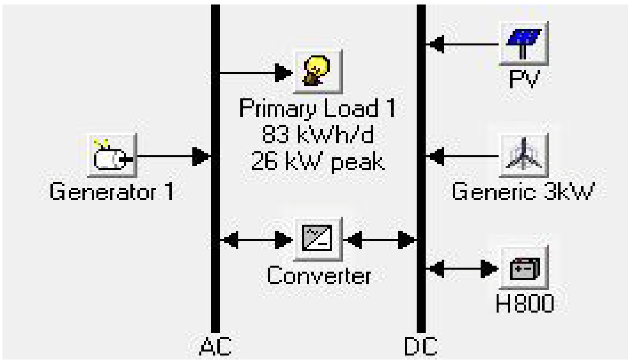

Fig. 2: Complete overview of a Hybrid Renewable Energy System (HRES).

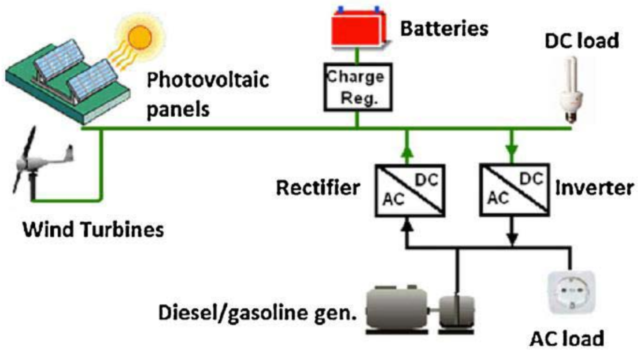

Fig. 3: Schematic diagram of hybrid energy system.

3.1 Electric Load

In this study, a community of 100 households and 20 shops has been considered. This load is based on 3 energy efficient lamps (compact fluorescent bulb, 20 W each), 2 fan (ceiling fan, 40 W), and 1 television (TV, 40 W) for each family and 1 energy efficient lamps (20 W each), 1 fan (40 W) for each shop and overall 2 refrigerators (150 W each). Total electrical demand is calculated by considering the same average electrical load for all the houses in the island. Same average electrical load also calculated for 20 shops. For random variability of the load profile, day to day factor of 10.8% and time-step to time-step of 7.9% is considered in the design. Including all the factors and assumptions, energy demand per day is 83 KWhr and the peak demand is 26 KW. In Fig. 4 & 5 hourly & monthly averaged load profile for all houses and shops are given below.

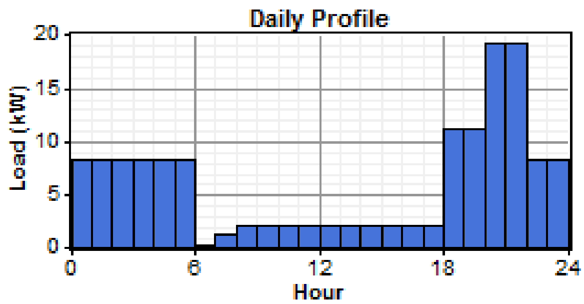

Fig. 4: Load profiles on a day of summer (June).

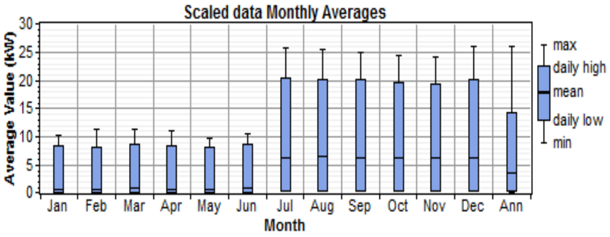

Fig. 5: Load profile on monthly basis at St. Martin Island.

4. RENEWABLE ENERGY RESOURCES

4.1 Solar Energy Resources

As hourly data is not available therefore monthly averaged global radiation data has been taken from NASA. HOMER introduces clearness index from the latitude Information of the selected site (Fig. 6). HOMER creates the synthesized 8760 hourly values for a year using the Graham algorithm [9], which results in a data sequence that has realistic day-to-day and hour-to-hour variability and autocorrelation. Solar energy data inputted in HOMER is given in following table 1.

Table 1: Solar Energy Data inputted in HOMER.

		Daily Radiation
Month	Clearness Index	(kWh/m^2/d)
January	0.651	4.812
February	0.627	5.270
March	0.592	5.682
April	0.551	5.790
May	0.496	5.424
June	0.323	3.560
July	0.320	3.502
August	0.327	3.476
September	0.385	3.796
October	0.514	4.487
November	0.562	4.269
December	0.646	4.560

HOMER introduces clearness index from the latitude and longitude information of the selected site. HOMER creates the synthesized 8760 hourly values for a year using the Graham algorithm. Fig. 5 illustrates that the solar radiation is high from February to April. The average annual clearness index is 0.484 and the average daily radiation is 4.549 kWh/m^2/d.

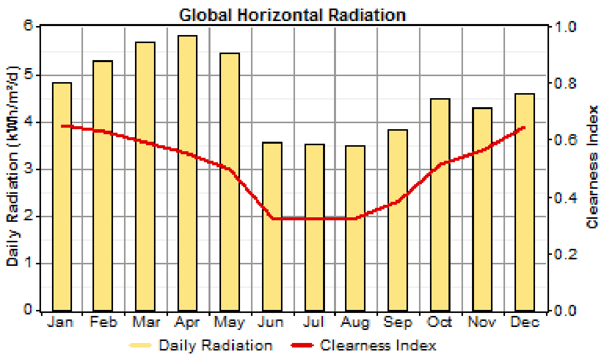

Fig. 6: Solar Resource.

4.2 Wind Energy Resources

Bangladesh has a 724 km long coastal line along the Bay of Bengal. There are also many islands in the Bay where wind speed is high enough to provide Electricity commercially. The strong south/south-western monsoon wind come from the Indian Ocean travelling a long distance over the Bay of Bengal, through the coastal area of Bangladesh. This wind blows over Bangladesh from March to September with a monthly average speed of 3 m/s to 9 m/s at different height [10]. According to studies of Meteorological Department, BACS, LGED, BUET winds are available in Bangladesh mainly during the monsoon. (7 months, March to September). Rest of months (October to February) wind speed remains either calm or too low. The peak wind speed occurs during the month of June and July.

Wind velocity at the coastal area and isolated island is quite higher than rest of the locations [11].Wind speed at 30m height in Saint Martin's Island has given in Table 2.

Table 2: Wind speed at 30m height inputted in HOMER.

Month	Wind Speed (m/s)
January	4.480
February	4.620
March	4.540
April	4.090
May	5.370
June	6.470
July	5.860
August	5.980
September	4.770
October	4.410
November	3.830
December	4.310

When hourly data is not available, hourly data can be generated synthetically from the monthly averages. HOMER's synthetic wind speed data generator is a little more different to use than the solar data because it requires four parameters [12] -

(1) The Weibull value: k value is a measure of distribution of wind speed over the year. In this study the value of k is taken as 2.
(2) The autocorrelation factor: This factor measures the randomness of the wind. Higher values indicate that the wind speed in 1 h tends to depend strongly on the wind speed in the previous hour. Lower values mean that the wind speed tends to fluctuate in a more random fashion from hour to hour. The autocorrelation factor value is taken as 0.91.
(3) The diurnal pattern strength: It is the measure of how strongly the wind speed depends on the time of the day. In this study, 0.25 is used.
(4) The hour of peak wind speed: It is simply the time of day tends to be windiest on an average throughout the year. In this study, 14 is used as the hour of peak wind speed [13].

Fig. 7 & 8 shows the average monthly wind data in Saint Martin's Island.

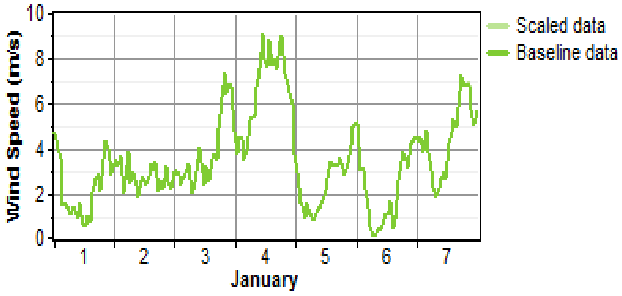

Fig. 7: Average monthly data in Saint Martin Island.

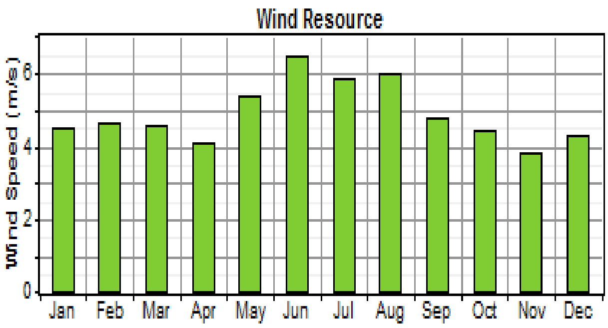

Fig. 8: Average yearly wind speed data.

5. HYBRID SYSTEM COMPONENTS

The major components of hybrid energy system are PV panels, wind turbines, diesel generator, batteries and converters. For economic analysis, the number of units to be used, capital costs, replacement and O&M costs and operating hours to be defined in HOMER in order to simulate the system.

5.1 Photovoltaic Method

The cost of PV module including installation has been considered as BDT 270/W for Bangladesh. Life time of the modules has been taken as 25 years and tilt angle considered as 20.6167. 10 kW PV modules are considered. The parameters considered for the simulation solar PV are furnished in Table 3.

Table 3: Solar PV array–technical parameters and cost assumptions.
(1 USD = 78 BDT)

Parameter	Unit	Value
Capital cost	BDT/W	270
Replacement cost	BDT/W	220
Operation and maintenance cost	BDT/W/yr.	45
Lifetime	Years	25
Derating factor	Percent	85
Tracking system	No tracking system	-

5.2 Wind Generator

For the hybrid system a Generic 3 kW wind turbine has been considered. Technical and economic parameters for selected wind turbine are furnished in Table 4.

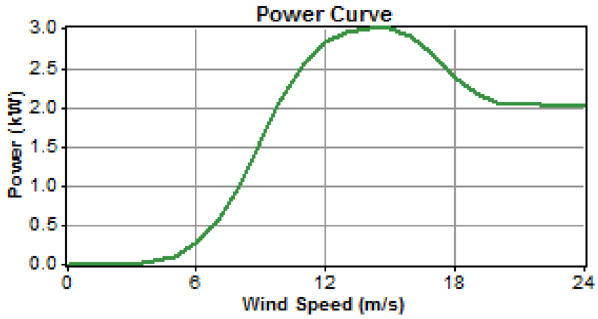

Fig. 9: Power Curve for generic 3 kW generator used in HOMER software.

Table 4: technical and economic Parameters of wind turbine.
(1 USD = 78 BDT)

Parameter	Unit	Value
Rated power	kW	3
Starting wind speed	m/s	4
Rated wind speed	m/s	14
Cut-off wind speed	m/s	16
Capital cost	BDT/kW	1,90,000
Replacement cost	BDT/kW	1,45,000
Operation and maintenance cost	BDT/yr./turbine	10,000
Lifetime	Years	20

5.3 Diesel Generator

A diesel generator of 15 kW rated power with technical and economic parameters furnished in Table 5.

Table 5: Technical parameters and cost assumptions for diesel generators.
(1 USD = 78 BDT)

Parameter	Unit	Value
Capital cost	Taka (BDT/kW)	9,000
Replacement cost	BDT/kW	7,000
Operation and maintenance cost	BDT/h	40(20 kW)
Operational Lifetime	Hours	15,000
Minimum load	Ratio Percent	20
Fuel curve intercept	$l/h/kW_{rated}$	0.08
Fuel curve slope	$l/h/kW_{rated}$	0.25
Fuel price	BDT/liter	78

5.4 Battery with Charge Controller

As the system considered the DC load only, battery and controller were also as a main part of the system. Battery from Hoppecke Company (Model: Hoppecke 8 OPzS 800, nominal V: 2v nominal capacity: 800 Ah) has been used at a cost of 7,500.00 BDT/battery with charge controller.

5.5 Converter

A converter is required to convert AC-DC or DC-AC. Converter inputs used in HOMER is 10kW size and cost is 15000/kW. Inverter inputs lifetime is 15 years and it has efficiency of 90%.

5.6 Economics and Constraints

The project life time has been considered to be 25 years and the annual real interest rate has been taken as there is 5% capacity shortage for the system and operating reserve is 10% of hourly load and percent of renewable output taken as 2% and 30% respectively. No cost subsidy has been taken.

6. RESULTS AND DISCUSSION

To evaluate the performances of different hybrid systems in this study, optimal systems' performance and the sensitivity analysis have been carried out using HOMER simulation tools. In this software the optimized results are presented categorically for a particular set of sensitivity parameters like solar radiation, wind speed, diesel price, maximum annual capacity shortage and renewable fraction. HOMER performs thousands of hourly simulations over and over in order to design the optimum hybrid system.

7. OPTIMIZATION RESULTS

Simulations have been conducted considering different values for solar radiation, wind speed, minimum renewable fraction, and diesel price providing more flexibility in the experiment. The optimization results for specific wind speed 4.898 m/s, solar irradiation 4.549 kWh/m^2/d and diesel price 78 BDT are illustrated in Fig. 12. It is seen that a PV, diesel generator and battery hybrid system is economically more feasible with a minimum COE of BDT 28.719/kWh and a minimum NPC of 13,568,504 BDT.

The hybrid system comprised of 10 kW PV array, a diesel generator with a rated power of 20 kW and 25 storage batteries in addition to 10 kW converters is found to be the most feasible system. The system shows wind generators are costly for this model. Fig. 11 shows the details related to energy generated by PV, wind turbine and diesel generator system, excess electricity, un-met load, capacity shortage and renewable fraction for the most economically feasible system applicable for the selected location.

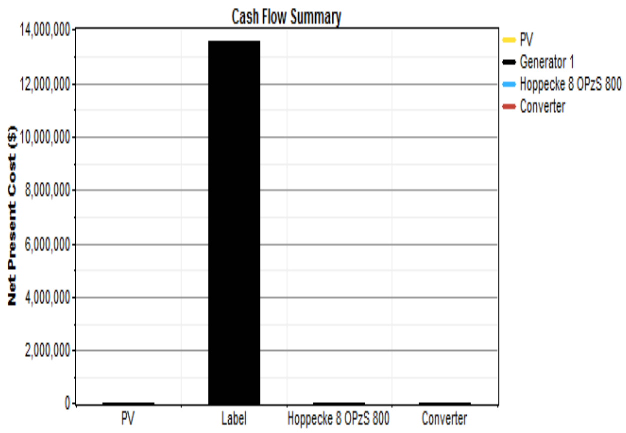

Fig. 10: Cash Flow of the optimized output Solar-Diesel-battery.

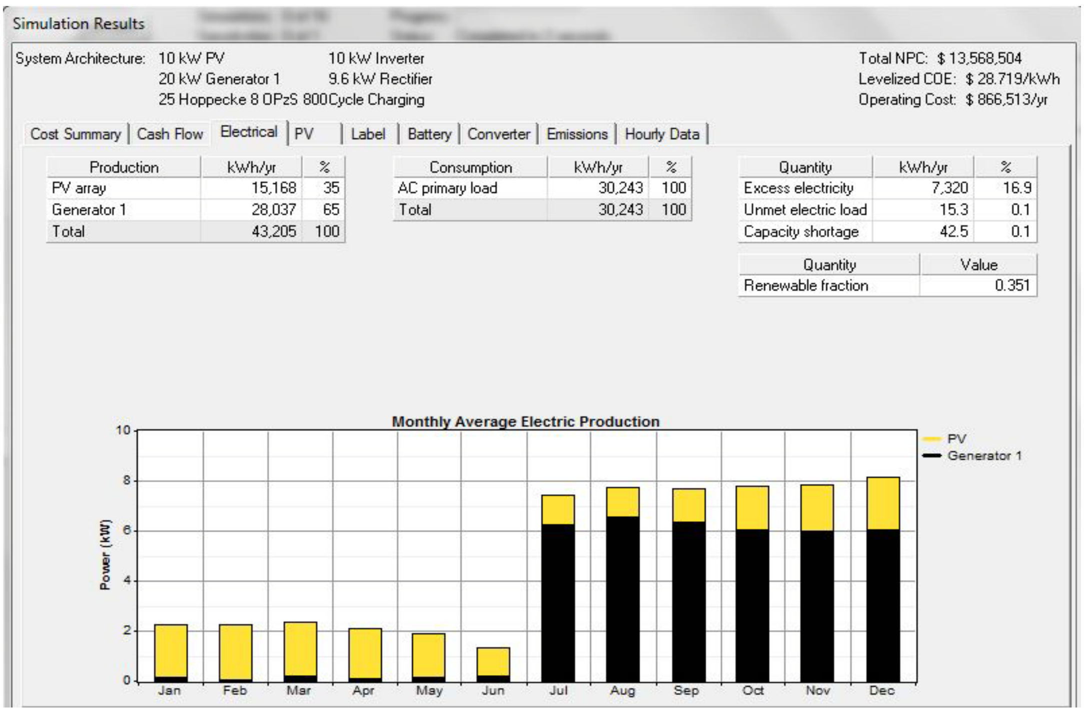

Fig. 11: Energy generated by PV, wind turbine and diesel generator system, excess electricity, un-met load, capacity shortage and renewable fraction with feasible system.

PV (kW)	G3	Label (kW)	H800	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Label (hrs)
10		20	25	10	$ 31,770	866,513	$ 13,568,504	28.719	0.35	0.00	10,520	2,194
10	3	20	25	10	$ 221,770	878,138	$ 13,940,107	29.505	0.35	0.00	10,520	2,194
		20	25	10	$ 31,500	1,050,656	$ 16,444,938	34.789	0.00	0.00	12,839	2,359
	3	20	25	10	$ 221,500	1,062,281	$ 16,816,540	35.575	0.00	0.00	12,839	2,359

Note: All the currency values were considered in terms of BDT instead of $.

Fig.12: Optimization results for PV-diesel-wind turbine-battery system for a solar radiation of 4.549 kWh/m^2/d, diesel price of 78 BDT/L and maximum capacity shortage of 0%.

8. ENVIRONMENTAL EFFECT

Wind-diesel hybrid system with CHP technology reduces gas emission by a significant amount due to reduced fuel consumption. This reduction in gas emission is determined using HOMER software. The annual amount of reduction of gas emission is presented in Table 6.

Table 6: Reduction of gas emission

Pollutant	Emissions (kg/yr.)
Carbon dioxide	27,702
Carbon monoxide	68.4
Unburned hydrocarbons	7.57
Particulate matter	5.15
Sulfur dioxide	55.6
Nitrogen oxides	610

9. CONCLUSION

The study simulates a PV-wind-diesel-battery hybrid energy system in St. Martin's Island**.** On the basis of study it is found that solar-diesel is the most optimized combination in the Saint Martin's Island. The optimized hybrid energy system was developed considering manufacturing cost and efficiency. The result shows that the COE of the optimized system is BDT 28.719/kWh. This hybrid energy system reduces the emission of CO_2 significantly which reduces global warming.

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