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Ankur Das Avi

Department of Electrical and Electronic Engineering, Chittagong University of Engineering and Technology (CUET)

Fayaz, Tiham

Department of Electrical and Electronic Engineering, Chittagong University of Engineering and Technology (CUET)

Bidyut Baran Saha

International Institute for Carbon-Neutral Energy Research (WPI-I2CNER), Kyushu University

Ghosh, Sampad

Department of Electrical and Electronic Engineering, Chittagong University of Engineering and Technology (CUET)

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Optimization of Solar, Wind and Biomass-Based Hybrid Renewable Energy System in St. Martin's Island, Bangladesh

Ankur Das Avi¹, Tiham Fayaz¹, Bidyut Baran Saha^{2,3}, Sampad Ghosh^{1*}

¹Department of Electrical and Electronic Engineering, Chittagong University of Engineering and Technology (CUET), Chattogram, Bangladesh

²International Institute for Carbon-Neutral Energy Research (WPI-I²CNER), Kyushu University, Fukuoka, Japan

³Department of Mechanical Engineering, Kyushu University, Fukuoka, Japan

*Corresponding author email: sampad@cuet.ac.bd

Abstract: Hybrid renewable energy system (HRES) is an evolving power generation strategy that requires a combination of various energy resources and is common in modern pursuits. Allowing features, such as low CO₂ emissions, less environmentally damaging possibilities than traditional power generation techniques, and mostly unlimited power resources give more flexibility. Along with connecting these HRES power plants with the national grid for the addition of more power generation, electrification of remote areas is possible with stand-alone power plants. The proposed research model is a quantitative study on the potentiality of renewable sources in St. Martin's Island, a geographically important location of Bangladesh. This work incorporates solar, wind, and biomass sources in the HRES system, which is a relatively new concept when compared with other HRES strategies with a levelized cost of \$0.18. An enhanced HRES model is proposed considering different constraints revealing a new possibility of power generation on that island.

Keywords: Biomass; HOMER Software; Hybrid Renewable Energy System (HRES); Solar; Wind.

1. INTRODUCTION

Energy has been an indispensable necessity for human survival in recent periods. Energy demand is growing due to demographic growth, economic and technological progression [1]. Fossil fuel serves much of the planet's energy needs [2], resulting majority of the electric power generation is based on fossil fuels (e.g., coal, diesel, and natural gas [3,4]). More specifically, natural gas provides about 35% of the world's primary energy supply [5]. The most concerning aspect is that the globe will offer coal for 122 years, oil for 42 years, and natural gas for 60 years, considering the recent fossil asset supply and deployment rates [6]. Overall, there would be a 36% rise in fossil fuel intake between 2011 and 2030 if the average demand level is 1.6% [7]. Interestingly, over the recent decades, the dreadful circumstances of stand-in fossil fuels have been observed worldwide. The consumption rate for fossil fuels is rising dramatically, equal to insufficient reserves. Even while non-fossil sources have deteriorated by 10.8% over the last two decades, global fossil-based electricity generation has increased by 13% [8]. In addition, the production of electricity from fossil fuels produces an immense volume of greenhouse gas, which is the primary source of global warming [9]. Across the planet, the effects of changing climate on human and biological processes have already been observed [10,11]. This temperature rise is almost definitely the consequence of the anthropogenic emission of greenhouse gases, more than half of which are emitted by fossil fuel combustion [10]. The use of fossil fuels has been brought into question by these ever-growing issues [9].

Bangladesh is a developing country in the Southeast Asian subcontinent with a rapidly increasing population and economy, having almost 75-80% of the total population dwell in the rural areas [12,13]. The country's GDP growth (annual ~6%) and the energy consumption rate are rising significantly [12]. Energy plays an important role in the country's financial as well as social development [8]. Recently, the Government of Bangladesh has introduced a scheme named 'Hundred Percent Electrification' to improve electricity supply [14,15]. Through this scheme, Bangladesh has attained

97% access to electricity in the 2019-2020 fiscal year and produced 23,548 MW of electricity with captive and renewable resources [15]. However, the worrisome part is that only ~715 MW of energy is generated from renewable resources, covering only ~3% of electricity production [16]. So, the Govt. has set an aim of upgrading the consumption of renewable resources up to 10% in the future [15]. Currently, solar radiation, wind speed, and biomass are the major renewable resources commonly used in Bangladesh [17]. In a recent report by the Sustainable Renewable Energy Development Authority (SREDA), Bangladesh has disclosed that the current Government has a vision of generating 3493 MW of electricity from photovoltaics (PV) by 2041, 1360 MW from wind power by 2030, and 31.06 MW from biogas/biomass by 2021 [18–21]. Therefore, it is evident that modern power demand heeds us to consider the hybrid renewable energy system (HRES).

Due to the potentialities according to the national and global context, it is crucial to focus on large HRES ideas. That's why this study is focusing on optimization and modeling of an integrated HRES model in one of the country's priority islands with support of RE sources such as solar, wind, and biomass. Besides, this study has an attempt of least possible CO₂ emission along with efficient and clean power generation.

1.1 Proposed location

St. Martin, the only coral island of Bangladesh, is located in between 20°34' and 20°39' N and 92°18' and 92°21' E, locally known as "Narikel Jinjira" (Coconut Island) [22]. It is separated from the mainland by the Naaf Channel and plays a part in establishing Bangladesh's southernmost region, which is ~7.5 km long and ~1.5 km wide [23,24]. The average monthly air temperature is between 27 to 32 °C, with a minimum of 16 to 26 °C. The relative humidity is least in February (~65%) and most in July (90%). With a little (0 to 88 mm) and high (239 to 309 mm) precipitation, the climate is warm between October and February, and thunderstorms from March to May [25]. The geographical location is displayed in Fig. 1.

1.2 Present scenario

Solar energy is the safest source of electricity production out of all other resources as Bangladesh gains average solar irradiation of 4 to 6.5 kWhm⁻² per day [26,27]. In recent times, wind energy is growing as one of the fastest developing renewable energy sectors in Bangladesh [28]. The normal wind turbine speeds in the seashore belt maintain 3 to 4.5 ms⁻¹ in between March and September, while the remainder of the season falling between 1.7 ms⁻¹ and 2 ms⁻¹ [2]. In a hybrid generation model, primarily based on the PV, wind, diesel generator (DG), and battery system, many perspectives have been explored. This model is simulated by HOMER software [8]. Again several HRES configurations have been widely reported, including PV-wind, PV-DG, wind-DG, and micro hydro-DG [3]. Alternatively, as per the authors' statement, biomass is the form of energy that makes up the majority of renewable energy [29]. So, due to the high availability rate of biomass and its power generation possibility, Bangladesh can use this method to enrich the RE programs [12]. Moreover, solar-biomass or biomass powerplants are implemented in many corners of the world and are stated as important renewable resources for the world [26]. The island of St. Martin is too tiny to hold enough biomass to generate enough electricity. However, there is great optimism due to many dairy and poultry farms and available farming lands in the neighboring areas (e.g., Shahporir dwip, Teknaf, Ukhia). Biomass resources can be gathered and produced, and transported then to the power generation station in St. Martin's island [30].

Researchers have investigated the overall power demand in Bangladesh and found that renewable energy might be the possible alternative to conventional fossil fuels for boosting the power demand and energy sustainability [31]. Researchers have also recommended that actions must be taken to promote alternative sources to secure the country's energy security [1]. People have run many simulations combining RE sources with DGs and concluded that solar-wind-diesel is the most practical approach [8]. DGs were used in all the studies mentioned above [2,3,8,13,22,30,32]. As a result, there is a possibility of greenhouse gas (GHG) emissions, which can deadly impact on the current eco-life and existing species.

In this study, an HRES model is examined without DGs, resulting in no GHG emissions and 100% renewable energy production. This study aims to build a fully renewable powerplant using solar, wind resources with a battery bank system and biomass power generation system for additional support.

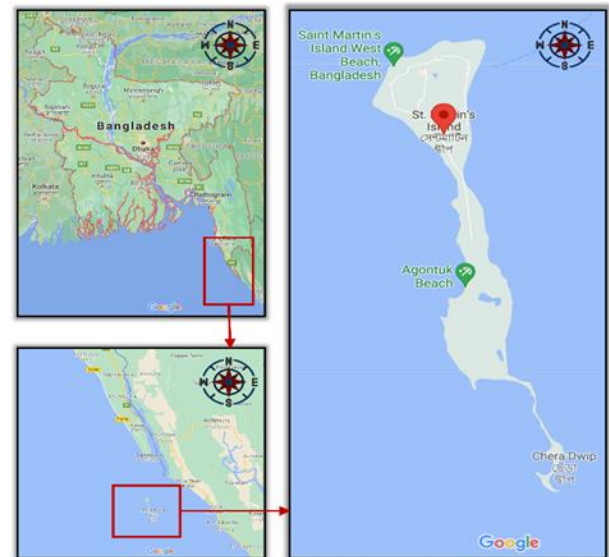


Fig. 1. The location of St. Martin's Island [33].

2. METHODOLOGY

2.1 Load estimation

About 7000 people are living on St. Martin's island. A community of ~1000 families, 100 shops, a 10-bed hospital, a 2-storied school, a 2-storied college, 11 mosques, and ~100 hotels are considered. The approximate load calculations for this study are summarized in Table 1. Data map (DMap) as shown in Fig. 2 illustrates the hourly load demand for a particular day throughout the year. It is seen that the load demand is relatively higher at the beginning and end of a year.

2.2 PV resources

Hourly data is not available for PV resources; thus, monthly data is taken from the National Aeronautics and Space Administration (NASA) [34], readily available in HOMER tools that use the Graham algorithm for synthesizing 8760 hourly values for a year. From Table 2 and Fig. 3, it can be seen that the daily radiation and clearness index is low for June, July, and August. The annual average clearness index is found to be 0.527 annually and radiation per day is about 4.8 kWhm⁻²/day.

2.3 Wind resources

The data for wind resources has also been taken from NASA [34]. Four advanced parameters are considered for wind resources. The Weibull value (k) is set around 2 that measures the distribution of the wind speed. The autocorrelation factor that quantifies the randomness of the wind is set to be 0.84. The diurnal pattern strength has been determined to be 0.26 that implies how vigorously the wind speed differs with time per day. The maximum and average wind speeds are judged to be 6.7 ms⁻¹ and 4.85 ms⁻¹, respectively. It is seen from Table 2 and Fig. 3 that average wind speed is higher in June, July and August that mitigates the shortage of PV power production for having a lower clearness index.

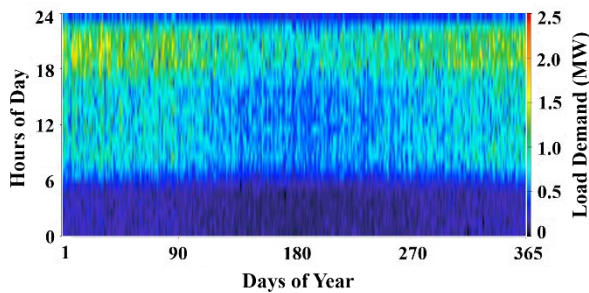


Fig. 2. DMap of load data.

Table 1. The approximate load estimation.

Load Profile	Component	Number	Rating (W)	Hours Used/Day	Consumption (kWh/Day)
Residential Load	Television	750+250	50+80	12	450+240=690
	Refrigerator	1000	150	24	3600
	Fan	3000	75	20	4500
	Light	5000	20	8	800
	Water Pump	1000	1120	0.5	560
	Mobile	3000	18	4	216
A 10-bed Hospital	Fan	16	75	20	24
	Light	28	20	12	6.72
A 2 - storied School	Fan	14×4=56	75	8	33.6
	Light	14×5=70	20	8	11.2
A 2- storied College	Fan	14×4=56	75	8	33.6
	Light	14×5=70	20	8	11.2
11 Mosques	Fan	132	75	2	19.8
	Light	132	20	3	7.92
100 Hotels (avg. 20 rooms)	Fan	2000	75	12	1800
	Tubelight	2000	40	10	800
	LED Bulb	6000	20	10	1200
	Television	600	150	4	360
100 Shops	Water Pump	100	1120	2	224
	Fan	100	75	16	120
	Light	300	20	16	96
	Fridge	40	150	24	144
Total approximate load consumption = (10366+30.72+44.8+44.8+27.72+4384+360) kWh/Day = 15258.04 kWh/Day					

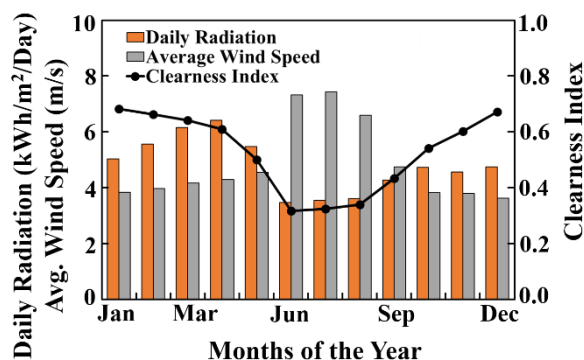


Fig. 3. Monthly PV-wind resource graph.

2.4 Biomass resources

Biomass resources in the locations near St. Martin's island are given in Table 3 and Table 4. Due to the insufficiency of its biomass resources, it needs to be transported from Teknaf and Ukhiya. According to the study, resources of 1550 tons/day of cow manure are available along with many other biomass sources (e.g., chicken liters, rice husks) [30]. This mixture carries a high percentage of methane [35]. This study accounted

for at least 350 tons/day to be transported for the generation.

Table 2. Monthly PV-wind resource variation.

Month	PV resource		Wind resource
	Clearness index	Daily radiation (kWhm ⁻² /Day)	Avg. wind speed (ms ⁻¹)
Jan.	0.682	5.040	3.830
Feb.	0.662	5.560	3.970
Mar.	0.642	6.160	4.170
Apr.	0.610	6.410	4.290
May	0.501	5.480	4.550
Jun.	0.316	3.470	7.330
Jul.	0.324	3.540	7.430
Aug.	0.339	3.600	6.600
Sept.	0.433	4.270	4.740
Oct.	0.542	4.730	3.820
Nov.	0.602	4.570	3.790
Dec.	0.672	4.740	3.630

Table 3. Biomass resource in Teknaf [30].

Poultry and Layer Firm	
	Quantity
Boiler poultry firm	35
Total boiler chicken	35000
Total layer hens (3 firms)	3000
Total chickens	38000
Dairy firm	
Total dairy firm	29 (Recorded)
Total cattle	49000
** The main crops are rice, betel leaves, and betel nuts.	

Table 4. Biomass resource in Ukhiya [30].

Poultry firm's name	No. of firms	Chickens/firm	Total Chickens
Beauty	53	1000	53000
Jannat	60	1000	60000
Sohel	9	1000	9000
Moriccha	50	1000	50000
Dairy Firms			
Total dairy firm	8 (Recorded)		
Total cattle	53982 (Recorded)		

2.5 Design

Solar panels for PV, wind turbines for harvesting wind energy, biogas generator for biomass energy, battery bank for storage, and converter devices for converting power from ac to dc and vice versa have been employed. The proposed system has been designed to provide about 15258.04 kWh/d with a peak load of 2268.31 kW and simulated using HOMER. HOMER tool integrates all the resources and gives different feasible solutions. Solar panels manufactured by Peimar from Italy will be used

as the component for producing solar energy. It will be connected to the DC busbar of the proposed model. The chosen solar panel has a lifecycle of about 30 years. For storing the energy produced by the solar panels, there are battery storage components. Battery banks used in this model are manufactured by Generic and its rated capacity is about 1 kWh with a roundtrip efficiency of about 90%. Battery banks are also connected to the DC busbar. For converting the DC power generated by the solar panels into AC power, converters are used that can convert the DC power to the desired AC power. The efficiency of the converter used in this model is about 95%. For wind power generation, a generic 3 kW wind turbine will be connected to the AC busbar that is manufactured by Generic. For producing biogas from biomass and converting its potential into energy, biogas generators with a rated capacity of 10 kW have been used and connected to the AC busbar. Its efficiency is about 31%. Fig. 4 demonstrates the design for simulation. Summary of the required components, as presented in Table 5 have been selected based on their properties and costs to reduce the net present cost of the proposed model. The efficiency of the PV is 19.1%, whereas the wind speed for maximum output power is 15 ms^{-1} . The power curve for a wind turbine, as illustrated in Fig. 5, implies that output power initially increases with wind speed (up to 15 ms^{-1}) then decreases gradually.

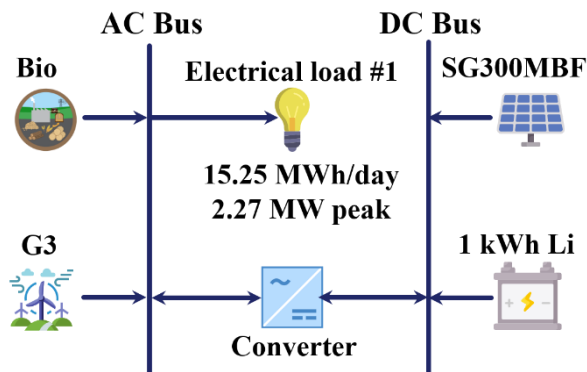


Fig. 4. Schematic design for HOMER simulation.

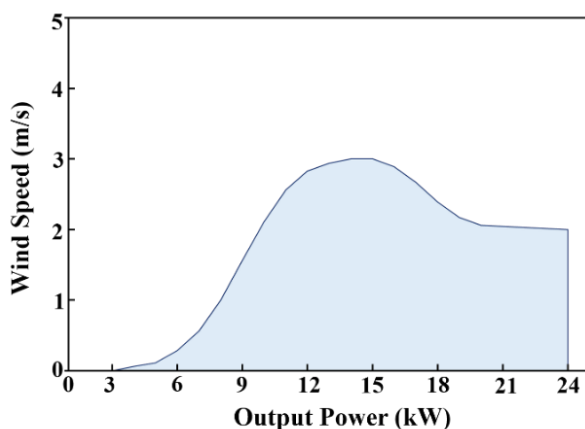


Fig. 5. Power curve of Wind Turbine.

Table 5. Overall summary of the components.

Component	Properties	Cost Subjects	Cost Amount (\$)
Peimar SG300MBF (For PV)	Panel Type: Flat Plate Rated Capacity (kW): 1 Temperature Coefficient: -0.4 Operating Temperature (°C): 25 Efficiency (%): 19.1 Lifetime: 30 years Derating factor: 80%	Capital Cost	650
		Replacement Cost	650
		Operation and Maintenance	10/year
Generic Wind Turbine (For Wind)	Rated Capacity: 3 kW Hub Height: 30 m Lifetime: 20 years	Capital Cost	15,000
		Replacement Cost	15,000
		Operation and Maintenance	150/year
Generic Biogas Generator (For Biomass)	Rated Capacity: 10 kW Lower Heating Value: 5.5 MJ/kg Density: 0.720 kg/m ³ Carbon Content: 5% Sulfur Content: 0% Lifetime: 20,000 Hours	Capital Cost	3500
		Replacement Cost	1500
		Operation and Maintenance	1/hour
System Converter (for Converter)	Rated Capacity: 1 kW Efficiency: 95% Lifetime: 20 years	Capital Cost	300
		Replacement Cost	300
		Operation and Maintenance	0
Generic Li-ion Battery (For Storage)	Output Voltage: 222 V Nominal Capacity: 1 kWh Roundtrip Efficiency: 90% Initial State of Charge: 100% Minimum State of Charge: 20% Lifetime: 15 years Throughput: 3000 kWh	Capital Cost	550
		Replacement Cost	550
		Operation and Maintenance	10/year

3. RESULTS AND DISCUSSION

3.1 Simulation results

HOMER simulates the designed model with all the input data supplied and generates various optimization solutions with different setups. Fig. 6 investigates the optimized results obtained from the HOMER tools. The cost summary and monthly average energy production are shown in Fig. 7 and Fig. 8, respectively. It is found that the majority of the cost accounts for PV. The monthly average production of electricity is relatively on the lower side in June, July, and August months as the clearness index for PV is lower. However, the wind speed is relatively high during that time of the year, mitigating the shortage of electricity production. The PV accounts for ~84% of total energy generation which is from renewable sources with no capacity shortage. The average feedstock required is 19.4 tons/day to produce ~16% of total energy. The monthly percentage of average electricity production and required inputs for biogas has been shown in Table 6 and Table 7, respectively.




























ARCHITECTURE											COST (<i>M = Million</i>)			
					SG300MBF (kW)	G3	Bio (kW)	1 kWh Li	Converter	Dispatch	COE (\$)	NPC (\$M)	Operating Cost (\$M/yr)	Initial Capital (\$M)
					8173	16	1000	3589	1470	CC	0.18	13.2	0.38	8.32
-	-				-	-	1000	6660	1080	CC	0.20	14.6	0.79	4.34
-					-	64	1000	6253	1941	CC	0.21	15.5	0.79	5.33
		-			8541	214	-	25049	2658	CC	0.44	32.1	0.67	23.3
	-	-			8965	-	-	38517	2478	CC	0.55	39.9	0.93	27.8
-		-			-	2456	-	2024048	6117	CC	25.11	1810	50.7	1150

Fig. 6. Optimized results obtained from HOMER tools.

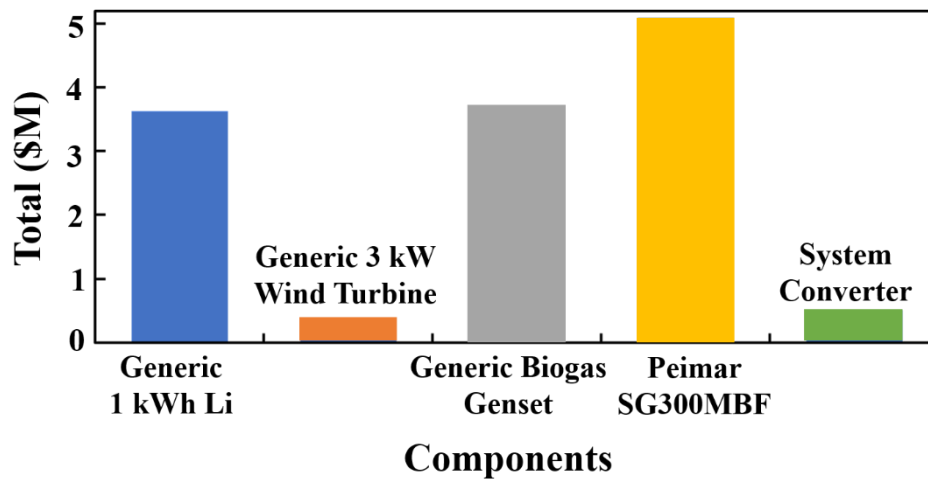


Fig. 7. Cost summary of the simulated model.

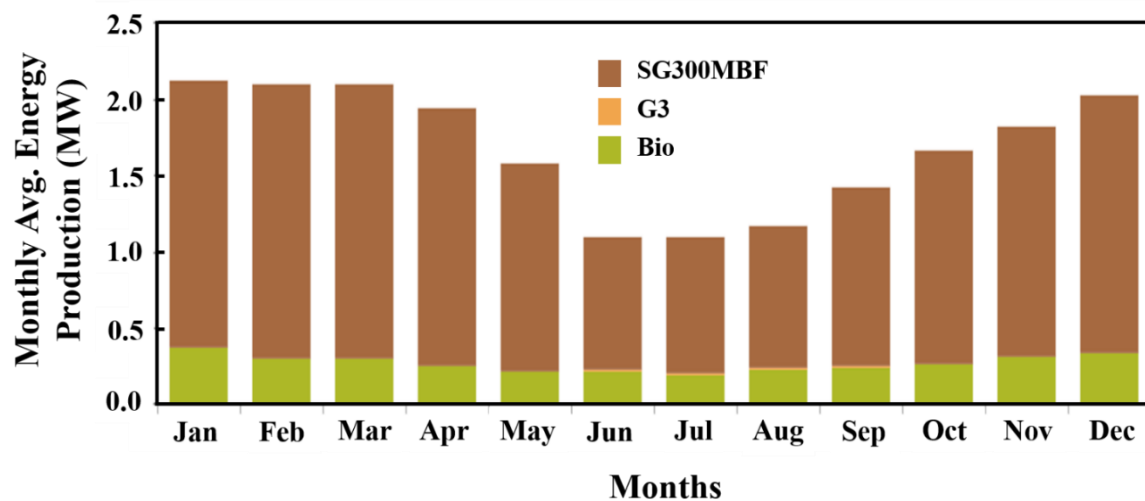


Fig. 8. Monthly average electricity production.

Table 6. Average production of electricity.

Production	kWh/yr	%
<i>Peimar SG300MBF</i>	12,237,064	83.70
<i>Generic biogas genset</i>	2,349,416	16.10
<i>Generic 3 kW wind turbine</i>	40,957	0.280
<i>Total</i>	14,627,436	100

Table 7. Inputs for biomass energy production.

Quantity	Value	Units
<i>Total feedstock consumed</i>	7,066	tons
<i>Avg. feedstock/day</i>	19.40	tons/day
<i>Avg. feedstock/hour</i>	0.807	tons/hour

3.2 Feasibility analysis

From the simulation, the best possible solution is found having a Net Present Cost (NPC) of about \$13,240,440, Levelized Cost of Energy (COE) as \$0.184 or ~15 BDT (1 USD = 84 BDT), and an operating cost of \$382,842/year with no capacity shortage. These values are displayed in Table 8. Diesel generators based HRES models revealed the Levelized COE as 42.17 BDT and emitted a significant amount of CO₂ emissions [32]. The emission of different gasses is analyzed and found they tend to be on the lower side in terms of kilograms per year as presented in Table 9.

Table 8. Optimized values for the proposed model.

Subjects	Amount
<i>Total NPC</i>	13,240,440.00 USD
<i>Levelized cost</i>	0.184 USD or 15 BDT
<i>Operating cost</i>	380,842.00 USD
<i>Capacity shortage</i>	Null or 0%

Table 9. Emission rates of different gasses.

Quantity	Value (kg/yr)
<i>Carbon dioxide (CO₂)</i>	1,273
<i>Carbon Monoxide (CO)</i>	14.1
<i>Unburned hydrocarbons</i>	0
<i>Particulate matter</i>	0
<i>Sulfur dioxide (SO₂)</i>	0
<i>Nitrogen oxides (NO_x)</i>	8.33

4. CONCLUSIONS

As the price of fossil fuels has escalated over the past few years, hybrid renewable energy systems (HRES) are more feasible than the conventional technique. In contrast to the grid-connected scheme, HRES, particularly in remote islands, is a promising alternative. Moreover, the price of diesel is rising very quickly in Bangladesh. So, diesel generators would not be viable to use in the future. The studied island (St. Martin) has immense potential for solar PV, wind, and biomass resources. This research work facilitates the most commercially viable alternative to produce energy in that island via HOMER analysis. The results obtained from

the feasibility analysis would be helpful to make decisions for preparing and developing the optimum power generation systems in St. Martin's island of Bangladesh.

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