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# Design and Optimization of Hybrid Energy System for an Off Grid Area of Bangladesh by using HOMER and Validation by RETScreen

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**ABSTRACT**
Bangladesh being the populated country and aspires to be a developed nation by 2041, Bangladesh is in race to generate electricity for economic emancipation. To get clean energy, renewable energy option is the first requirement to replace the environment degradation fossil fuels. This paper highlights the generation of electricity by renewable sources. However, precise energy prediction is important in total power demand especially for the energy mix. Moreover, any data measured or simulated should be validated for its reliability as well as prediction of future active loads properly. The main advantage is that RETScreen links between input and output parameters and concludes with a precise numeric value. About the initial cost, initial capital is obtained by HOMER is 40,451.200 taka for scenario A and 58,251.600 taka for scenario B whereas from RETScreen, the cost of scenario A and B are 91396.26 taka and 114000.56 taka respectively. Electricity Production by REScreen for Scenario A and B are 1037,390 kWh and 950,009 kWh respectively and by HOMER for both scenarios are 714,287 kWh and 704,706 kWh.

Keywords: Solar Energy, wind energy, biogas, HOMER, RETScreen

## 1. Introduction

Bangladesh being the populated country is in race to generate electricity for economic emancipation. This generation is closely link with greenhouse effects, climate change and pollution of environment as lion share of generation is contributed by non-renewable sources. However, generation of electricity of Bangladesh is the main focus in recent past and as per energy division statistics, Bangladesh has made a satisfactory progress of covering 95% of the total population under electrification scheme [1]. Rural electrification is not mark high as of urban areas. Among the rural population, a large number of people live in remote areas such as hilly areas, the coastal belts, islands and isolate villages. These people still have a hope to have access to electricity because grid connection to those remote areas is not economically feasible. So far, the principal sources of generation of electricity in Bangladesh are based on natural gas, coal, imported oil and hydro-electricity. Less hydroelectricity, other sources of energy are actually fossil fuels which are non-renewable. These fossil fuels are not plenty in nature and becoming too expensive day by day as their supplies are reducing.

The Government of Bangladesh (GoB) has targeted to generate 24,000 MW for universal access to electricity by 2021, 40,000 MW for affordable, reliable, sustainable and modern energy for all according to SDG 7 by 2030 and 60,000 MW to be for developed nation by 2041. In Bangladesh, generation of electricity is mostly dependent on non-renewable fuels. Approximately 91.54% of electricity is produced from fossil fuels whereas 5.56% from import and the rest 2.9 % of power is generated from the renewable energy sources. Approximately 46.29% of electricity is being generated from the natural gas [3]. To minimize the fossil fuel utilization in power generation and to ensure future energy security, Bangladesh is transforming to energy mix policy where renewable sources like solar panels, hydroelectricity and wind turbines in the coastal areas are given the due attention. To meet the present and future electricity demand, renewable energy is a forerunner in generating electricity for off-grid electrification in the country. For this, in renewable energy policy which is formulated in 2008, it is targeted that by 2020, there will be 10% generation of electricity from renewable sources [4]. As per the plan of GoB, the renewable energy generation capacity to be increased to 2896.68 MW by 2021, where solar power is like to share 1470 MW and wind energy is 1153 MW [5]. Among the renewable energy sources, solar energy has an excellent potential in Bangladesh with an average solar radiation varies between 4 to 6.5 $kWh/m^2/day$. Bangladesh possesses a favorable atmosphere for the biogas production also. The perfect temperature is approximately $35^0$ for biogas. The temperature ranges from $6^0$ to $40^0$ here. It is not only produce gas and electricity but also gives organic fertilizer for the

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farmers. Wind is cheaply available and plenty in costal belts and other areas of Bangladesh. Therefore, according the expert of National Renewable Energy Laboratory (NREL), USA, electricity generation is expected more than 10,000 MW in Bangladesh with help of wind power [5]. Due to the unfavorable topography, at present only Kaptai hydropower has installed capacity of 230 MW. It is considered as the lion share of electricity generation from renewable energy sources in Bangladesh. However, expert has identified more locations which are suitable for hydropower around the country.

Renewable energy may be regarded as the future of electricity production as it is replenishable and environment friendly. Renewable energy sources are plenty in nature, yet no one can depend only one renewable source as solar, wind or biomass etc. are not 100% dependable due to their fluctuating continuity over the period of time. Therefore, in recent past, due attention is given to integrate two or more renewable energy resources for generation of electricity in remote areas which is considered as suitable solution. Therefore, from the combination of solar PV, biogas, wind sources, hybrid electricity generation is preferable. However, precise energy forecasting can contribute significantly in total power demand especially for the energy mix. Moreover, any experimental results or data recorded are required to be validated for its reliability as well as estimation of future active loads properly. For this RETScreen is used. A validation between the predicted model of RETScreen and simulated software of HOMER has been conducted.

## 2. Surveyed Area Swarna Dweep

The selected off-grid remote rural area for this study is Swarna Dweep. It lies about 4 km to the south of the Noakhali district mainland and nearly 4.5 km west and about 13.5 km north-east of Hatiya. Map of study area is given in Fig. 1.

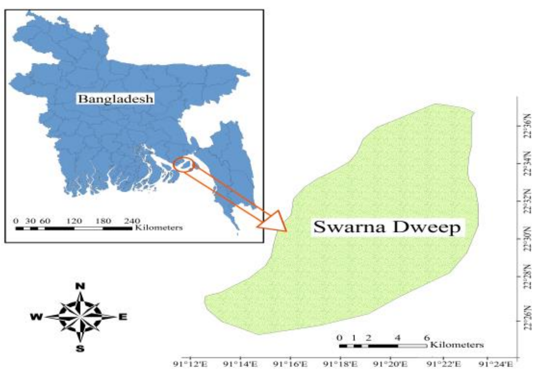



**Fig. 1** Map of study area Swarna Dweep

Swarna Dweep is located within the extent between 22°37'35.5''North Latitude to 91°23'3.6''East Longitude and 22°25'12.7''North Latitude to 91°11'32.0'' East Longitude. This island is approximately 3 meter above sea level. Its dimension is now 28 kilometer long and 14 kilometer wide in area (392 km$^2$). There is no grid connected electricity in this island as it is not economically viable to connect electricity from grid.

## 3. Load Profile of Swarna Dweep

Electrical loads light, fan, mobile charger, television and fridge are considered as main load for household requirement. The power consumption of the Swarna Dweep decreases from midnight upto 4 o'clock and electrical consumption varies from 5 o'clock to 23 hours as electrical appliances are used at different rate. The electricity consumption becomes the highest at around 1800 hours when almost all the electrical appliances are used. The daily load profile of study area is shown in Fig.2.

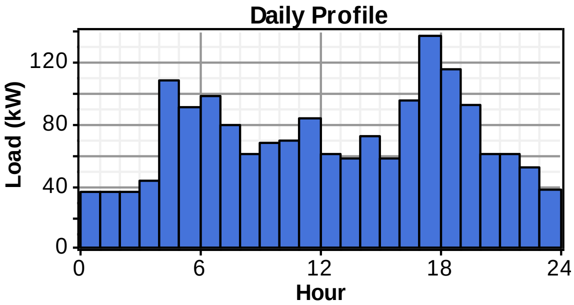



**Fig. 2** Daily load profile of study area Swarna Dweep

## 4. HOMER Simulation Design

The system is designed composed of Solar PV, SW AIR X-Wind turbine, Biogas generator, H200-Battery and Diesel generator. The average power consumption of Swarna Dweep is 1685 kWh/d. The maximum load is 226 kW which is taken into consideration for the system size. However, the system architecture is given in Fig. 3.

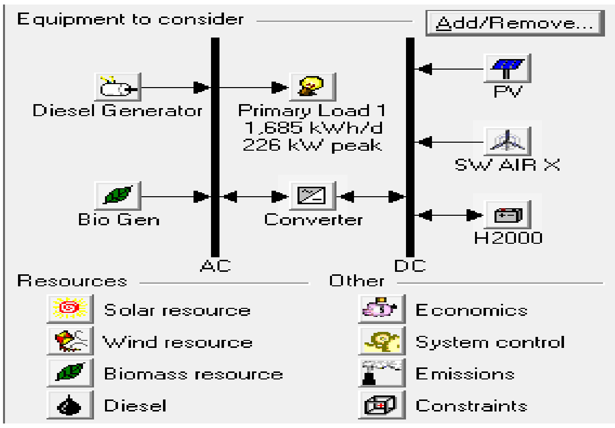



**Fig. 3** System architecture in Homer (PV-Photovoltaic, SW AIR X-wind turbine, biogas generator, H200-battery and diesel generator

## 5. Renewable Energy Potential of Swarna Dweep

5.1. Solar and wind resources

Solar radiation data is obtained from NASA surface meteorology and solar energy database through RETScreen Expert and HOMER software. According to NREL, USA at height 60 meters, speed ranges from 6 to 6.5 m/sec and the annual average wind speed of Swarnadweep is 6.31 m/sec. It can be also observed that from April to October the wind speed is higher than the annual average wind speed. Table 1 shows the monthly solar radiation and wind speed of study area.

**Table 1** Monthly solar radiation and wind speed of study area

| Month | Daily Radiation (kWh/m$^2$/d) | | Wind speed (m/s) | |
|---|---|---|---|---|
| | RETScreen Expert Software | From HOMER Software) | NASA (10m) (From RETScreen Expert Software) | Measured by NREL (60 m) |
| January | 4.35 | 4.348 | 2.6 | 6.232 |
| February | 4.95 | 4.809 | 2.5 | 6.257 |
| March | 5.57 | 5.422 | 3.0 | 6.308 |
| April | 5.65 | 5.450 | 3.8 | 6.360 |
| May | 5.25 | 5.475 | 4.0 | 6.352 |
| June | 4.05 | 4.072 | 4.4 | 6.342 |
| July | 3.89 | 3.771 | 4.5 | 6.337 |
| August | 3.91 | 4.020 | 3.9 | 6.329 |
| September | 3.83 | 3.848 | 3.1 | 6.321 |
| October | 4.29 | 4.506 | 2.3 | 6.314 |
| November | 4.23 | 4.182 | 2.2 | 6.295 |
| December | 4.24 | 4.206 | 2.3 | 6.273 |
| **Average** | **4.51** | **4.836** | **3.2** | **6.31** |

By HOMER software, the annual average solar radiation is calculated to be 4.836 kWh/m$^2$/day whereas 4.51 kWh/m$^2$/day is by RETScreen Expert software and the average annual clearness index is 0.515. The maximum solar radiation was projected at (5.475 kWh/m$^2$) in May and the lowest was (3.771kWh/m$^2$) in July by HOMER software and by RETScreen Expert software maximum solar radiation was projected 5.65 kWh/m$^2$) in April and the lowest was (3.83 kWh/m$^2$) in September.

Again wind resources can be found for the same location from NASA by using RETScreen software at a height 10m for the terrain identical where it is observed that the wind speed from April to August is higher than the annual average wind speed (3.2 m/s).

5.2 Biomass resources

There are more than 207 buffaloes, 8 cows, 190 sheep and 1,200 hens and ducks in the dairy farms. In addition to that, a large number of cattle (of which 2142 are buffalo and 1227 are cow and approximately 1065 are sheep) are grazing in the island. On average dung that can be obtained from a single healthy buffalo is 15 Kgs, a cow produces 10 kg of cow dung each day and 2 kgs by a sheep [6]. Here the recovery rate of the dung cake for grazing cattle is considered only 20%. There will be cost for collection and transportation of dung to gather in plant area of the Island. However, collection and transportation cost may be compensated by selling the slurry. Therefore, it can be said that in average 12 ton/day dung is available throughout the year.

## 6. System Components Assessment

The hybrid energy system of the Swarna Dweep is composed of Solar PV, wind turbine, biogas, diesel generator and power converter. The different parameters of renewable energy resources and other data need to be inserted in HOMER software to get the optimized result. The principal renewable hybrid energy source is solar PV, wind turbine and biogas to give input to HOMER.

6.1. Solar photovoltaic

370 watt JA Solar monocrystalline PV module is considered for this system. The solar PV installation cost is likely to vary from (150 Tk to 300 Tk/ W). The Solar PV arrays lifetime are considered as 25-year product warranty and 25-year linear power output warranty. Table 2 shows the costs considered for Solar PV.

**Table 2 *C***osts considered for solar PV [7]

| Parameter | Unit | Value (Tk) |
|---|---|---|
| Initial Capital Cost | Tk/W | 100 |
| Replacement Cost | Tk/W | 50 |
| Operation and Maintenance Cost | Tk/W/Yr | 50 |
| Lifetime | Years | 25 |

6.2 Wind turbine

Depending on the wind speed, generation of electricity from wind turbine varies greatly. Turbine blades are made of aluminum alloy. SW AIR X-Wind turbine is considered for wind energy. The cost of one unit is considered to be 2,50,000 Tk/kW while replacement costs are taken 1,50,000 Tk/kW which is shown in Table 3.

**Table 3** Cost analysis for wind turbine [7]

| Parameter | Unit | Value (Tk) |
|---|---|---|
| Initial Capital Cost | Tk/kW | 2,50,000 |
| Replacement Cost | Tk/kW | 1,50,000 |
| Operation and Maintenance Cost | Tk/Yr/ Turbine | 5000 |
| Lifetime | Years | 20 |

6.3. Biogas generator

Puxin Biogas Generator is considered for this setting, Its rated power is 3 kW and it is a single phase brush motor. Its output volt is 12 V and output current is 8.3 A. Table 4 portrays the cost of Puxin biogas generator.

**Table 4** Costs considered for biogas generator [8]

| Parameters | Unit | Value |
|---|---|---|
| Initial capital cost | Tk/kW | 149.71 |
| Replacement cost | Tk/kW | 50 |
| Operation and management cost | Tk/hr | 7 |
| Continue Working Time | Operating hour | Not more than 6 hours |
| Size of Biogas Generator | kw | 3 |

6.4. Diesel generator

For off grid areas, the diesel generators are normally used for electrification as its installation and operation is easier. Cost of generator is taken (7000 Tk/kW) and cost of replacement is 5000 Tk/kW. Table 5 shows the cost which are considered for diesel generator.

**Table 5** Costs considered for diesel generator [7]

| Parameters | Unit | Value |
|---|---|---|
| Capital cost | Tk/kW | 7000 |
| Replacement cost | Tk/kW | 5000 |
| Operation and management cost | Tk/hr | 5 |
| Life time | Operating hour | 45000 |

6.5. Battery

For an off grid area, battery contributes as a major cost for power systems. The battery chosen is Hoppecke 16 OPzS from the manufacturer Hoppecke. Replacement cost for battery is considered about 95% of its capital cost. The parameters and costs considered for Hoppecke 16 OPzS storage batteries are shown in Table 6.

**Table 6** Parameters and costs considered for Hoppecke 16 OPzS storage batteries [7]

| Parameter | Unit | Value |
|---|---|---|
| Nominal capacity | Ah(kWh) | 2000(4) |
| Lifetime throughput | kWh | 6801 |
| Capital cost | Tk/kWh | 7500 |
| replacement | Tk/kWh | 7200 |
| Operation and management | Tk/kWh | 80 |

6.6. Power converter

A power converter is a device that covert current and makes an energy linkage between the AC and DC components. The power converter cost of installation and replacement are same i.e 1000 Tk/kW each. It is ideal that the rated power of the converter should be same or greater than the peak load. Cost Analysis for converter is given in Table 7.

**Table 7** Cost analysis for converter [7]

| Parameter | Unit | Value (Tk) |
|---|---|---|
| Capital Cost | Tk/ kW | 10,000 |
| Replacement Cost | Tk/ kW | 10,000 |
| Lifetime | Years | 20 |

7. **Renewable Energy Technologies Screen (RETScreen) Analysis**

RETScreen is a Clean Energy Management Software system for energy efficiency, renewable energy. It also offers cogeneration project feasibility analysis and ongoing energy performance analysis. For this reason, this study is carried out using RETScreen to predict the total hybrid energy comprising of solar, wind and biogas to generate electricity to a remote area, namely Swarna Dweep of Bangladesh.

7.1 Best two-cases of HOMER analysis using RETScreen

Cost Analysis obtain from Homer is shown in Table 8. The COE for scenario A and B is 21.65 and 23.491 Tk/kWh respectively.

**Table 8** Cost analysis obtain from HOMER

| System | Initial Capital (Tk) | Operating Cost (Tk) | Total NPC (Tk) | COE (Tk/kWh) | Renewable Fraction |
|---|---|---|---|---|---|
| PV-Wind-BG-DG | 40,451.200 | 10,225.784 | 171,171 120 | 21.665 | 0.95 |
| PV-Wind -BG | 58,251.600 | 9,963.191 | 185,614 .6 | 23.491 | 1 |

From above table, best two scenarios are taken to simulate renewable energy projects HOMER result by RETScreen to get Cost of energy (COE) and initial cost and compare with HOMER result. The parameters are designed based on input and output parameters of HOMER pro.

a) Scenario A: Solar PV- wind-diesel generator-biogas-Battery-converter
b) Scenario B: Solar PV- wind-biogas-Battery-converter

7.2 Weather data of the survey area by RETScreen

Swarna Dweep is our survey area. The RETScreen software gives the complete weather details of the place of analysis. The data displayed both solar radiation and wind speed is the data as per the data given by NASA as shown in Fig. 4 and Fig. 5 respectively.

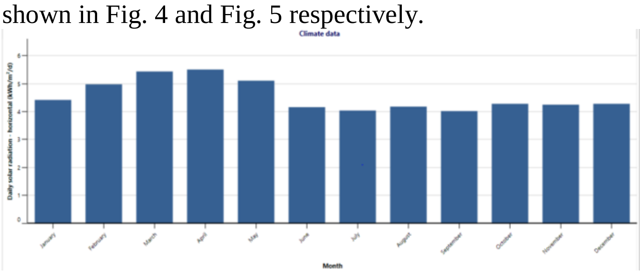



**Fig. 4** Month wise data for daily solar radiation

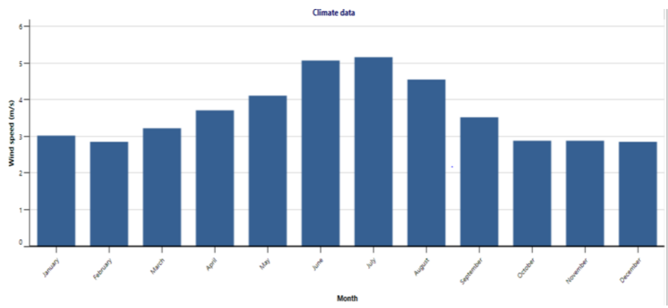



**Fig. 5** Month wise data for wind speed

7.3 RETScreen Simulation Result

RETScreen simulation result is highlighted in Table 9 and 10 for scenario A and B respectively. Table 9 and 10 shows the capacity factor of scenario A and B are same, but the initial cost, O&M, electricity export to grid and electricity export revenue are different.

**Table 9** Simulation result for scenario A

| Parameters | Solar | Wind | Biogas |
|---|---|---|---|
| Capacity Factor | 18.4% | 20% | 20% |
| Initial Cost (Tk) | 10,000 | 57,500 | 1,200 |
| O&M (Tk) | 4,500 | 1,600 | 3,000 |
| Electricity Export to Grid (kWh) | 161,390 | 438 | 282.800 |
| Electricity Export Revenue (Tk) | 3,389.193 | 9,198 | 5,518.800 |

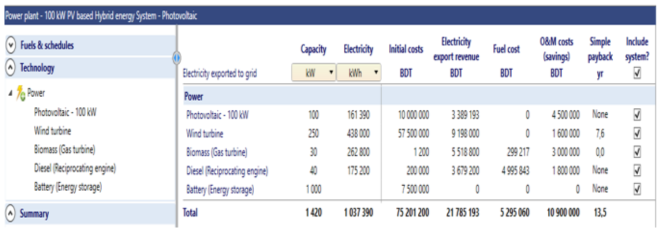
**Table 10** Simulation result for scenario B

| Parameters | Solar | Wind | Biogas |
|---|---|---|---|
| Capacity Factor | 18.4% | 20% | 20% |
| Initial Cost (Tk) | 10,000 | 57,500 | 1,600 |
| O&M (Tk) | 4,500 | 6,400 | 4,000 |
| Electricity Export to Grid (kWh) | 161,609 | 438 | 350.400 |
| Electricity Export Revenue (Tk) | 3,717.003 | 10,074 | 8,059.200 |

7.4 Cost analysis

By using RETScreen, the user is able to enter the initial, annual and periodic costs for the proposed system. To get overall expenditures, user need to provide all the details of the cost of various components required for the establishment of the combined system. This gives the users details of annual savings and the annual and periodic costs. It gives option of entering all types of costs included in the making of the project. The details of the cost sheet analysis are given as in fig. 6 and 7 for scenario A and B respectively. For scenario A and B, total initial cost is 75,201.200 taka and 95,501.600 taka and O&M cost is 10,900 taka and 16,100 taka respectively.

For this hybrid system, inflation & discount rate is considered 2% and 9% respectively. Project life is 25 years. Considering the debt ratio, the equity is 33850.600 taka and per year debt payment is 4599.212 taka.

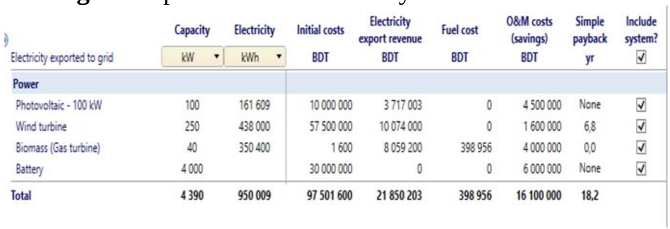


Power plant - 100 kW PV based Hybrid energy System - Photovoltaic

Fuels & schedules · Technology · Power · Summary

| Electricity exported to grid | Capacity (kW) | Electricity (kWh) | Initial costs (BDT) | Electricity export revenue (BDT) | Fuel cost (BDT) | O&M costs (savings) (BDT) | Simple payback (yr) | Include system? |
|---|---|---|---|---|---|---|---|---|
| Power | | | | | | | | |
| Photovoltaic - 100 kW | 100 | 161 390 | 10 000 000 | 3 389 193 | 0 | 4 500 000 | None | ☑ |
| Wind turbine | 250 | 438 000 | 57 500 000 | 9 198 000 | 0 | 1 600 000 | 7,6 | ☑ |
| Biomass (Gas turbine) | 30 | 262 800 | 1 200 | 5 518 800 | 299 217 | 3 000 000 | 0,0 | ☑ |
| Diesel (Reciprocating engine) | 40 | 175 200 | 200 000 | 3 679 200 | 4 995 843 | 1 800 000 | None | ☑ |
| Battery (Energy storage) | 1 000 | | 7 500 000 | 0 | 0 | 0 | None | ☑ |
| Total | 1 420 | 1 037 390 | 75 201 200 | 21 785 193 | 5 295 060 | 10 900 000 | 13,5 | |

**Fig. 6** Snap shot of cost summary of scenario A



| Electricity exported to grid | Capacity (kW) | Electricity (kWh) | Initial costs (BDT) | Electricity export revenue (BDT) | Fuel cost (BDT) | O&M costs (savings) (BDT) | Simple payback (yr) | Include system? |
|---|---|---|---|---|---|---|---|---|
| Power | | | | | | | | |
| Photovoltaic - 100 kW | 100 | 161 609 | 10 000 000 | 3 717 003 | 0 | 4 500 000 | None | ☑ |
| Wind turbine | 250 | 438 000 | 57 500 000 | 10 074 000 | 0 | 1 600 000 | 6,8 | ☑ |
| Biomass (Gas turbine) | 40 | 350 400 | 1 600 | 8 059 200 | 398 956 | 4 000 000 | 0,0 | ☑ |
| Battery | 4 000 | | 30 000 000 | 0 | 0 | 6 000 000 | None | ☑ |
| Total | 4 390 | 950 009 | 97 501 600 | 21 850 203 | 398 956 | 16 100 000 | 18,2 | |

**Fig. 7** Snap shot of cost summary of scenario B

7.5 Emission Analysis

RETScreen helps to determine the annual reduction in the emission of greenhouse gases stemming from using the proposed technology in place of the base case technology. After the simulation by RETScreen, greenhouse factor of Swarna Dweep is found 1202 $kgCO_2/kWh$. Fig. 8 shows the emission output by RETScreen.

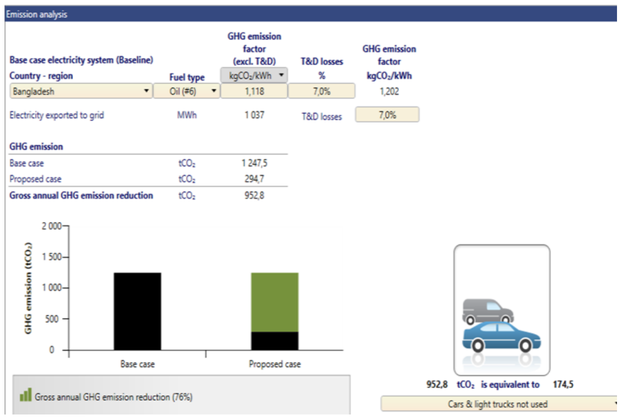



**Fig. 8** Emission output by RETScreen

According to the HOMER analysis, proposed hybrid system offers low Carbon di oxide ($CO_2$) emission, continuous power supply, reduction the COE, additional income from biogas fertilizer.

## 8. Result and Discussion

The project's lifetime is planned for 25 years with an annual discount rate of 9%. Out of two scenarios, scenario A consists of 100 kW PV array, 25 Wind turbine (10 kW each), a diesel generator with a rated power of 40 kW, 30 kW biomass generator, 1000 kW storage and scenario B consists of 100 kW PV array, 25 Wind turbine (10 kW each), 40 kW biogas generator, 4000 kW storage. About the initial cost, initial capital is obtained by HOMER is 40,451.200 taka for scenario A and 58,251.600 taka for scenario B whereas from RETScreen, the cost of scenario A and B are 91396.26 taka and 114000.56 taka respectively. Electricity Production by REScreen for Scenario A and B are 1037,390 kWh and 950,009 kWh respectively and by HOMER for both scenarios are 714,287 kWh and 704,706 kWh.

**Table 11** Comparisons of two best scenarios by RETScreen

| Scenario | Hybrid System Size ( kW) | Electricity Production kWh | Initial Cost (Tk) |
|---|---|---|---|
| a | b | c | d |
| Scenario A | 420 | 1037,390 | 75,210.200 |
| Scenario B | 390 | 950,009 | 97,501.600 |

| Total Cost (Tk) | Net Revenue (Tk) | Simple Payback (Year) | COE (Tk/kWh) (From HOMER Analysis) |
|---|---|---|---|
| e | f | g | h |
| 91,396.26 | 21,785.193 | 13.5 | 21 |
| 114,000.56 | 21,850.203 | 18.2 | 23 |

Comparison of the two cases of best RETScreen simulation result is given in Table 11. In addition, the payback period by RETScreen is shown 13.5 years and 18.2 years for both scenarios. The COE is 21 Tk/kWh for scenario A and 23 Tk/kWh for scenario B by RETScreen which has completely commensurate with HOMER result as COE for scenario A is 21.665 Tk/ kWh and scenario B is 23.491 Tk/kWh. Therefore, the result validates the HOMER results for hybrid energy sources. Among them, scenario A, namely solar, wind, biogas and diesel configured hybrid renewable energy sources is considered the best proposed configuration in terms of COE and initial cost.

## 9. Conclusion

As per HOMER, the Hybrid energy system has the electricity generation mix of 29 % from PV, 56% from the wind turbine, 5% from diesel generator and 10% from biogas resources. The proposed hybrid system was able to produce 1957 kWh/day against the 1694 kWh/day required for lighting and power loads. Therefore, it is evident that with more than two renewable resources, the hybrid system is likely to operate well. But system reliability cannot be confirmed due to unpredictable behavior of the nature. It is assumed that solar irradiation and wind speed likely to be low in winter. The off grid area like Swarna Dweep's load demand will meet from the hybrid power system solar PV, wind, biogas combination. RETScreen validated the HOMER software result where COE is completely commensurate. As RETScreen normally add the local climatic conditions, therefore planning of energy model is much simpler. So the results become accurate by using RETScreen software and this software gives very promising results for Hybrid systems.


## 10. Acknowledgement

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