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Research/Technical Note

Selection of the Most Appropriate Off-Grid Hybrid System for Rural and Coastal Areas in Bangladesh Using Analytical Hierarchy Process (AHP)

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Abstract: The objective of this study is to select the most appropriate hybrid system for reliable and affordable electricity generation for sustainable development. To reach this goal Analytical Hierarchy Process (AHP) model was applied. The methodology was developed and applied considering experts and stakeholder's judgment based on six criteria such as resource availability, Net Present Cost (NPC), Cost of Electricity (COE), Technical, Environmental and social to determine and prioritize the best alternative among PV-Battery-Wind-Diesel, PV-Battery-Diesel, Wind-Battery-Diesel and PV-Wind-Battery. After the experts and stakeholder's pair-wise comparison and considering relative weights the most prioritized hybrid system measured is PV-Battery-Wind-Diesel by receiving 31.49% priority. Later an environmental analysis showed that emission from the selected system is around 52% less, compared if, the electricity drawn from the national grid. The second most prioritized system is PV-Wind-battery. Although it is totally environment friendly but due to the magnitude of the alternative resources it cannot reach the goal. In addition, ranking and prioritizing outcomes of these hybrid systems can be implemented in renewable energy policy as a long-term rural electrification plan.

Keywords: Hybrid System, Renewable Energy, Analytical Hierarchy Process, Electricity Generation, CO_2 Emission

1. Introduction

Energy is indispensable to the economic, social and environmental aims at sustainable human development. If this objective is to be accomplished through, the types of energy that must be developed and the approach in which they will be used must also change the form the manner it is being produced and used presently. Access to the latest energy facilities not only elevates financial development and domestic earnings but also confirm enhanced education and health which results better lifespan.

Electricity plays a vital role to reduce poverty and socio-economic development of a country like Bangladesh as it is the convenient and efficient form of energy. Vast population and growing industrial sector of Bangladesh need uninterrupted supply of electricity and due to this context Bangladesh government aims to confirm affordable and reliable electricity for all of its citizens by 2021 [1]. At present, 32% of the total population has no access to electricity and most of them are in rural areas and although the rest of the percentage has access to electricity but not uninterrupted [2]. Annual energy consumption per capita of the country is one of the lowest in South Asia and the demand is growing at a percentage of 8.1 for last few years. As on April, 2016 total installed capacity is about 12,365 MW, although, the actual generation varies in between 8000-8500 MW [1]. A projection showed that to reach an annual GDP of 8%, Bangladesh requires power about 41,900 MW by 2021 [3]. It is a fact that energy security is essential for sustainable development of Bangladesh.

Grid connected electricity in rural areas requires huge development and investment by the government. Currently fossil fuel contributes the maximum percentage in generating electricity. Due to the limitation of these fossil fuels, the government is unable to supply uninterrupted electricity. Moreover, greenhouse gases (GHGs) are producing in vast amount while burning these fossil fuels in the power plant. But the country has very good potential of renewable resources like solar, wind, hydro and utilization of these resources could be a long term solution to meet up energy crisis and electricity generation. Using these resources through distributed generation could be possible in rural or coastal areas where grid extension is not possible in near future.

The geographical location of Bangladesh is very promising for solar radiation; the average insolation varies between 4-6.5 kWh/m^2. Also Southern part of the country has average wind speed of above 4m/s [4, 5]. Distributed generation hybridization would be the most attractive solution of utilizing these resources which can be effectively install in rural or coastal areas. Due to the variation of magnitude throughout the year these alternative resources cannot meet the demand solely and that's why these sources can be shared with diesel generators. Some literature proposed various configurations of hybrid systems like PV-battery-wind-diesel, PV- battery-diesel, and wind-diesel so on. With the help of donor organizations the government is also working to set up an efficient hybrid model for electricity generation in those areas. As a short or medium term plan hybrid system of medium size could be install to meet the basic and productive needs for economic and social development.

The elementary scopes of sustainability of electricity generation are sustainable supply of energy resources that should be reliable, affordable and adequate in the long run. To make a hybrid system sustainable it is obligatory to follow and involve some fundamental factors as illustrated in Figure 1 [6, 7]. The outset and execution of the hybrid project should be consistent with the rural electrification plan. A cost-benefit analysis must be executed among the alternatives to select the least-cost system/project. Technology selection must be based on practical considerations like resource availability, technology maturity and O&M simplicity. Social awareness and involvement is one of the key to make the project sustainable and as well as government involvement must be carried in various ways like financing as soft loan or subsidy. Government could also explore the opportunities for co-financing by international donor agencies.

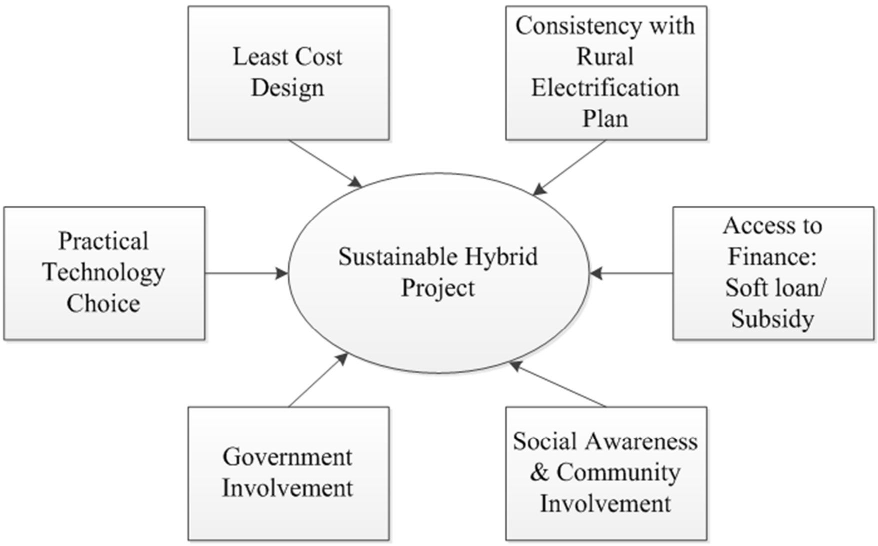

Figure 1. *Fundamentals of sustainable hybrid project.*

To select the best hybrid configuration there are several approaches can be applied together with multi-criteria decision analysis (MCDA) methods. In this study, Analytical Hierarchy Process (AHP) method is used as one of the MCDA method to select the best configuration because it is very practical and powerful technique. There are several literatures where researchers used AHP to select most appropriate alternative like selection of renewable energy technologies in Pakistan [8], selection of technology in Bangladesh among biogas, wind, PV [9]. AHP model is applied here to select the most appropriate hybrid configuration among PV-battery-wind-diesel, wind-battery-diesel, PV-battery-diesel, PV-wind-battery considering different issues like energy resource availability, Net Present Cost (NPC), Cost of Electricity (COE), technical maturity, environmental benefits and social improvement.

2. Methodology

The objective and goal of this study is to select the most appropriate hybrid model for electricity generation in rural and long coastal areas in Bangladesh. The distributed generation needs to be hybridization to meet up the electricity demand. To reach this goal there are some steps which need to follow like evaluation of renewable energy resources in that area, explore hybrid system components and AHP model execution. Performing these steps will reach to the final destination, the best hybrid system.

2.1. Renewable Energy Resources

This study has carried out mostly on southern part rural and coastal areas in Bangladesh like Kutubdia, St. Martin Island, Cox's Bazar, Chittagong, Kuakata etc. The reason behind selecting these locations is because these areas have good potential of wind speed as an addition of solar radiation.

2.1.1. Solar Energy

This alternative energy is the most dominating source of energy around the globe. PV and concentrating solar power (CSP) are extensively using for generating electricity. Geographical location of Bangladesh has huge scope to utilize this resource. Therefore, data collected from Bangladesh Meteorological Department and NASA showed that, the solar insolation ranges from 4-6.5 kW/m^2/day [13].

Table 1. *Solar radiation at different locations in Bangladesh.*

Location	Latitude (Degree)	Longitude (Degree)	Radiation (kW/m^2/day)
Dhaka	23.7	90.4	4.65
Chittagong	22.3	91.8	4.56
Khulna	22.8	89.6	4.55
Sylhet	24.9	91.9	4.57
Barisal	22.7	90.4	4.51
Rangpur	25.7	89.3	4.88
Cox's Bazar	21.4	92.0	4.69
Saint Martin	20.6	92.3	4.80
Kutubdia	21.8	91.9	4.77
Dinajpur	25.6	88.6	5.00
Mymenshing	24.8	90.4	4.64
Kuakata	21.8	90.1	4.75

Research shows that 50GW power can be generated by only using solar PV technology [21]. The Table 1 shows solar radiation availability for different locations in the country and the radiation at our locations of interest is over 4.5 kW/m^2/day [5].

The Figure 2 shows the solar radiation data and clearness index throughout a year [5, 11]. It illustrates, except the monsoon season (July-September) radiation and clearness index is quite high.

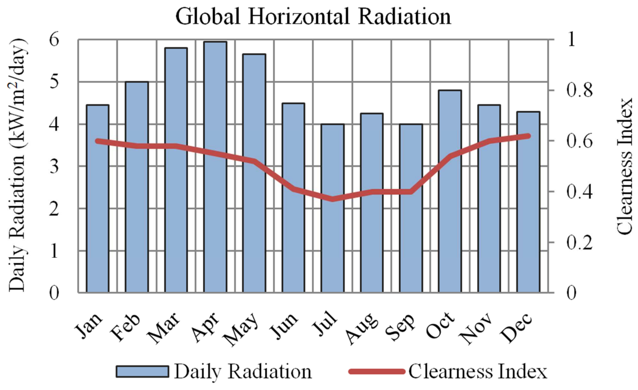

Figure 2. *Solar radiation and clearness index for a year.*

2.1.2. Wind Energy

Wind energy is the eco-friendly source of renewable energy. The southern part of the country especially the 724 km long coastal line and islands have high wind speed which is highest in monsoon season and lowest in winter season. Reference from several literatures showed that, wind speed in these areas varies from 2.8 to 5.9 m/s and average is 4.18 m/s at a height of 25m, 30m and 50m [12, 20]. Table 2 presents wind speed at different locations throughout a year [5, 12, 20].

In the case of low wind speed, maximum power can be extracted by modifying the aerodynamic design of blades. Therefore, modular basis wind turbine system in island and coastal areas could be a technological option for extracting the power from wind which could be effectively used for battery charging, residential and small commercial loads and possible smart grid connection for future extension. Theoretical power calculation from wind turbine follows equation (1),

$$P = 0.5\times \rho \times A \times V^3 \tag{1}$$

Where, P is the generated power in watt, ρ is the air density, A is the swept rotor area and V is the wind speed. Figure 3 shows wind speed at 30m height for a year [12].

Table 2. *Monthly average and 10-year average wind speed at coastal region of Bangladesh.*

Month	Monthly average wind speed (m/s)					
	Patanga	Kutubdia	Cox's Bazar	Kuakata	Char Fasion	Saint Martin
January	3.25	3.67	2.33	3.18	2.80	5.03
February	3.13	3.29	1.99	3.37	2.69	4.70
March	2.88	3.53	2.42	4.84	3.54	4.24
April	4.96	3.10	3.84	4.93	3.29	3.79
May	5.83	4.89	3.97	6.28	4.81	5.07
June	5.67	5.90	4.64	7.31	5.76	6.17
July	5.13	6.17	4.80	7.34	5.22	5.56
August	5.32	5.34	4.31	5.70	5.17	5.78
September	3.36	3.97	2.96	3.77	3.08	4.47
October	3.2	3.98	3.74	2.18	3.70	4.11
November	2.61	3.23	2.93	1.98	-	3.53
December	2.97	3.38	1.78	3.35	3.09	4.11
10-year average	2.73	3.55	3.64	3.45	2.63	4.85

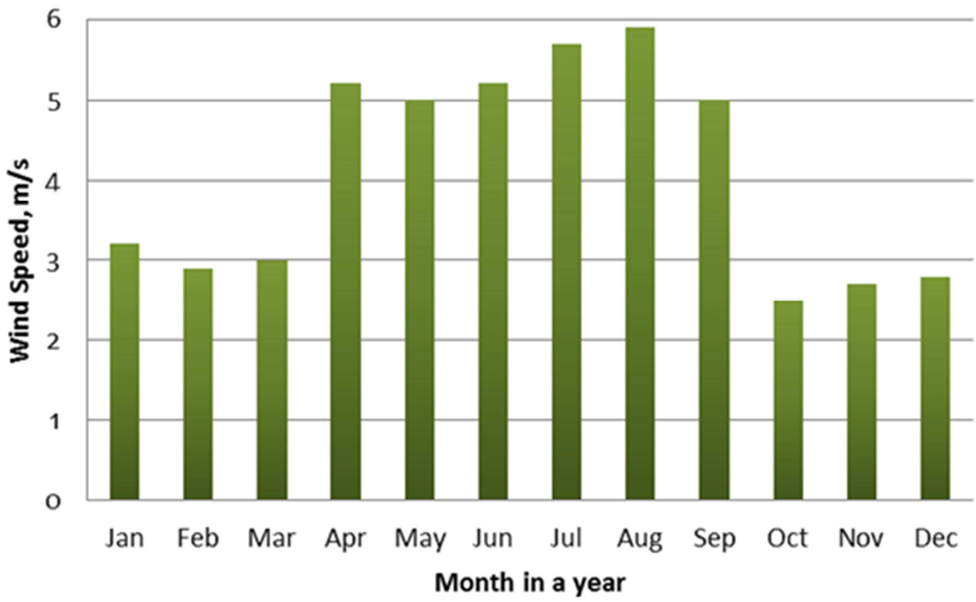

Figure 3. *Wind speed variation throughout the year.*

2.2. Hybrid System Component

2.2.1. Solar PV Module

Solar Photovoltaic (PV) uses the photovoltaic principle to convert the ionizing radiation into electricity. The solar PV is rated in Wp and its size depends on technical and economic factors. Usually output from the PV panel varies due to the variation of sun radiation thus its output is directly proportional to radiation. The basic material of solar cell is silicon and the output from the solar cell/panel depends on the type of silicon because of temperature effect. Solar PV generates DC which needs to store into a battery using charge controller. Lifetime of PV panel is 20-25 years.

2.2.2. Wind Turbine

The wind turbine uses the kinetic energy of moving air and then converted to mechanical energy and then generates AC electricity through alternator. Wind turbine lifetime varies from 9-15 years. The magnitude of wind speed is directly proportional to the electrical power output from wind turbine. The power output from the turbine depends also the size, number and orientation of the blades. Wind turbine can be installed in both on-shore and off-shore area.

2.2.3. Battery and Inverter/Converter

Magnitude of the renewable energy resources like solar PV, wind varies throughout the year. So, to get continuous supply of electricity the storage device like battery is essential part of the whole system. Although there are different types of battery available but usually deep cycle battery is used to store the charge. Battery carry almost half of the total solar system cost and due to this reason continuous maintenance is must to improve the lifetime of a battery. To control the charging and discharging charge controller may be used. An inverter is also used to convert the DC from Battery to AC loads and converter is used to convert the AC to DC.

2.2.4. Diesel Generator

Although this paper concentrates the renewable resources but to get continuous supply of electricity mostly to meet the peak load demand, diesel generator may possibly be used. Its efficiency depends on the load conditions which are maximum at full load and minimum at low load. The cost of generation is mainly depends on the diesel price. So, to make the economically profitable and reduce the generation cost it would be a wise decision to run the diesel at peak load time.

The technical and economical parameters of hybrid system components like solar PV, battery, converter, diesel generator and wind turbine is presented in Table 3 [19, 22]. The Table mentions typical sizing of different components and their pricing and other factors. It is noted that the price of these components has collected from literatures and internet sources therefore may vary from actual market values.

Table 3. *Technical and economical parameters of hybrid systems components.*

Characteristics	PV module	Battery	Converter	Diesel Generator	Wind Turbine
Model	Typical	Trojan T-105	Typical	Typical	WES 5 Tulipo
Power	250 Wp	Nominal voltage 6 V Nominal capacity 225 Ah	2 kW	50 kW	2.5 kW
Life time	25 years	Lifetime throughput 845 kWh	15 years	15000 hrs	15 years
Price	$355	$110	$730	$10000	$3000
Replacement	$355	$110	$730	$8500	$2700
Maintenance	$3/kW	$2/Battery	$1/kW	$0.03/hr/kW	$60/Turbine

2.3. Hybrid System Modeling

As mentioned earlier different combinations of renewable energy technologies will combine to form a hybrid system. During normal load conditions electricity will produce from renewable energy sources like PV and wind. While the peak loads period, the additional diesel generator will supply the electrical energy which cannot meet from the renewable sources. However, if there is no output from PV and wind then the generator supplies the full load. During hybrid system modeling the following conditions needs to be addressed-

- Size, Net Present Cost (NPC) of PV, battery, inverter, wind turbine, diesel generator
- Capacity of shortage is 5%.
- Annual real interest rate 5%.
- The project lifetime is 20 years

2.3.1. PV-Battery-Wind-Diesel

This hybrid system contains major components like PV array, battery bank, wind turbines and diesel generator and the system architecture shown in Figure 4. Also for conversion an AC/DC converter is designed here. The net present cost of this hybrid system is calculated considering the capital and O&M cost and is reflected in Table 4.

Table 4. *Economical comparisons among the hybrid system alternatives.*

Alternatives (Hybrid systems)	PV (kW)	Battery T-105	Wind Turbine WES 5 Tulipo (kW)	DG (kW)	Converter	Initial cost ($)	O&M cost ($)	NPC ($)	COE ($)
PV-Battery-Wind-Diesel	30	174	10	39	18.3	105036	18794	369915	0.26
PV-Battery-Diesel	30	190	-	39	17.5	76550	27925	470130	0.33
Wind-Diesel-Battery	-	68	10	39	11.2	48647	25602	409487	0.29
PV-Battery-Wind	30	254	10	-	19.7	106446	5792	188081	0.14

2.3.2. PV-Battery-Diesel

The configuration of this hybrid system is PV array, battery bank, diesel generator and a converter is used to convert DC to AC. The system architecture is shown in Figure 5. The net present cost and levelized cost of electricity (COE) for this system is $0.33 or BDT26.4 the highest among all systems.

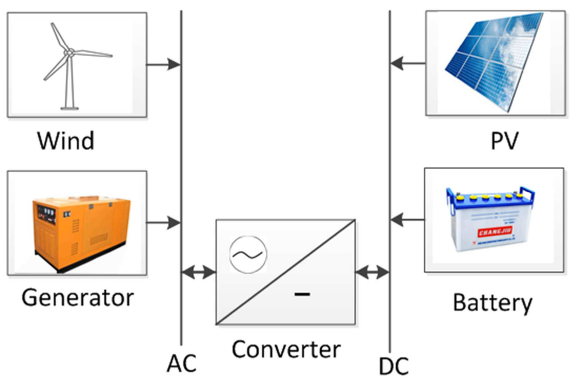

Figure 4. *PV-battery-wind-diesel hybrid system.*

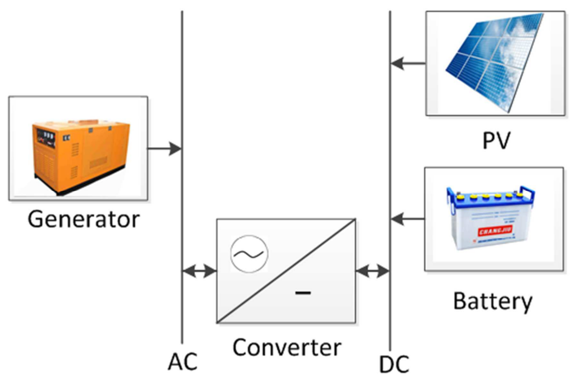

Figure 5. *PV-battery-diesel hybrid system.*

2.3.3. Wind-Diesel-Battery

The major components use in this hybrid system is PV array, battery bank, diesel generator and converter and the system architecture is shown in Figure 6. The cost of electricity (COE) for this system is $0.29 or BDT23.2 is based on the net present cost and O&M cost. Battery is used here to store charge from wind turbine after conversion through converter for the period when wind speed is not available to generate electricity.

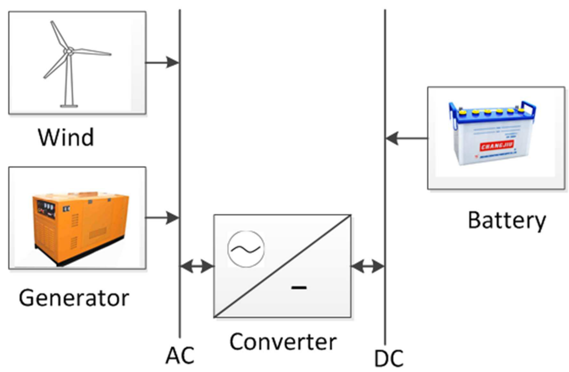

Figure 6. *Wind-battery-diesel hybrid system.*

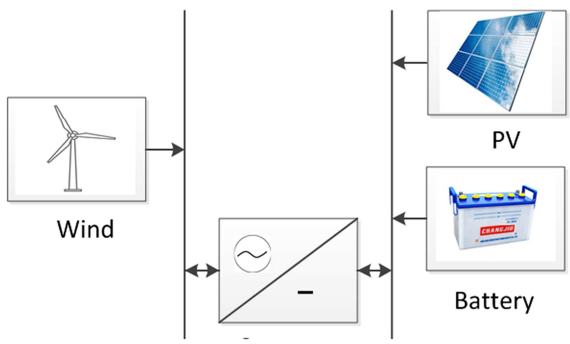

Figure 7. *PV-Wind-battery hybrid system.*

2.3.4. PV-Battery-Wind

The configuration of this hybrid system is PV array, battery bank and wind turbine and the system architecture shown in Figure 7. Also for conversion an AC/DC converter is designed here. The net present cost of this hybrid system is calculated considering the capital, replacement and O&M cost and is reflected in Table 4. The cost of electricity (COE) for this system is $0.14 or BDT11.2 which is lowest among the all hybrid systems.

2.4. AHP Model Description

Analytical Hierarchy Process (AHP) is very commonly used MCDA tool which was developed by Thomas L. Satty [13]. AHP method helps decision makers or researchers to solve the complex decision problems in a logical manner in the form of levels of a hierarchy shown in Figure 8.

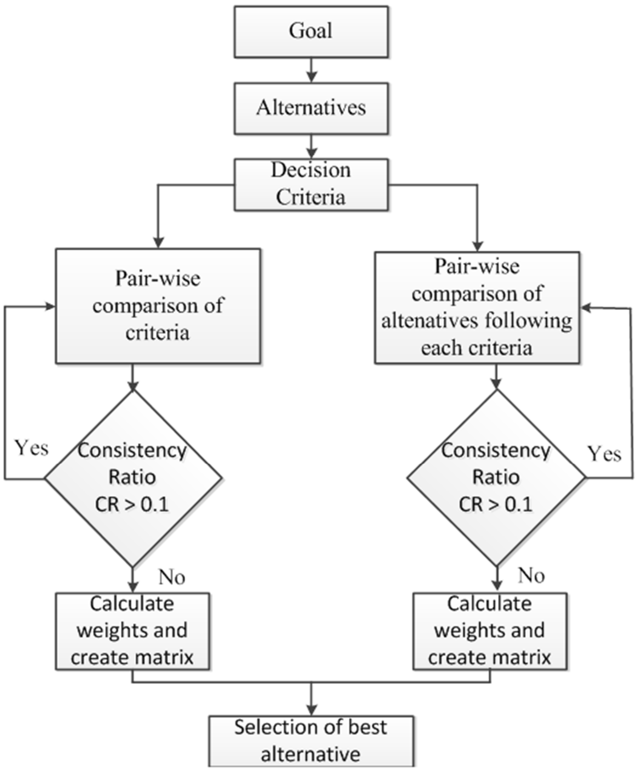

Figure 8. *AHP model flow chart.*

Thus AHP has the following three fundamental concepts-

i. Build complex decision problem and the hierarchy will follow goal, criteria and alternatives. Goal will be at the top, criteria at the middle and alternatives at bottom of the hierarchy.
ii. Pair-wise comparison of elements (criteria and alternatives) at every stage of AHP model with respect to each criterion on the preceding stage. Through pairwise comparison the importance/weightage of each alternative is calculated.
iii. Combining the judgments over the various stages of the hierarchy.

According to the flow chart of AHP model a pair-wise comparison of criteria like C1, C2, C3, C4, C5, C6 needs to be executed to form a new matrix. Similarly, a pair-wise comparison of alternatives like A1, A2, A3 and A4 using single criterion C1 need to be implemented which is shown in Table 5.

Table 5. *Hypothetical comparison table.*

	A1	A2	A3	A4
A1	1	p/q	p/r	p/s
A2	q/p	1	q/r	q/s
A3	r/p	r/q	1	r/s
A4	s/p	s/q	s/r	1

The hypothetical comparison table can be transferred into n×n pair-wise comparison matrix, M_1.

$$M_1 = \begin{bmatrix} 1 & p/q & p/r & p/s \\ q/p & 1 & q/r & q/s \\ r/p & r/q & 1 & r/s \\ s/p & s/q & s/r & 1 \end{bmatrix}$$

Pair-wise comparisons are used to rank the criteria and alternatives for decision making using 1-9 scale measurements and eigenvector method. Table 6 shows satty's discrete 9 value scale [14].

Table 6. *AHP Scale of Absolute Numbers.*

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgments	When compromise is needed
Reciprocal of above	Inverse importance	

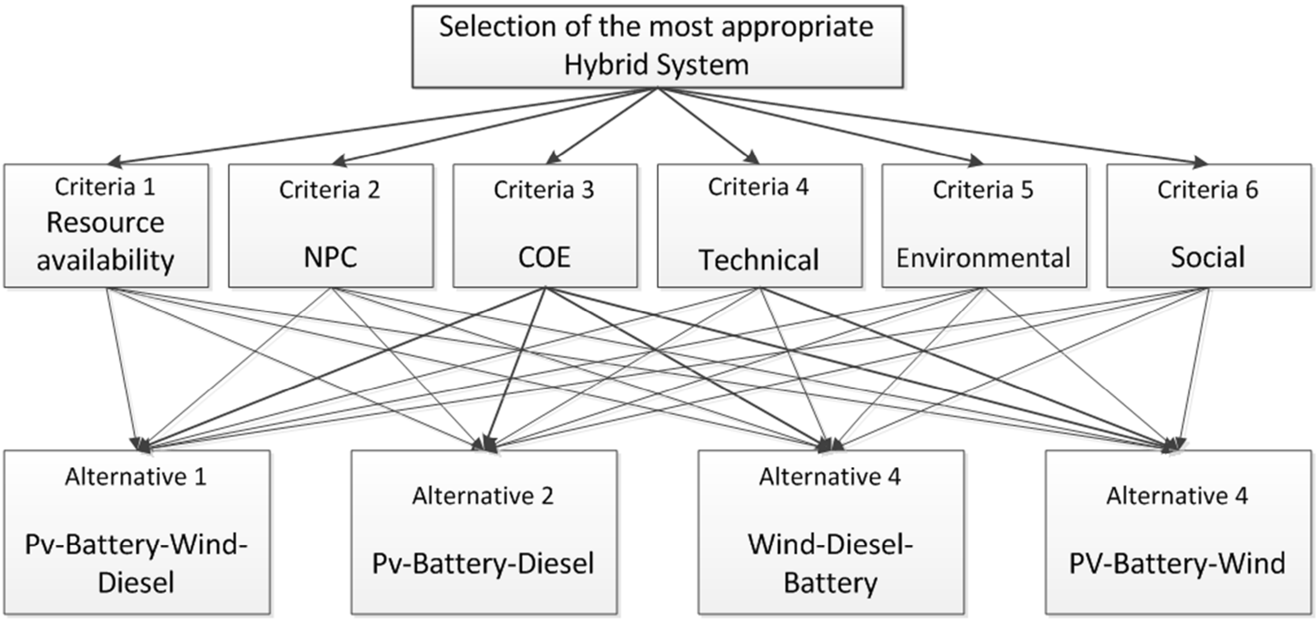

Figure 9. *Hierarchical structure for the selection of most appropriate hybrid system.*

The relative weights of A1, A2, A3 and A4 can be normalizing it into a new matrix M_2. The desired relative weights of four alternatives are then computed as row average of the new matrix M_3.

The next stage of the flow chart is the consistency check and estimates the consistency index (CI) and consistency ratio (CR) using equation 2 and 3

$$\text{Consistency Index, CI} = \frac{\lambda_{max} - n}{n - 1} \tag{2}$$

Here, n is the size of the matrix (n×n) and λ_{max} can be defined as the product of M_2 and M_3.

$$\text{Consistency Ratio, CR} = \frac{CI}{RC} \tag{3}$$

If consistency ratio (CR) is equal or less than 0.10, then the pair-wise comparison results will be accepted, or else these must rejected and reviewed. While calculating CR, the Random Consistency (RC) can be projected based on matrix size mentioned in Table 7.

Table 7. *The Random Consistency (RC) for number of matrix size.*

n	1	2	3	4	5	6	7	8	9
RC	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

The final stage of AHP flow chart is to rank the alternatives. It can be executed by multiplying the alternative decision matrix with criteria judgment matrix as:

$$\begin{bmatrix} A1_{C1} & A1_{C2} & A1_{C3} & A1_{C4} & A1_{C5} & A1_{C6} \\ A2_{C1} & A2_{C2} & A2_{C3} & A2_{C4} & A2_{C5} & A2_{C6} \\ A3_{C1} & A3_{C2} & A3_{C3} & A3_{C4} & A3_{C5} & A3_{C6} \\ A4_{C1} & A4_{C2} & A4_{C3} & A4_{C4} & A4_{C5} & A4_{C6} \end{bmatrix} \times \begin{bmatrix} C1 \\ C2 \\ C3 \\ C4 \\ C5 \\ C6 \end{bmatrix}$$

Where A1, A2, A3, A4 are the four possible alternatives and C1, C2, C3, C4, C5, C6 are the six selection criteria.

3. AHP Model for This Study

Selection of the most appropriate hybrid model for electricity generation is the one and only goal of this study. To reach this goal according to AHP model flow chart at first chooses the possible alternatives and the selection criteria.

After evaluating the renewable energy resource potential in Bangladesh, conducting extensive literature review to use the AHP method for the selection most appropriate hybrid model and interaction with experts and stakeholders, an AHP based hierarchical structure has generated which shown in Figure 9.

This model comprises of three levels consist of goal, alternatives and criteria. Selection of the most appropriate hybrid model is the goal which is placed on the top of the hierarchical model.

Later six criteria and four alternatives were identified that have direct impact to reach the goal of the decision model. Table 8 and 9 presents the options for alternatives and decision criteria respectively.

Table 8. *Alternative details for different hybrid model.*

Alternative No	Alternative Details
A1	PV-Battery-Wind- Diesel
A2	PV-battery-Diesel
A3	Wind-Battery-Diesel
A4	PV-Battery-Wind

***Table 9.** Decision criteria for AHP model.*

Criteria No	Criteria	Description
C1	Resource availability	Availability of the renewable energy resources like solar radiation, wind speed in the specific location of interest. Also the magnitude of the resources throughout the year.
C2	Net Present Cost (NPC)	Net present cost involves capital cost and operation & maintenance cost
C3	Cost of Electricity (COE)	Per unit electricity cost i.e. in kWh cost
C4	Technical	Technical maturity of the system components and availability in the country.
C5	Environmental	Environmental criteria involves considering land requirements during installation of the system components, emissions of GHGs from DG and landscape change
C6	Social	Social benefits in terms of job creation, social progress and acceptance of the local people.

4. Results and Discussion

4.1. Ranking of Hybrid System Alternatives

In applying AHP model, pair-wise comparison has made to define the importance of the elements of the decision problem with another. Expert and stakeholders were involved for judgments and they were requested to make pair-wise comparisons of the criteria with respect to each criterion considering the goal of the model.

After compiling the judgments from the respondents, it indicates that resource availability and NPC are the most important criteria by means of relative weights of 0.26 and 0.21 respectively. On the other hand social aspects received the least importance with relative weight of 0.088. The criteria judgment matrix is shown here.

$$\text{Criteria judgment matrix, } \begin{matrix} C1 \\ C2 \\ C3 \\ C4 \\ C5 \\ C6 \end{matrix} = \begin{bmatrix} 0.1765 \\ 0.2059 \\ 0.2647 \\ 0.1471 \\ 0.1177 \\ 0.0882 \end{bmatrix}$$

The next step of the AHP process is pair-wise comparison of alternatives using each criterion and the relative weights are presented in matrix below and in Figure 10. Alternatives decision matrix is

$$\begin{matrix} & \begin{matrix} C1 & C2 & C3 & C4 & C5 & C6 \end{matrix} \\ \begin{matrix} A1 \\ A2 \\ A3 \\ A4 \end{matrix} & \begin{bmatrix} 0.391 & 0.261 & 0.292 & 0.280 & 0.280 & 0.364 \\ 0.304 & 0.130 & 0.125 & 0.360 & 0.200 & 0.318 \\ 0.174 & 0.217 & 0.208 & 0.200 & 0.160 & 0.182 \\ 0.130 & 0.391 & 0.375 & 0.160 & 0.360 & 0.136 \end{bmatrix} \end{matrix}$$

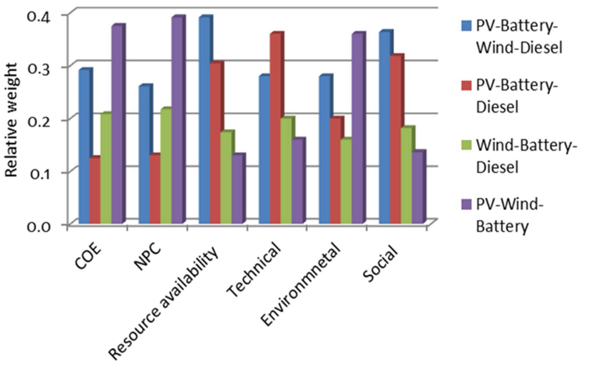

***Figure 10.** Relative weights of alternatives based on different criteria.*

Considering the criteria resource availability, PV-battery-wind-diesel generator (A1) is the most prioritized option and the priority percentage was 39%. Based upon the relative weights of the criteria and priority weights of each alternative, the overall weights have calculated by multiplying criteria judgment matrix with alternative decision matrix.

The final hybrid system matrix is shown below and the overall ranking of hybrid system alternatives shown in Figure 11. Due to higher resource availability and higher social benefits in terms of job creation, social progress and social acceptance the solar PV- Battery-Wind-Diesel generator system received the highest priority weight (0.315) among other hybrid system alternatives. Solar PV-Wind-Battery got the subsequent priority weight.

The final hybrid system matrix,

$$\begin{bmatrix} 0.391 & 0.261 & 0.292 & 0.280 & 0.280 & 0.364 \\ 0.304 & 0.130 & 0.125 & 0.360 & 0.200 & 0.318 \\ 0.174 & 0.217 & 0.208 & 0.200 & 0.160 & 0.182 \\ 0.130 & 0.391 & 0.375 & 0.160 & 0.360 & 0.136 \end{bmatrix} \times \begin{bmatrix} 0.176 \\ 0.205 \\ 0.264 \\ 0.147 \\ 0.117 \\ 0.088 \end{bmatrix} = \begin{matrix} A1 \\ A2 \\ A3 \\ A4 \end{matrix} \begin{bmatrix} 0.314 \\ 0.234 \\ 0.191 \\ 0.259 \end{bmatrix}$$

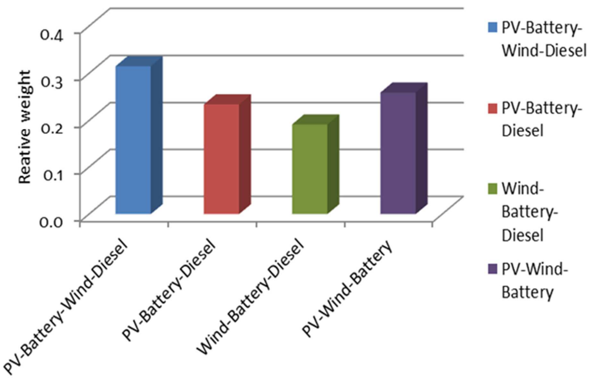

***Figure 11.** Ranking of hybrid model alternatives.*

4.2. Environmental Analysis of the Selected Hybrid System

Although the selected hybrid system consist PV array and wind turbine to generate electricity but to get uninterrupted electricity diesel generator is an obligatory component. But burning fossil fuel like diesel GHGs will be emitted. But among the GHGs CO_2 is the most dominant one. Therefore, in this study due to the dominant role of CO_2 only amount of CO_2 and carbon (C) emission has calculated using tier 1 approach [15]. The Table below presents an environmental analysis statistics for a year and also for the whole project life. Total electricity generated from the selected system is 127114 kWh whereas the generation share from diesel generator is 33.88% which is 43070 kWh.

Table 10. *Environmental analysis of the selected hybrid system.*

Consumption (liters/year)	Calorific value of Diesel (MJ/liter)	Total energy Released (TJ)	CO_2 Equivalent (tonne/year)	C Equivalent (tonne/year)	CO_2 Equivalent (tonne) for 25 years	C Equivalent (tonnes) for 25 years
13396	43	0.577	42.68	11.63	1067	290.75

If the total 12114 kWh has drawn from national grid then the total emission would be around 89 tonnes of CO_{2eq} and 25 tonnes of C_{eq} as 0.7 tonne CO_2/MWh is the emission factor for Bangladesh. For the 25 years of lifetime the total emission will be 2225 tonnes and 625 tonnes of CO_{2eq} and C_{eq} respectively. This clearly indicates that the selected hybrid system will reduce around 1158 tonnes and 334 i.e. tonnes of CO_{2eq} and C_{eq} respectively. So, it reduces more than half of emission i.e. 52%. Therefore, in a sense it is clear that the selected hybrid system is environmentally considerable with respect to totally fossil fuel based power station.

The above calculation was reflected only on-site factors. Moreover, land use change for installing raw material can add more emission in atmosphere although that amount is very insignificant thus negligible.

5. Conclusion

AHP is broadly used MCDA method which is used as a methodology to select the most appropriate renewable energy based hybrid model for electricity generation in rural and remote especially in coastal areas in the southern part of Bangladesh. In this model, six criteria were acknowledged for the selection of the best alternative among four alternatives. Judgment and opinion were collected from experts and stakeholder's to prioritize the alternatives.

The outcome from the intensive analysis showed that PV-Battery-Wind-Diesel Generator system appeared as the most prioritized option. Although, renewable energy sources are preferred but unfortunately none of them can meet the demand solely. But the selected system will definitely reduce the dependency on fossil fuel and thus reduce the emission. More notably it will improve social welfare by various means. Moreover, the rural part of the country has no access to electricity and these distributed generations could solve the problem in a sustainable manner. So, utilization of these resources by using convenient technologies considerably helps the country to overcome electricity shortage, economic growth, living standard and reduce environmental pollution.

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