

Investigating the environmental and socio-economic impacts of grid-tied photovoltaic and on-shore wind systems in Bangladesh

ISSN 1752-1416

Received on 29th November 2017

Revised 28th March 2018

Accepted on 11th May 2018

E-First on 12th June 2018

doi: 10.1049/iet-rpg.2017.0751

www.ietdl.org

Md Nurunnabi¹, Naruttam Kumar Roy¹ ✉, Md Apel Mahmud²¹Department of Electrical and Electronic Engineering, Khulna University of Engineering & Technology, Khulna 9203, Bangladesh²School of Engineering, Deakin University, Waurn Ponds, VIC 3220, Australia

✉ E-mail: nkroy@eee.kuet.ac.bd

Abstract: Current power generation scenarios all over the world are not climate friendly as the generation systems are mainly dependent on fossil fuels that produce greenhouse gas (GHG). As renewable energies (especially solar and wind energies) have the sustainable characteristics, by replacing the conventional energy system with them, it is possible to significantly contribute to reducing the dependency on fossil fuels as well as GHG emissions. Though biomass is the primary renewable source in Bangladesh, this study is exploring new options in photovoltaic (PV) and on-shore wind in the 0.5–2 MW capacity range. This research presents environmental and socio-economic impacts of grid-connected hybrid (PV/wind) power systems by investigating the potentials of the solar and wind energy with considering various sensitivity variables for two different locations, namely Magnama and Dinajpur, in Bangladesh. The main goal of this research is to generate the lowest possible adverse socio-economic and environmental impacts ensuring a certain degree of monetary benefits. Three sizes of plants have been chosen for quantifying the variations in socio-economic and environmental impacts. It is found that the proposed model of the hybrid power system can maximise the benefits by reducing the adverse effects of conventional power plants.

1 Introduction

Every sector of modern civilisation is dependent on energy which comes from various energy sources such as nuclear energy, renewable plants and fossil fuels (coal, oil and natural gas). The combustion of fossil fuels emits a huge amount of greenhouse gases (GHGs) such as carbon dioxide, sulphur dioxide, and nitrogen dioxide that harm the atmosphere and health of the population [1, 2]. Therefore, there is an acute need for a power generation system which is reliable and sustainable that overcomes various problems related to the existing power system. As renewable energy (RE) can play an important role in reducing global warming and they are clean and environmental friendly, the insertion of them instead of fossil fuels would be a great alternative solution for the present situation [3–5].

Recently, hybrid power systems using RE are becoming popular due to their potential benefits on the environment [2, 6]. The electricity demand of Bangladesh is increasing due to the advancement of economic activities in the country with sustained gross domestic product growth [7]. The maximum demand in FY 2016 was 11,405 MW which is 10.91% higher than the previous year [8]. With the increase in energy demand, per capita GHG emission rate is increasing day by day [9]. The per capita carbon dioxide (CO₂) emissions from grid electricity in 2015 were 0.16 ton/annum. Though this value is lower than the world's average rate, it would go up in the near future due to the integration of a large amount of coal-based power generation system [9, 10]. According to the power development board of Bangladesh, power generation systems in this country are highly dependent on natural gas and in 2016, a 68.63% of the total net generation (national) came from natural gas; however, the present reserve of natural gas would be depleted by a decade [11]. Therefore, finding an alternative way of energy generation in Bangladesh is very urgently needed [12]. There is no other way for meeting the future power demand except to increase the utilisation of RE which is one of the important strategies adopted as part of fuel diversification programme [13]. Most of the developed countries are highly motivated to increase the contribution of RE systems to the national grid [3]. Currently, RE sources meet 15%–20% of the world's energy demand and it is increasing progressively [3, 6].

However, the development of RE is not significant in Bangladesh. The RE contributes only 3.7% of the total capacity where the hydroelectricity contributes 1.86% and other renewables contribute the rest [8].

An extensive research has been conducted worldwide in the area of RE but the techno-economic assessments of different RE sources in Bangladesh received much less attention. Asif *et al.* [14] describe the prominent features of Grameen Shakti programme that provides the micro-generation renewable systems to the rural population of Bangladesh over the last 14 years. By investigating the different RE projects, it is observed that with careful advanced planning RE sources can provide comprehensive socio-economic and environmental benefits to the rural community in Bangladesh. Some of the obstacles that need to be overwhelmed by the successful development of RE technology sector and improvement of rural livelihoods are also identified [15]. A recent study by Baki *et al.* [3] presented a thorough review of the current status and future potentials of RE sector in Bangladesh. Hossain *et al.* [12] investigated the business policy and problem for the solar energy system in Bangladesh. By investigating the solar energy potential in two different locations in Bangladesh namely Sirajganj and Jessore district, the analysis showed that the solar home systems for small business enterprise and household with small income generation are more viable compared with solar photovoltaic (PV) systems used for only household lighting [16]. A feasibility study has been performed for a stand-alone hybrid system in St. Martin Island, Bangladesh, and the cost of energy (COE) is found to be \$0.345/kWh which is much higher than the present grid price of Bangladesh [17]. A PV/diesel hybrid system configuration has been conducted in the Northern part of Bangladesh and analysis showed that it is more economical than the only diesel system [18].

Bangladesh has a good potential for harnessing RE sources such as solar and wind [15]. Due to the short of literature in the sense of grid-connected RE system, there are lots of scopes to concentrate on this topic. For achieving the target value of renewable power generation (10 of the total generation) within 2020 [3, 8], it is highly essential to investigate the environmental issues of Bangladesh to bring the higher percentage of RE sources into the energy mix to build an eco-friendly environment for the future. Therefore, the specific objectives of this paper are:

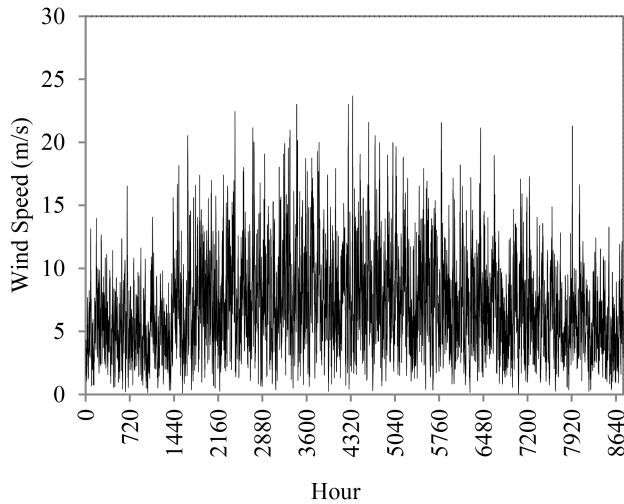


Fig. 1 Wind speed in a year at Magnama (40 m height)

- to investigate the RE (solar and wind) economics in Bangladesh,
- to analyse the feasibility of hybrid energy systems in a specific meteorological condition,
- to determine the environmental and socio-economic impacts of hybrid energy systems connected to the national grid of Bangladesh, and
- to determine how the access to electricity of the lower income group can be increased by RE systems.

2 RE resources

Although the GHG emission is not a primary concern for a developing country like Bangladesh, the incorporation of RE is obvious because of rapidly reducing natural resources. Besides biomass Bangladesh has few RE potentials among which wind and solar are promising sources.

2.1 Wind energy resources

Although the Meteorological Department of Bangladesh implemented the 20 monitoring stations for measuring wind resource data, it is essential to implement more stations in the coastal area to study the prospects of wind precisely. Most of the wind speed data are not taken at the desired level [7, 19]. The wind speed at desired height can be obtained by using the logarithmic law that is given as follows [20]:

$$V_2 = V_1 \times \frac{\ln(h_2/Z_0)}{\ln(h_1/Z_0)} \quad (1)$$

where V_2 represents the wind speed at height h_2 (m/s), V_1 is the known wind speed at height h_1 (m/s), h_2 is the desired level where wind speed is needed (m), Z_0 is roughness length in the current wind direction (m), and h_1 is the anemometer height (m). In this paper, after collecting wind speed data [19], an area has been selected according to the availability of high wind energy potential which is Magnama located in the South-East part of Bangladesh. Fig. 1 shows the hourly average wind speed around the year at Magnama, Cox's Bazar.

2.2 Solar energy resources

Bangladesh having geographical location between 20.30° and 26.38° North latitude and 88.04° and 92.44° East longitude is an ideal location for solar energy harvesting [15]. From the radiation data, it is found that the daily solar radiation varies between 4 and 6.5 kWh/m² [21, 22] over Bangladesh. This strong solar potential indicates that by implementing the solar power system, it is possible to electrify the maximum region of Bangladesh particularly in the northern part of this country. In this research, investigating and analysing the solar potential has been performed

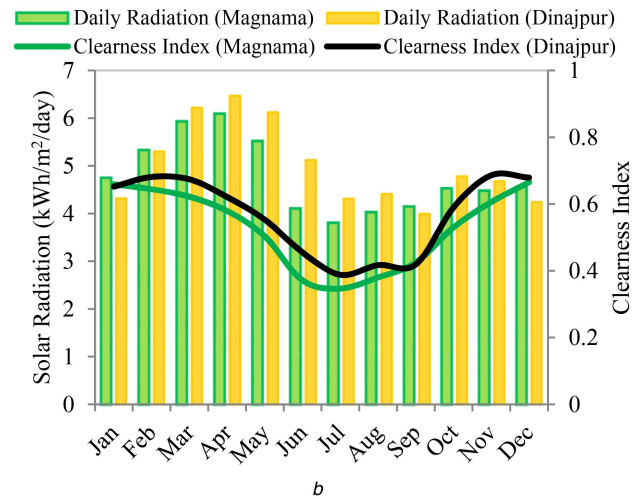
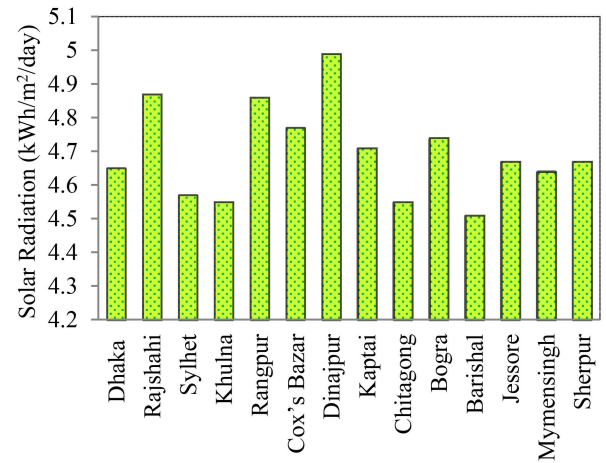


Fig. 2 Solar data (a) Solar radiation for 14 locations of Bangladesh, (b) Monthly average solar radiation and clearness index for selected sites [22]

not only for power generation but also to reduce the GHG emission which is an urgent need. Fig. 2a shows the daily solar radiation for 14 locations in Bangladesh and it is observed that the highest solar radiation areas are Dinajpur and Rajshahi. Fig. 2b shows the average daily solar radiation and clearness index for the Dinajpur (25°37'N 88°38'E) and Magnama (21°87'N 91°87'E).

3 RE economics

The cost parameters associated with the renewable power generation systems are described in this section.

3.1 Net present cost (NPC)

An NPC means the present value of all components that are installed in the plant minus the present value of all the revenues that it earns over the lifespan [6, 20].

3.2 Total annualised cost

The total NPC in a year is called the total annualised cost. It expressed as [6, 20]

$$C_{yr, total} = CRF(i, R_{plant-life}) \times C_{NPC, Total} \quad (2)$$

where $C_{NPC, Total}$, i , CRF , and $R_{plant-life}$ represents the total NPC in the dollar, the annual real interest rate, capital recovery factor and the plant lifetime in year, respectively.

3.3 Capital recovery factor

It is a ratio which is needed to calculate the present value of a series of equal yearly cash flows. It can be expressed as [6, 20]

Table 1 Distribution of the total capital cost for a typical onshore wind power system [29]

Section	Contribution(%)
wind turbine	64%
foundation	16%
grid connection	11%
planning & miscellaneous	9%
total	100%

$$CRF(i, n) = \frac{i \times (1 + i)^n}{(1 + i)^n - 1} \quad (3)$$

where n is the number of years and i is the real interest rate in a year.

3.4 Annual real interest rate

It is the discount rate which is used to transform between one-time costs and yearly costs. It is calculated as follows [6, 20]:

$$i = \frac{i' - F}{1 + F} \quad (4)$$

where i , i' and F is the real interest, nominal interest and annual inflation rate, respectively.

3.5 Cost of energy

It is defined as the mean value of cost per kWh of useful electrical energy produced by the plant. Total electrical loads are divided into AC primary load and DC primary load. It is calculated by the following equation [6, 20]:

$$COE = \frac{C_{yr, total}}{AC_{load} + DC_{load}} \quad (5)$$

where $C_{yr, total}$, AC_{load} and DC_{load} is the total annualised cost, AC primary load and DC primary load, respectively.

3.6 Discount rate and inflation rate

The interest rate or discount rate is used to convert between one-time and annualised costs. The average value of last few years of interest rate in Bangladesh is 11.78% [23]. Expected inflation rate has been taken as 5.71 for economic analysis [23].

3.7 System fixed capital cost

The fixed capital cost involves housing the battery bank, charge controllers, generator, inverter and other relevant electrical instruments. It also includes the labor, engineering design and construction costs of distribution lines. An estimate of the fixed capital cost including 3 km long three-phase distribution lines has been estimated at \$19,320/MW [18, 24].

3.8 System fixed operation and maintenance (O&M) cost

A system's fixed O&M cost firstly includes labor and insurance costs. Assuming the engineer and technician is full-time employed in the powerhouse, the annual fixed O&M cost has been taken as \$15/kW [25].

3.9 Project lifetime

It is the number of years the system is operated which is needed to compute the annualised replacement and capital cost of each component, as well as the total NPC of the system. In this paper, the project lifetime has been taken as 25 years.

4 Components costs of the hybrid energy system

The components cost of the hybrid energy system are given below.

4.1 Solar PV

In order to use reliable economic inputs, after contacting several companies and analysing some technical reports [24–27] and their quotations and specifications, the capital cost for the solar system is estimated as \$1340/kWp with 20 years warranty [26]. This cost also includes various equipment cost, installation cost, shipping cost and maintenance cost. The replacement cost of solar panel is estimated as 67% of the total capital cost and the O&M cost is estimated as \$26/kWp per year [24].

4.2 Wind turbine

The H21.0–100 kW wind turbine (WT) has been selected for the analysis due to its robust characteristics [28]. The capital cost of a typical onshore wind power system is associated with various factors such as the turbine cost, plant installation cost, planning cost and grid connection cost. The installation cost of a wind power project is dominated by the capital cost for the WTs (including towers and installation) and this can be as much as 64% of the total plant installed cost that is shown in Table 1 [29].

In this paper, the capital cost of a wind turbine is estimated as \$161,125/100 kW [28], as a consequence, the total capital cost of a typical onshore wind power system is found approximately \$251,758/100 kW. The replacement and O&M costs are estimated 75% and 2% of the total capital cost, respectively [30].

4.3 Inverter

In this research, the capital cost including shipment cost of the inverter is taken as \$214/kW [26]. The replacement cost is 93% of total capital and O&M cost is estimated as 1.2% of the capital cost [30].

4.4 Grid parameter

In grid-connected design, a grid supplies power when there is not enough renewable power to meet the load demand and it consumes power when an excessive power is available. In this paper, the unit purchase price is estimated as \$0.0975 per kWh [8]. Estimating the sellback price is a very argumental issue because no fixed sellback price is declared by the power division of Bangladesh [31]. A sensibility analysis has been performed by assuming various sellback prices and the nominal discount rates at fixed grid power price.

4.5 Land requirement for plant installation

For the solar system, a 9.29 m² per 100 kW footprint is needed for plant installation. Therefore, rooftops are the best suited for implementing 1, 2 even 3 MW plant. On the other hand, for a WT, a 46.45 m² footprint area is needed for a 100 kW size [25–28].

According to the National Renewable Energy Laboratory, the area requirements for wind energy are about 3000–17,000 m² per MW where the permanent infrastructure impacts amounted to 3000–4000 m², and temporary impacts amounted to 2000–10,000 m² [32]. In terms of land impact, wind plants sited on cropland require the largest total land. In this paper, 36,422 m² areas for every MW of wind farm have been estimated. Most of the land used was devoted to roads, where only 10% of the total lands are needed for installing WTs, 6% for substations, and 2% for transmission infrastructures. Land requirements for the land base system are considered 24,281 m²/MW for crystalline and 28,328 m²/MW for thin film-based PV farms [33]. It should be mentioned that depending on various parameters like region and efficiency of solar panel, the actual land requirement may also vary.

5 Load estimation for the proposed region

The load estimation is the preliminary essential part of plant installation. The estimation of the power demand was done after analysing the previously made case studies of rural electrification in developing countries [18, 30, 34, 35]. In this paper, the electric

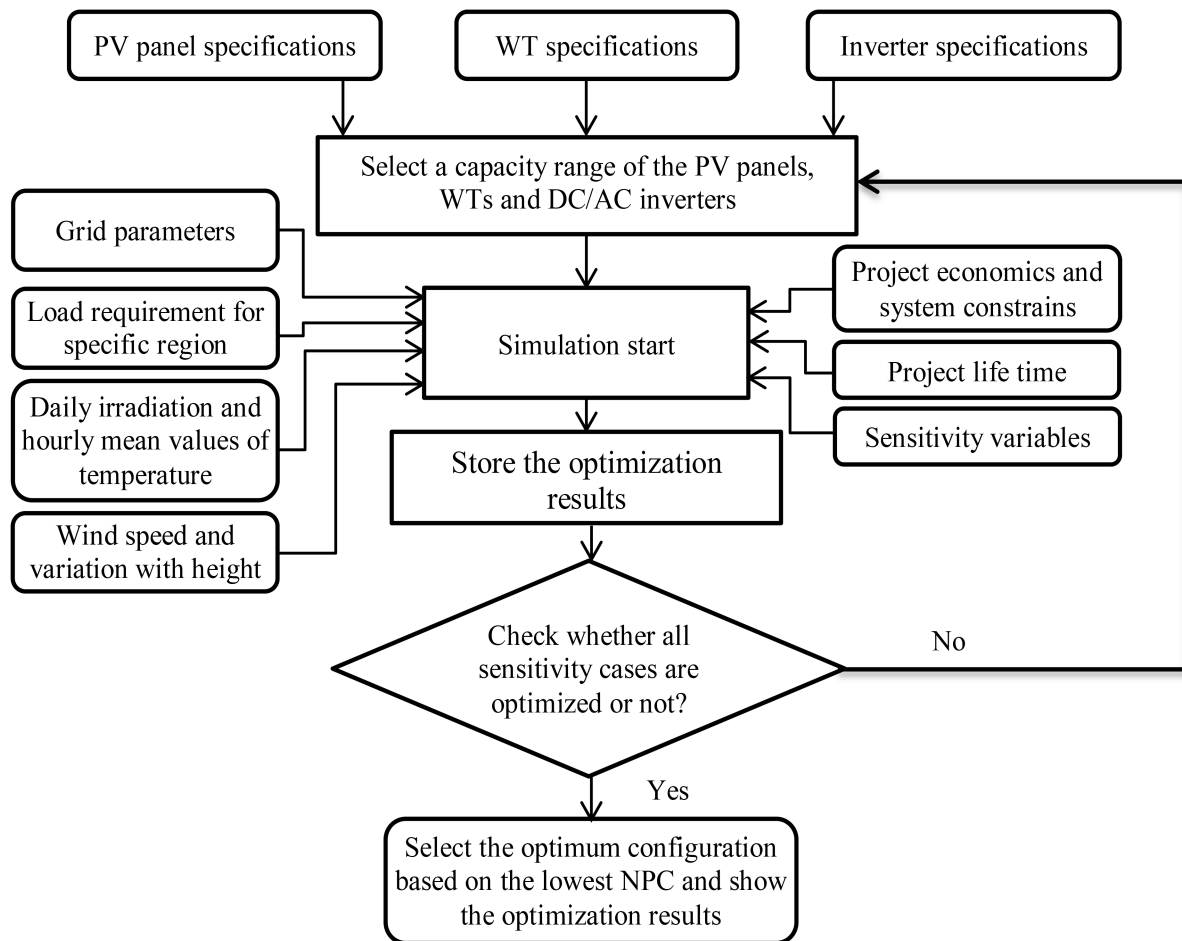


Fig. 3 Flowchart of the optimisation methodology

load demand is divided into the following three major categories such as household/domestic sector which includes lighting, TV, radio and baking appliances; commercial loads (shops); community loads which consist of school lighting, health clinic which includes vaccine refrigerator, communication radio, television, microscope, computer and printer and deferrable loads (water supply and irrigation systems, battery run auto-rickshaw). The total electric load estimated for the listed appliances above was summed up to get the required load to be supplied by the system [36].

5.1 Electricity demand at Dinajpur

The case study of this paper involves serving the load of an area of 300 households (average 5 people per household) located at Daptori Para, Dinajpur. The energy access of households was categorised into three different categories based on economic condition, i.e. high-class, medium-class and low-class household. For generating more accurate hourly load profile, a 10% hour to hour random variability and 10% day-to-day random variability has been considered. The total daily average electricity demand at Daptori Para is found as 2627 kWh and the load factor is found as 0.28 where the peak load is 395 kW.

5.2 Electricity demand at Magnama, cox's bazar

In Magnama, more than 1200 families are living but only a very few of them are getting access to electricity [37]. In this paper, 100 families have been considered as a rich family having four light bulbs, three ceiling fans, one small TV, one refrigerator and one water pump for each family. Seven hundred families have been estimated as a solvent family having four lights, two fans and one TV set for each family. In the poor category, 400 families have been considered having two lights and one fan of each family. According to the load estimation, 50 shops, one community health centre, one school and 100 street lights are also considered for that region. By adding the 10% random variability, a peak load is

observed as 645 kW, load factor 0.26, and daily average load 4029 kWh.

6 Methodology

Flowchart of the optimisation methodology that is used in this research is shown in Fig. 3. Initially, the technical characteristics of PV panels, WTs, and converters beside with their capital and O&M costs are fed as an input parameter to HOMER [20]. Multiple sensitivity variables are set for sensitivity analysis. Various sizes of the component have been specified as a search space for selecting the best combination of WTs/PV/converters. Utilising the value of daily average solar radiation with clearness index, temperature data, wind speed, project economic and system constraints, project lifetime, grid parameters which contain grid power price and emission rate and the consumer power demand, and sensitivity variables, an optimum solution is determined. By calculating the optimal total system cost and device configuration, an optimal sizing procedure is performed for each combination of devices. Finally, the overall optimal system configuration and the corresponding optimisation results are found based on the lowest NPC.

6.1 Sensitivity variables

A detailed scenario of a system model for the specific meteorological condition has been found by analysing sensitivity and optimising output. It also gives a marginal condition whether the hybrid systems are economically or environmentally feasible or not. This also needed in support decision making or the improvement of certain conditions from the proposed model. To observe the impacts of solar irradiation variability, wind resources, and some economic constraints and to make right decisions in developing hybrid system models, a sensitivity analysis has been performed. In this paper, the model has been simulated based on the sensitivity variables: wind speed or solar irradiation, grid

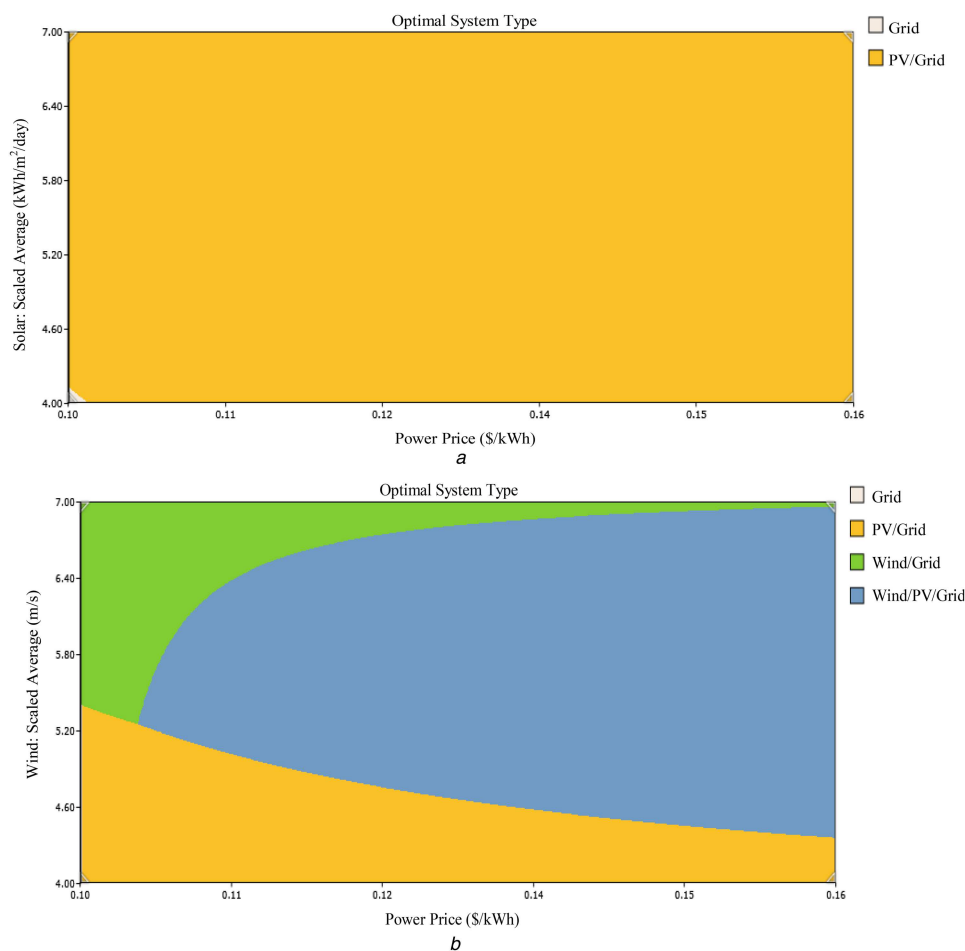


Fig. 4 Sensitivity analysis results for variable grid power price (a) Dinajpur, (b) Magnama

electricity price, grid sellback price, nominal discount rate and system size.

6.2 Sensitivity results for the optimum configuration

After considering all input parameters associated with the system, a sensitivity analysis has been performed using optimal system type for obtaining the optimum system configuration at desired locations. In these cases, sensitivity variables were grid power price (\$/kWh), solar radiation (kWh/m²/day) and wind speed (m/s). Fig. 4 shows the sensitivity results for the specific locations. Fig. 4a shows that when the solar radiation is above the 4 kWh/m²/day, the PV/grid system is feasible at Dinajpur region. As the solar radiation at Dinajpur region lies between 4 and 6.5 kWh/m²/day, it is an ideal location for implementing the PV/grid system model.

On the other hand, from Fig. 4b, it can be seen that with the increase in grid power price, different types of feasible system configurations were found for Magnama's local weather condition. At \$0.097/kWh (country's levelised COE or LCOE point) [8], for instance, a PV/grid system is feasible when the wind speed is observed below 5.5 m/s and wind/grid for above the 5.5 m/s. With the increase in the grid power price, the feasible system configuration will be changed at the same sensitivity variable range of wind speed. For example, if the grid power price increases \$0.2/kWh from the current LCOE then the PV/wind/grid system will be feasible between 4.8 and 6.6 m/s wind speed range and PV/grid system for beyond this range and wind/grid system for above this range. As the wind speed is observed between 6 and 7 m/s in Magnama region, the wind/grid system is the most feasible solution in this region.

7 Energy, socio-economic and environmental impact

After finding the optimal system configuration for a specific location, an optimisation process has been conducted for evaluating the socio-economic impact considering a plant capacity in the range of 0.5–2 MW.

7.1 Energy impact

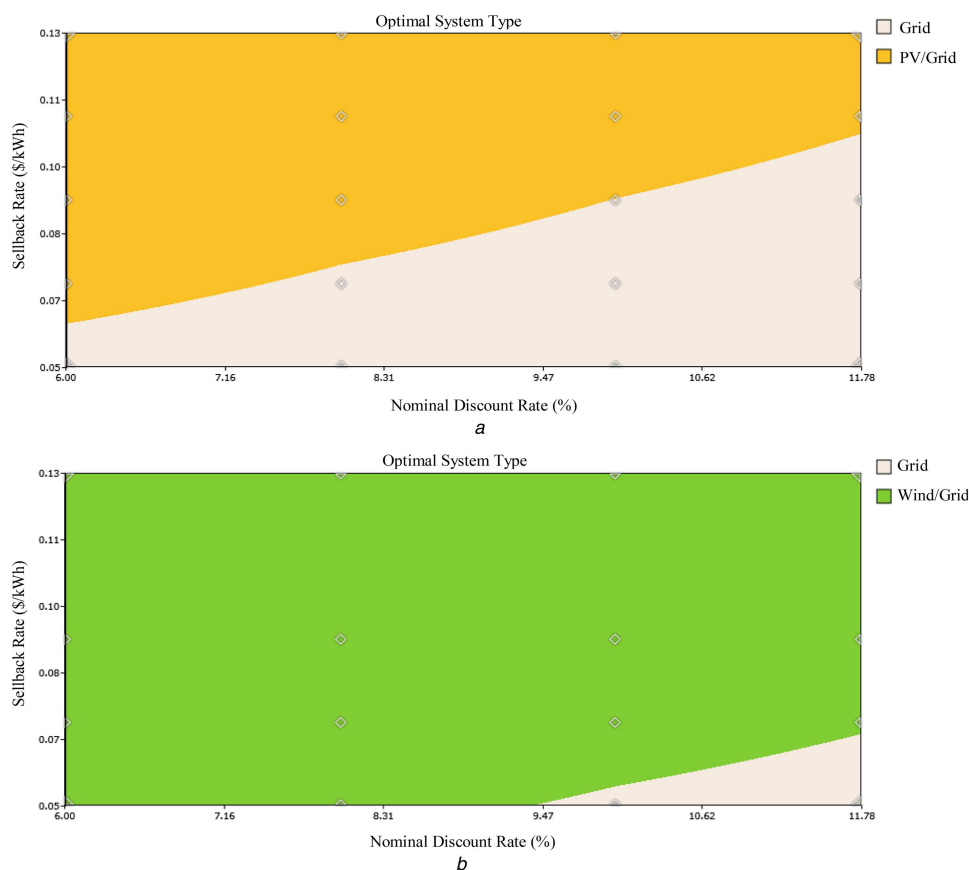
Installing the proposed model in the suitable area will result in a significant amount of electrical energy. Table 2 shows the estimated annual renewable electricity generation in both regions. The first and second columns of this the table indicate the size of the plant and name of the region, respectively. The third column of Table 2 'Type of plant' shows which type of RE is estimated in that particular location. As Dinajpur has high solar potential, a grid-connected PV system would be best suited for economically and environmentally. On the other hand, Magnama has high wind energy. Due to the availability of high wind energy, a grid-connected wind farm is the best choice in that location. Fourth column 'generation (kWh/year)' reflects the total output energy that comes from the RE. It shows that by installing a 500 kW plant, it is possible to produce 810,820 kWh (annual) for Dinajpur region and 1,698,140 kWh (annual) for Magnama region. The next column of the table 'Energy purchased (kWh)' indicates the total amount of energy that is purchased from the grid when RE sources are not capable of producing enough power. When excess electricity is produced by this system, it will sell this to the grid as shown in the next column.

7.2 Economic impact

Economic analysis for hybrid system model is dependent on various input variables such cost of installing and operating of the plant and economic constrains such as nominal discount rate, real discount rate, expected inflation rate, project lifetime which are described in Sections 3 and 4. A detail economic analysis has been

Table 2 Power generation scenario

Size of the plant	Region	Type of plant	Generation, kWh/yr	Energy purchased, kWh/yr	Energy sold, kWh/yr
500 kW	Dinajpur	(PV + grid)	810,820	715,110	522,868
	Magnama	(wind + grid)	1,698,140	621,616	849,171
1 MW	Dinajpur	(PV + grid)	1,621,641	672,415	1,228,724
	Magnama	(wind + grid)	3,396,281	399,009	2,324,704
2 MW	Dinajpur	(PV + grid)	3,243,282	644,395	2,737,965
	Magnama	(wind + grid)	6,792,561	225,215	5,547,192

**Fig. 5** Sensitivity analysis results for fixed grid power price (\$0.097/kWh) (a) Dinajpur, (b) Magnama

evaluated after specifying the suitable input and sensitivity variables.

7.2.1 Sensitivity results: A detail sensitivity analysis has been performed for the uncertainty of some input variable such as nominal discount rate and grid sellback price. By keeping the grid power price at a fixed rate (LCOE), the sensitivity analysis has been done by setting the certain range of sellback price (\$/kWh) and nominal discount rate (%). HOMER simulates the results for every possible sensitivity cases which are shown in Fig. 5. From Fig. 5a, it can be seen that PV/grid system is feasible when grid sellback price is above \$0.06/kWh for a certain condition. It also observed that, with the increase in the nominal discount rate, the feasible grid sellback price is increases, i.e., the grid sellback price is dependent on the nominal discount rate or vice versa. For instance, in Fig. 5a, the minimum feasible sellback price is found \$0.105/kWh for 11.78% nominal discount rate at the feasible situation. Similarly, the minimum feasible sellback price is found \$0.07/kWh at 11.78% discount rate point for Magnama which is shown in Fig. 5b. From this sensitivity analysis, it is possible to find out a suitable grid sellback price according to the nominal discount rate or vice versa at a certain environmental condition.

7.2.2 Optimisation results: The socio-economic analysis has been carried out with the aid of HOMER tools by considering all economic parameters as input. Optimisation results give the economic output for every possible system configuration according

to the sensitivity variable. Fig. 6 shows the cost summary for two different locations which includes the initial capital, O&M cost, faulty equipment replacement cost and salvage value for 500 kW, 1, and 2 MW power plant, respectively. Fig. 6a shows the cost summary for Dinajpur and Fig. 6b for Magnama. It is observed that with replacing the plant size with double capacity, approximately twice capital and replacement cost is required for both regions. On the other hand, the O&M and salvage value is declined around fourfold and twofold, respectively. More importantly, in Magnama region, the initial investment and other cost values are required almost 66% higher than the Dinajpur region for the same capacity of the plant.

Fig. 7a shows the variations in NPC and COE for Dinajpur (PV/grid) while Fig. 7b for Magnama (wind/grid) with varying the plant's size. It also shows a comparative analysis between only grid system and grid-tied hybrid energy systems. It can be visualised that, in case of COE, the similar decreasing pattern is observed for both regions; however, the different changing scenario for the NPC value has been seen. For Dinajpur region, the PV/grid system model (0.5 to 2 MW) requires comparatively lower NPC and COE value than the only grid system. On the other hand, in Magnama region, less NPC value is required for implementing up to 1 MW wind/grid model compared to the only grid system but for 2 MW hybrid system model higher NPC value is needed than the only grid system. From this figure, it can be concluded that all models in both regions have the significant economic benefit except 2 MW plant in Magnama. Though 2 MW plant in Magnama region is not

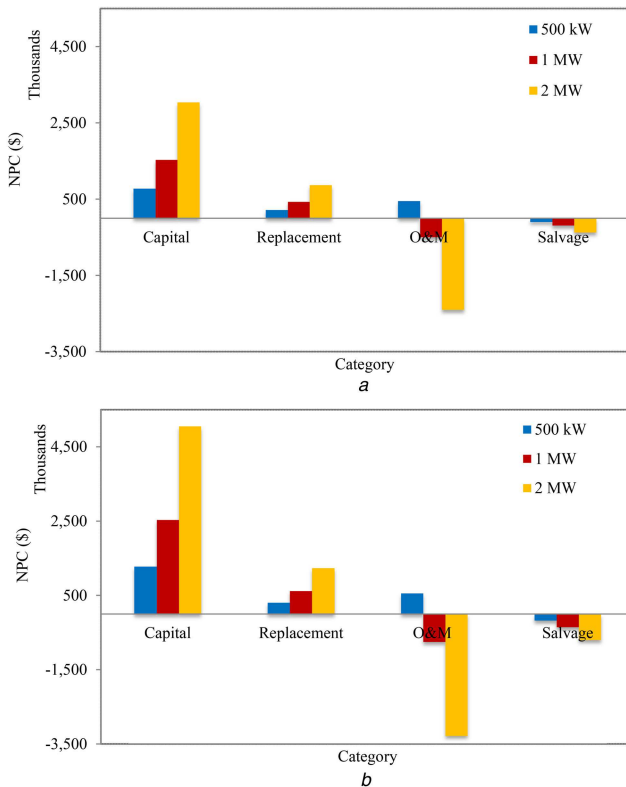


Fig. 6 Cash-flow summary (a) Dinajpur (PV/grid), (b) Magnama (wind/grid)

economically feasible, it has massive social and environmental benefit which is described in the next section.

7.3 Social impact

This section explores the social impact of RE (solar and wind) on the basis of following three parts.

7.3.1 Access to electricity: A direct access to grid electricity in Bangladesh is about 66% [8]. That means that about one-third of the people do not have direct access to the grid electricity. It will be a great challenge for Bangladesh to increase an access to grid electricity up to 90–95% by 2021 by expanding transmission and distribution networks and other related facilities including additional generation capacity. With the aid of implementation of green energy based power plant especially in remote areas, the electrification problem would be solved in few decades. This research is able to show that how the access rate can be increased by RE systems. For example, this research model tries to electrify more than 1500 families with average 5 family members. According to the present access rate of electricity, 1000 families have electricity facilities and rests are not electrified. By installing the proposed renewable-based power plant, rest of the 500 families who do not have an access to electricity would be electrified and other 1000 families can get green electricity with a lower price than the grid prices.

7.3.2 Job creation: The RE technology would be more labor-oriented system rather than fossil fuel technologies because the later one is generally mechanised and capital dependent. This means, in the renewable system, more jobs are created for per unit energy generation than that of fossil fuels. Between 0.4 and 1.4 jobs per MW of nameplate capacity of wind farms may produce during construction and 0.06–0.2 jobs per MW for O&M of WTs [38]. The job creation by wind farms depends on several factors and can be varied with nameplate capacity. For this reason, finding the exact job creation statistics by the wind farm is so difficult. However, approximately 20–70 jobs might be created by 50 MW wind farm during its construction and 3–10 jobs for its O&M [38]. According to the Renewable Energy Policy Project, there are about

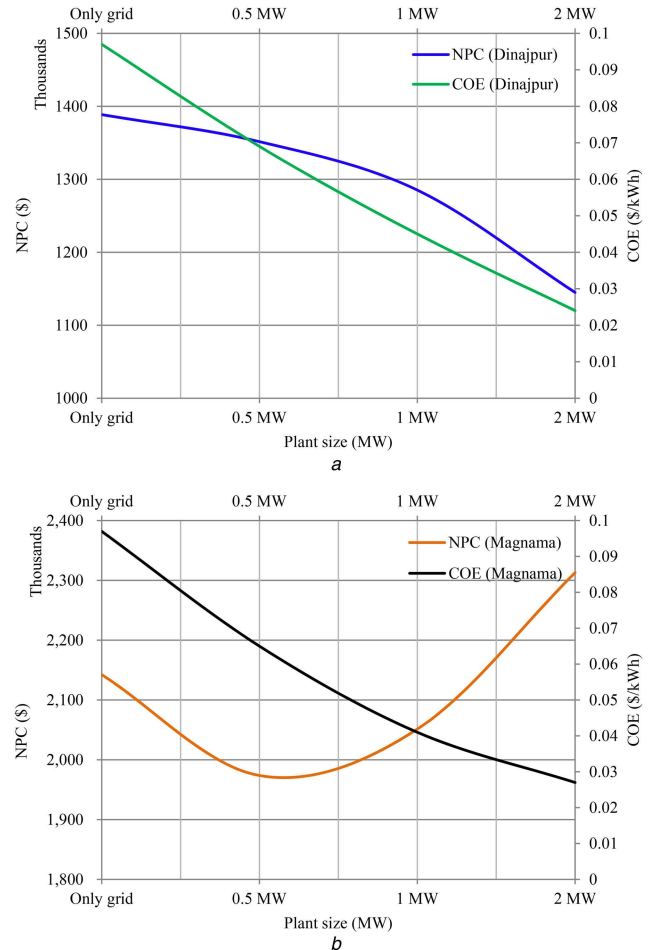


Fig. 7 Comparison of the NPC (\$) and COE (\$/kWh) (a) Dinajpur (PV/grid), (b) Magnama (wind/grid)

35 jobs associated with the manufacture and installation of 1 MW of PV-based power system [39]. In this paper, the job creation is estimated as 3 permanent jobs/MW solar systems which earn \$7538/yr and 5 permanent jobs/MW for wind system which earn \$11,230/yr.

7.3.3 Fiscal impacts: When PV cells or wind farms are sited on any private land then individual landowners can be benefited from annual lease payments of \$2000–5000 per turbine [40] and property-owners may get \$2500–4000 per MW per year in terms of facility nameplate capacity [38]. As a WT requires small footprints, agricultural lands may not be affected in a large context by it. Therefore, landowners may get dual economic benefits from lease payments and agriculture works. For PV, the landowner may receive annual \$2500 for per MW solar system and \$3744 for per MW wind system. On the other hand, in case of community-owned wind/solar farms, the facility's owners would be benefitted by selling electricity to the local utility.

7.4 Environmental impact

In this section, analysis has been carried out by investigating the GHG emission rate by various power sources given in [41]. The amount of GHG emission reduced by integration of renewable sources instead of fossil fuels can be calculated by emission factor or fossil fuel emission rate. A wide range of GHG emission factor or rate was found in the literature but only three sets of emission rates are shown in Table 3. The first row of this table indicates the GHG emission rate for Bangladesh and the analysis is carried out based on it.

Fig. 8 shows the CO₂ emissions for two different locations. By estimating the consumption of about 300 families in Dinajpur region from utility grid as 980,953 kWh/yr, GHG is accounted as 530 tons of CO₂, 1.3 tons of NO_x and 2.6 tons of SO₂. For

Table 3 GHG emission rate

References	CO ₂ , g/kWh	NO _x , g/kWh	SO ₂ , g/kWh
BPDB and PSMP 2010 (gross generation) [10]	540	1.34	2.74
ECONorthwest, eGRID 2006 (natural gas) [39]	530	0.31	0.09
ECONorthwest, eGRID 2006 (coal) [39]	982	1.58	4.67

Table 4 Emission reduction by proposed model

Region	Plant size	CO ₂ , kg/yr	NO _x , kg/yr	SO ₂ , kg/yr
Dinajpur	500 kW	425,904	1056	2161
	1 MW	830,121	2059	4212
	2 MW	1,660,242	4119	8424
Magnama	500 kW	916,996	2276	4653
	1 MW	1,833,992	4551	9305
	2 MW	3,667,983	16,553	11,160

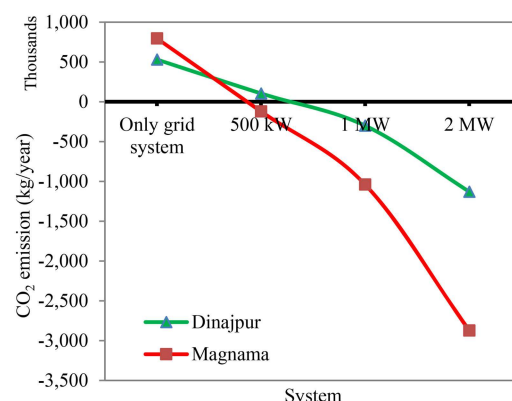
Magnama region, the annual power consumption is estimated as 1,470,585 kWh which produces approximately 794 tons of CO₂, 2 tons of NO_x and 4 tons of SO₂. The total CO₂ emission for only grid system and hybrid system model at the proposed regions is shown in Fig. 8. Some of the models have negative CO₂ emission as those models sell more energy to the grid than they purchase.

The analysis shows that by installing a 500 kW PV system in Dinajpur region, it would be possible to reduce 426 tons of CO₂, 1 tons of NO_x and 2.2 tons of SO₂ gas annually as shown in Table 4. For a 1 MW plant, the emission reductions are found 830 tons of CO₂, 2 tons of NO_x and 4 tons of SO₂. For 2 MW plant, these values are found 1660 tons of CO₂, 4 tons of NO_x and 8.5 tons of SO₂. Table 4 also shows that with the insertion of 500 kW wind-based power plant in Magnama, it is possible to reduce 916 tons of CO₂, 2.3 tons of NO_x and 4.6 tons of SO₂ which are almost double compared with that of Dinajpur region.

8 Conclusion

This paper investigates the impacts of RE in Bangladesh. Based on the analysis, it is found that installing the proposed plant presented in this paper will result in a wide range of substantial impacts that include:

- In terms of energy impacts, installing the grid-connected hybrid power system would produce a large amount of energy per annum. For a 500 kW plant, the total renewable generation is found about 811 and 1698 MWh for Dinajpur and Magnama region, respectively. If the plant size is increased in double amount than the energy output will have a net increase of 811–1621 MWh for Dinajpur and 1698–3396 MWh for Magnama. The results presented in this paper also show that the renewable generation increases proportionally with the increase of the plant size.
- The sensitivity analysis gives a suitable relation between sellback price and nominal discount rate in a certain meteorological condition which definitely will be useful for the future hybrid system development. The socio-economic analysis shows that by installing 0.5–2 MW plant instead of the only grid system, a significant amount of socio-economic development could be achieved. Results also show that for PV/grid system at Dinajpur, with the increase in the plant size from 0.5 to 2 MW, the NPC value decreases, i.e. 5% less NPC is required for making the plant size at double value and 15% less for fourfold value. On the other hand, for wind/grid system, a higher value of NPC is required for upgrading the plant size in a higher capacity. Approximately 4% and 17% higher NPC required for installing 1 and 2 MW plant, respectively, instead of 0.5 MW. More importantly, the COE is found much lower than the grid

**Fig. 8** CO₂ emission for different system architectures

power price for every size of the plant in both regions. As a consequence, government, as well as local community, can be benefited in a great context by it.

- The integration of grid-connected renewable-based hybrid model will also have an enormous impact in reducing emissions. The analysis shows that 500 kW, 1 and 2 MW PV/grid system can able to reduce CO₂ emissions at an amount of 425, 830 and 1660 tons, respectively. For the wind/grid hybrid system, it is about 916, 1833, and 3667 tons, respectively.

Finally, it can be concluded that wind and solar power are proficient not only in economic aspects but also in environmental features. As Bangladesh's energy demand increases rapidly, a growth in RE deployment with proper planning in the overall energy mix of the country can reduce COE and a massive amount of GHG emissions at the national level extensively.

9 References

- [1] Rezzouk, H., Mellit, A.: 'Feasibility study and sensitivity analysis of a stand-alone photovoltaic–diesel–battery hybrid energy system in the north of Algeria', *Renew. Sustain. Energy Rev.*, 2015, **43**, pp. 1134–1150
- [2] Goel, S., Sharma, R.: 'Performance evaluation of stand-alone, grid-connected and hybrid renewable energy systems for rural application: a comparative review', *Renew. Sustain. Energy Rev.*, 2017, **78**, pp. 1378–1389
- [3] Baky, M.A.H., Rahman, M.M., Islam, A.K.M.S.: 'Development of renewable energy sector in Bangladesh: current status and future potentials', *Renew. Sustain. Energy Rev.*, 2017, **73**, pp. 1184–1197
- [4] Basaran, K., Cetin, N.S., Borekci, S.: 'Energy management for on-grid and off-grid wind/PV and battery hybrid systems', *IET Renew. Power Gener.*, 2017, **11**, (5), pp. 642–649
- [5] Guo, L., Liu, W., Jiao, B., *et al.*: 'Multi-objective stochastic optimal planning method for stand-alone microgrid system', *IET Gener. Transm. Distrib.*, 2014, **8**, (7), pp. 1263–1273
- [6] Shafiuallah, G.M., Amanullah, M.T.O., Shawkat Ali, A.B.M., *et al.*: 'Prospects of renewable energy – a feasibility study in the Australian context', *Renew. Sustain. Energy Rev.*, 2012, **39**, (1), pp. 183–197
- [7] Ahmed, F., Al Amin, A.Q., Zaman, M.H., *et al.*: 'Alternative energy resources in Bangladesh and future prospect', *Renew. Sustain. Energy Rev.*, 2013, **25**, pp. 698–707
- [8] Available at http://www.bpdb.gov.bd/download/annual_report/Annual20Report202015-16.pdf, accessed 15 January 2017
- [9] Ahiduzzaman, M., Islam, A.K.M.S.: 'Greenhouse gas emission and renewable energy sources for sustainable development in Bangladesh', *Renew. Sustain. Energy Rev.*, 2011, **15**, pp. 4659–4666
- [10] Mizanurrahman, M.: 'Bangladesh national conservation strategy', Power Sector of Bangladesh. Available at http://fd.portal.gov.bd/sites/default/files/files/fd.portal.gov.bd/notices/c3379d22_ee62_4dec_9e29_75171074d885/19.20Power_NCS.pdf, accessed on 28 November 2017
- [11] Islam, M.T., Shahr, S.A., Uddin, T.M.I., *et al.*: 'Current energy scenario and future prospect of renewable energy in Bangladesh', *Renew. Sustain. Energy Rev.*, 2014, **39**, pp. 1074–1088
- [12] Hossain, M.F., Hossain, S., Uddin, M.J.: 'Renewable energy: prospects and trends in Bangladesh', *Renew. Sustain. Energy Rev.*, 2017, **70**, pp. 44–49
- [13] Tania, U., Anisuzzaman, M.: 'Social, cultural and political dimensions of off-grid renewable energy programs in developing countries', *Renew. Energy*, 2016, **93**, pp. 159–167
- [14] Asif, M., Barua, D.: 'Salient features of the Grameen Shakti renewable energy program', *Renew. Sustain. Energy Rev.*, 2011, **15**, pp. 5063–5067
- [15] Mondal, M.A.H., Kamp, L.M., Pachova, N.I.: 'Drivers, barriers, and strategies for implementation of renewable energy technologies in rural areas in Bangladesh – an innovation system analysis', *Energy Policy*, 2010, **38**, (8), pp. 4626–4634

- [16] Halder, P.K.: 'Potential and economic feasibility of solar home systems implementation in Bangladesh', *Renew. Sustain. Energy Rev.*, 2016, **65**, pp. 568–576
- [17] Islam, A.K.M.S., Rahman, M.M., Mondal, M.A.H., *et al.*: 'Hybrid energy system for St. Martin island, Bangladesh: an optimized model', *Procedia Eng.*, 2012, **49**, pp. 179–188
- [18] Salehin, S., Rahman, M.M., Islam, A.K.M.S.: 'Techno-economic feasibility study of a solar PV/diesel system for applications in the northern part of Bangladesh', *Int. J. Renew. Energy Res.*, 2015, **5**, (4), pp. 1220–1229
- [19] Azad, M.A.K.: 'Design and validation of wind turbine's power simulation by remote controlled AC motor', M.Sc. thesis, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh, October 2010
- [20] HOMER Pro Microgrid Analysis Tool (version 3.7.6) Energy. Available at <http://www.homerenergy.com/>, accessed 22 October 2017
- [21] Islam, M.R., Beg, M.R.A.: 'Renewable energy resources and technologies practice in Bangladesh', *Renew. Sustain. Energy Rev.*, 2008, **12**, (2), pp. 299–343
- [22] NASA's Surface meteorology and Solar Energy (SSE) database. Available at <https://eosweb.larc.nasa.gov/sse/HOMER/>, accessed on 3 March 2018
- [23] Available at <https://www.bb.org.bd/econdata/inflation.php>, accessed 22 November 2016
- [24] Investment Plan for Bangladesh.: 'Scaling up renewable energy in low-income countries (SREP)', October 2015. Available at https://www.climateinvestmentfunds.org/sites/default/files/meeting-documents/bangladesh_srep_ip_final.pdf, accessed 22 November 2017
- [25] Fu, R., Feldman, D., Margolis, R., *et al.*: 'U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017', National Renewable Energy Laboratory, Technical Report, NREL/TP-6A20–68925, September 2017
- [26] Available at <http://www.solarland.com/>, accessed 22 November 2017
- [27] Qingdao Allrun New Energy Co., Ltd.: Available at '<http://www.qdallrun.cn/>', accessed on 22 November 2017
- [28] Available at <http://www.chinahummer.cn/index.php/index/content/164>, accessed on 21 November 2017
- [29] International Renewable Energy Agency.: 'Renewable energy technologies: cost analysis series', 2012, **1**, (5/5),
- [30] Collen, Z.: 'A study into the techno-economic feasibility of photovoltaic and wind-generated electricity for enhancement of sustainable livelihoods on Likoma island in Malawi', Doctoral thesis, Loughborough University, 2015. Available at <https://dspace.lboro.ac.uk/2134/16630>, accessed 28 November 2016
- [31] Electricity Tariff. Available at <http://powerdivision.portal.gov.bd/site/page/2b909cce-9787-483d-a447-137d3f9edfa4>, accessed 28 November 2016
- [32] Yonk, R.M., Simmons, R.T.: 'Renewable energy siting and transmission resource requirements', Final report, May 2012. Available at <http://www.usu.edu/ipe/wp-content/uploads/ipePublications/Renewable-Energy-Siting-and-Transmission-Resource.pdf>, accessed on 22 October 2016
- [33] The final report.: 'Developmental impacts and sustainable governance aspects of renewable energy projects', Ministry of New and Renewable Energy (MNRE), September 2013. Available at <http://mnre.gov.in/file-manager/UserFiles/report-on-developmental-impacts-of-RE.pdf>, accessed on 28 November 2016
- [34] Camblong, H., Sarr, J., Niang, A., *et al.*: 'Micro-grids project, part I: analysis of rural electrification with a high content of renewable energy sources in Senegal', *Renew. Energy*, 2009, **34**, pp. 2141–2150
- [35] Himri, Y., Stambouli, A.B., Draoui, B., *et al.*: 'Techno-economical study of the hybrid power system for a remote village in Algeria', *Energy*, 2008, **33**, (7), pp. 1128–1136
- [36] Available at <https://www.desco.org.bd/?page=bill-calculator>, accessed 22 October 2016
- [37] Bangladesh Bureau of Statistics 'District Report, Cox's Bazar', Ministry of Planning, Bangladesh, December 2013. Available at <http://203.112.218.65:8008/WebTestApplication/userfiles/Image/District20Statistics/Cox60s20Bazar.pdf>, accessed 24 November 2016
- [38] Flowers, L., Kelly, M.: 'Wind energy for rural economic development', National Renewable Energy Laboratory, 2005. Available at <https://www.nrel.gov/docs/fy04osti/33590.pdf>, accessed 28 November 2016
- [39] Grover, S.: 'Energy, economic, and environmental benefits of the solar america initiative', 2007. Available at <http://www.nrel.gov/docs/fy07osti/41998.pdf>, accessed 28 November 2016
- [40] US Department of Energy.: '20 wind energy by 2030: increasing wind energy's contribution to U.S. Electricity supply', July 2008. Available at <https://www.energy.gov/sites/prod/files/2013/12/f5/41869.pdf>, accessed March 2018
- [41] Akella, A.K., Saini, R.P., Sharma, M.P.: 'Social, economic and environmental impacts of renewable energy systems', *Renew. Energy*, 2009, **34**, pp. 390–396