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Photovoltaic energy in Bangladesh: Recent scenario, techno-economic evaluation, potential and challenges

Mashudur Rahaman*[a,b], Abu Kowsar*[a], Nawshad Haque[b], Firoz Alam[c], Khondkar Saleque[d], Md. Sadequl Azam[a], Md. Abdul Gafur[a] and Farid Ahmed[e]

[a]Institute of Fuel Research and Development (IFRD), Bangladesh Council of Scientific and Industrial Research (BCSIR), Dhanmondi, Dhaka-1205, Bangladesh

[b]Commonwealth Scientific and Industrial Research Organization (CSIRO), Melbourne, Australia

[c]School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Melbourne, Australia

[d]Global Consultants and Educational Services Pty Ltd, Melbourne, Australia

[e]Department of Physics, Jahangirnagar University, Savar, Dhaka

E-mail: mashudurbd@gmail.com, apukowsar@gmail.com

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In recent years, solar photovoltaic energy has experienced a reasonable growth in Bangladesh. As a remote and off-grid power sources over 5.8 million solar home systems (SHSs) have already been installed having a total capacity of 370 MW. Four large scale solar power plants have also been installed recently and another 30 plants are under planning and construction phase having capacity of 1,910 MW. This article presents a review of solar power and other renewable resources in Bangladesh, their scenario, progress, related government policies, potentials and challenges for successful implementation. Techno-economic evaluation for stand-alone SHSs with supply to a grid-tied system has been performed. This evaluation has shown that the solar photovoltaic energy is likely to be an economically attractive source of clean energy and an alternative long-term energy security for sustainable development of Bangladesh.

Keywords: Photovoltaic energy, solar home system, grid-tied system, techno-economic evaluation.

Introduction

Power and energy are considered as a driving force for the economic prosperity, poverty eradication and sustainable development of a country. The gradual increase of energy demand, decrease of fossil fuels and the detrimental effects of these fuels forced the researchers and policy makers to ascertain other sustainable and alternative renewable energy sources for clean energy generation. Therefore, the world is experiencing an exponential growth of the renewable power production capacity. According to the International Renewable Energy Agency (IRENA), at the end to 2019, the global renewable energy generation capacity is reached to 2,537 GW, where the contribution of solar photovoltaic (PV) energy is 586 GW[1]. The main factor of this significant increment of global renewable energy generation is to reduce the greenhouse gas emission[2]. Among renewable sources, photovoltaic (PV) energy is believed to be a promising candidate for clean energy production in Bangladesh[3]. This energy can be harnessed through the PV system and the solar thermal power plant for different applications[4]. Recently, World Bank (WB) has recognized that Bangladesh is a fastest growing economy in the world[5]. Economy of Bangladesh is gradually developing but sufficient power supply would be a vital input for the rapid and sustainable development of the country. WB mentioned that the access of electricity (power) was increased from 47% to 80% since 2009 to 2017. By 2030, electricity demand is expected to grow to a 34 GW[5]. According to Bangladesh Power Development Board (BPDB), to date, about 94% of the population is accessing electricity[6]. As per the Power Sector Master Plan-2010, Government of Bangladesh formulated a goal to bring its 100% population under national electric grid coverage by 2021. The estimated electricity demand will be 19,000 MW in 2021 to meet that target[7]. According to Sustainable and Renewable Energy Development Authority (SREDA), a sister concern of BPDB, the total electricity generation capacity currently is 21,307 MW[8].

However, the challenge is that the country is still relying on dwindling natural gas for power generation. Natural gas accounts for 46.1% of the total installed capacity. Another power generating source, the heavy furnace oil (HFO) is a significant source of greenhouse gas emission. A study reported that among all sources, the energy sector account for ~40% of the total CO_2 emission in Bangladesh[9].

In order to address the high target of providing electricity supply with lower greenhouse gas emission, it is impossible for fossil fuel driving power plant to meet up the expectation. Here, renewable energy based emerging power generation technologies would be an alternative candidate for playing important role. Based on the technical and economic analysis, scientific community find out a list of limiting factors for economic growth, greenhouse gas emission, climate change and, prospective energy resources[10–18].

Recently, Islam and Khan have briefly presented the entire energy sector of Bangladesh[10], where they mentioned about the electricity generation mechanism, government policies, recently undertaken projects and challenges. They also descirbed the reneable energy programs conducted by government and non-government organizations (NGOs) briefly. Besides, there are few review articles that reported the assesment of entire renewable energy in Bangladesh, its potential application for electricity generations and challenges[13,16,19].

However, there is no complete presentation on the techno-economic evaluation and potential of PV energy in literature. Rahaman *et al.* reported the progress of solar photovoltaic energy related R&D in Bangladesh from 1996 to 2010 and identified the critical barriers for large scale dissemination and reported most appropriate ways to solve those obstacles[18]. For Bangladesh context, Halder demonstrated the potential of the PV energy and SHSs extension in remote rural and coastal belts and studied the economic appraisal of this systems for two district in 2016[20].

Besides, Mondal and Islam[17] has described the promising features of grid-tied photovoltaic system in 2011. Furthermore some researchers have investigated the prospects of concentrating solar power (CSP) system for Bangladesh[21,22], but there is no CSP plant and proper metrological data. Thus, they were unable to present realistic prospects, potential and techno-economic evaluation. However, to the best of our knowledge, there is no systematic review article in PV literature that quantifies the potential of solar power for Bangladesh. In this paper, PV energy technologies are deliberately reviewed. In addition, the potentials and challenges of these technologies and explored the economic feasibility of a SHSs and grid-tied photovoltaic system utilizing data in the HOMER simulation software for Bangladesh.

Renewable energy scenario of Bangladesh

Bangladesh has a good annual average sun hour that is promising for renewable energy. There is a list of technology for renewable energy such as solar photovoltaic, bio-energy (biogas and biomass), hydro, wind, tidal, geothermal etc. However, not all of these technologies show their promising features for Bangladesh context. The following sections review the technology, present scenario, challenges and potential of wind, biogas, biomass, hydro and photovoltaic energy. To date, renewable energy contributes to a total capacity of 605 MW of electricity in country's energy sector shown in Table 1.

Table 1. Present installed capacity of different renewable energy technologies

Sr. No.	Technology (MW)	Off-grid (MW)	On-grid (MW)	Total
1.	Solar	297.6	73.1	370.7
2.	Wind	2.00	0.90	2.90
3.	Hydro	0.00	230	230
4.	Biogas to electricity	0.63	0.00	0.63
5.	Biomass to electricity	0.40	0.00	0.40
	Total	301	304	605

Biomass energy:

Biomass energy is considered as the largest resources for energy generation in the world. Since the inception of civilization, it has been used for cooking and heating purposes in rural and urban settlements and still provides an important energy source in rural inhabitants of the most developing countries. In Bangladesh, around 55% of total land has been used for agricultural purpose[23]. The main crops of agriculture are rice, wheat, jute, beans, maize, groundnut, vegetables, sugarcane etc. The residues of the earlier mentioned crops such as rice husk and straw, bagasse and jute stick mainly produce biomass energy. Besides, municipal solid waste (MSW) is an important source for this energy in regional cities and urban area in Bangladesh[24]. Two technologies such as direct combustion and gasification have been intensively utilized for this energy generation.

In most of the villages of Bangladesh, there is no national gas pipe line. In very recent, a tiny percent of villagers uses commercial cylinder gas for cooking. However, still most village settlements using bio-energy from the agricultural residues for cooking. Beside the residues, dry cow dung, leaves, fuelwood, kitchen by-product, etc. have been frequently used[25]. Study reported that rice straw and husk, sugarcane bagasse, jute stick accounted for about 46% of biomass energy[23].

Recently government of Bangladesh has formulated an agenda "waste to electricity". From this agenda, the proper conversion of biomass resources could play a significant role for increment of bio-energy. Like other implemented projects, German Development Cooperation Agency (GIZ) conducted a detail feasibility study to identify prospective energy solutions from waste in Keraniganj, outskirt of Dhaka in 2015 and recommended the dry fermentation technology. Power Division of Bangladesh assigned to implement the waste to energy generation plant on a pilot basis. The capacity of this combined heat and power unit is expected to be 1 MW[8].

Biogas energy:

Upgradation of existing biomass resources to biogas promises the significant potential of this sector. In fact, mixing of methane, carbon-di-oxide and other gases produce biogas. These gases are systematically generated mainly from cow-dung, poultry excreta and other bio-degradable organic wastes[26]. This biogas is combustible; it can be used to electricity generation. In each year, approximately 5 billion cubic meter of biogas could be produced from the livestock wastes of Bangladesh[14]. In Bangladesh, BCSIR, IDCOL, Grameen Shakti (GS), BRAC and some other private enterprises are actively engaged in biogas dissemination. According to SREDA, around 100,000 working biogas plants are now available in Bangladesh[8]. Though Bangladesh has abundant biogas feedstock, but till now this technology is not economically viable for power generation.

Hydro energy:

Hydro energy researchers expressed a mixed reaction on this sector for Bangladesh. Halder *et al.* showed that Bangladesh has good scope of hydro power because of country's owing a numerous canals and branches of the rivers[11]. Mondal and Denich reported[16] that the scope of hydro power generation is very limited because most lands are flat in Bangladesh. However, the only hydro-electric power plant of Bangladesh named Karnafuli hydro-power plant located in Rangamati having 230 MW installed capacity. This plant is operated by the government agency BPDB. The BPDB is planning to extent the capacity of this power plant to 330 MW. The additional 100 MW hydro-power will be available only during monsoon. With utilizing micro hydro harnessing technology, Bangladesh can increase its hydro-power potential close to 1,000 MW.

Solar photovoltaic energy:

CO_2-emission free photovoltaic energy is becoming increasingly popular in Bangladesh. Source of solar PV energy is eventually the inexhaustible. The Earth surface receives 1.4×10^5 TW power from the sun, among them ~3.6×10^4 TW of this power is usable[2]. Bangladesh lies in a suitable geographical location for harnessing abundant solar energy. The monthly average solar insolation in Bangladesh is 4 to 6.5 kWh/m^2 [23] per day. The total solar energy available in Bangladesh is estimated to be about $1{,}018\times10^9$ GJ considering the daily average solar radiation. In 2014, 1.2×10^9 GJ, equivalent to 28.2 Mtoe primary energy was required for the whole country, which could be generated from 0.12% of the country's total solar radiation[20]. This indicates a great prospect of solar energy of Bangladesh.

Renewable energy policy was approved in 2008 to envisages to generate at least 5% total electricity from renewable sources by 2015 and 10% by 2020[27]. Wind, small hydro and biomass energies are also needed to meet this target in addition to solar energy by 2020[28].

Current status of solar photovoltaic energy in Bangladesh

The application of PV technology is significantly increasing because of its simple design, installation, and extremely lower installation cost, although the cost of PV technology is relatively higher in Bangladesh than other technology. Moreover, its' long term durability and environmental benign nature attracts much attentions[29]. The performance of solar panel known as efficiency is depends on the installation site temperature, dust particles in air, solar irradiance and relative humidity[30]. The solar irradiance could fluctuate between 40–60% for low to medium temperature. For low to medium power application in remote countryside or coastal areas, standalone PV technology is more effective and shows more reliability[31]. Table 2 presents the current status of PV installation.

Table 2. Present installation capacity of photovoltaic technologies

Sr. No.	Items	Number	Capacity (MW)
1.	Solar home system	5,804,225	248.3
2.	Solar park	34	73.1
3.	Solar telecom tower	1,933	8.1
4.	Solar irrigation	1,372	30.3
5.	Solar drinking water system	152	1.6
6.	Solar street light	202,017	10.6
		Total	371

In Bangladesh, people mostly accepted the SHSs, mini and micro-grid PV system and solar irrigation pumps. Beside this conventional technology, CSP plant is still in research and development phase. In this section, the present scenario, potential and challenges of SHSs, grid-tied system and solar irrigation have been discussed.

Solar home system (SHS):

There is a phenomenal growth of SHS installation in Bangladesh, since the inception of twenty fist century, for electrifying the remote areas where national grid did not reach. Eventually this technology is considering as emerging option for contributing significant portion of electricity generation in the country. In Bangladesh, most of the population (~70%) is still live in villages. Currently, off-grid SHSs are widely used in the remote areas for electrification to the settlements those are not connected with national electrical grid. SHSs are comprised of solar panel, battery, charge controller, mounting system, connecting wires and different types of various DC loads. Sometimes, AC loads are used by using inverters.

The country's first SHS project was installed with the help of the Government of France with a capacity of 62 kWp[32]. Rahimafrooz Renewable Energy Limited started SHS project in 1985[20]. The dissemination programs of SHS was initiated in 1993 by Rural Electrification Board (REB). In 2003, IDCOL took SHS projects through its Partner Organizations (POs) such as Grameen Shakti (GS), BRAC, Srizony Bangladesh and BGEF NGOs[33]. Still to date, the SHS is the most effective technology for rural areas in Bangladesh perspective and approximately 5,804,222 SHSs have been installed with their total 298 MW[34] generation capacity.

Adoption of this blessing PV technology in rural households extends the working hours in the night which eventually facilitates more time to do the productive works to lead the increase the family income. Once, rural poor people in the country led very ordinary life without modern energy like electricity. SHS facilitates them to good lighting system which encourages them to get primary and secondary education. This SHS also support them to communication facilities like internet browsing and the use of voice over internet (e.g. Skype) phone calls. Additionally, the remotely settled villagers are enjoying standard medical facilities in their local healthcare center. Using solar pump, peoples also get pure drinking water. Besides, the installation of SHS in household is reducing a large amount of fossil fuels consumption such as kerosene burning. In this way, SHS is reducing the emission of greenhouse gas and its' detrimental effects on environment that ultimately protecting the climate change[36]. The techno-economic evaluation has showed that the SHS is feasible and sustainable in rural areas of Bangladesh where national grid is not available[37].

The potentiality of SHS in Bangladesh is confirmed as satisfactory, but the progress of promotion is not expected. High price, comparatively lower efficiency of solar panel and other accessories, lack of genuine quality and lack of proper maintenance are the main drawbacks for meeting up the expectation. To get uninterrupted electricity with affordable price by solar energy and to resolve these issues, some renowned government organizations such as BCSIR, BPDB, LGED, REB etc. have already taken different initiatives for successful dissemination SHSs program and pursuing their research work for developing cost-effective technology for Bangladeshi people as well as for the world.

Grid-tied PV system:

Grid-connected PV system introduces a new dimension in energy sector especially in solar photovoltaic energy utilization. A list of grid interactive systems is being tested in Bangladesh where extensive utility grid lines are available. The main advantage of this system is that it does not require any additional energy storage capacity. The grid itself plays the storage medium role for this system. It delivers electricity to the grid when the required sunlight is available. This grid-tied system is basically integrated directly into the structural elements of the buildings, can capable to reduce the electrical energy and capacity losses in the utility distribution line[38]. As this system does not required storage device and can save the building materials, so these features made the system cost-effective and attractive to the policy makers and consumers.

Grid-connected system also shows its promising features in Bangladesh context. According to Islam and Huda, 6.8% (10,000 km^2) of country's total land is required for electricity generation from the photovoltaic system to meet electricity demand of 3,000 kWh/capita/year[39]. Another report shows that total household roof area is about 4,670 km^2 which is about 3.2% of total land area of the country[7]. In urban area (especially in Dhaka city), 7.86% of total land is suitable for PV electricity generation[40]. Considering the grid availability, only 1.7% of the land in Bangladesh is assumed technically suitable for generating electricity from PV[23,41]. Along with some small scale mini-grid photovoltaic source, total power generation capacity from grid-tied systems are reported to be 73 MW[8].

Techno-economic analysis of solar photovoltaic energy

Off-grid system:

The development of a model was undertaken for this paper for techno-economic analysis of an off-grid PV power in Bangladesh[37].

Techno-economic of PV system in Bangladesh – Example scenarios evaluation:

A techno-economic model was developed to assess PV system of various sizes for Bangladesh. This model calculated capital cost, levelized cost of electricity (LCOE) production, yearly electricity generation, revenue from electricity sale and payback period. Fig. 1 shows the capital cost and revenue per year in US$ for 1 to 5 kW system and Fig. 2 shows this in Bangladesh currency (BDT or Taka). In Bangladesh, these systems can suit for typical homes to a small or medium enterprise (SME) facility.

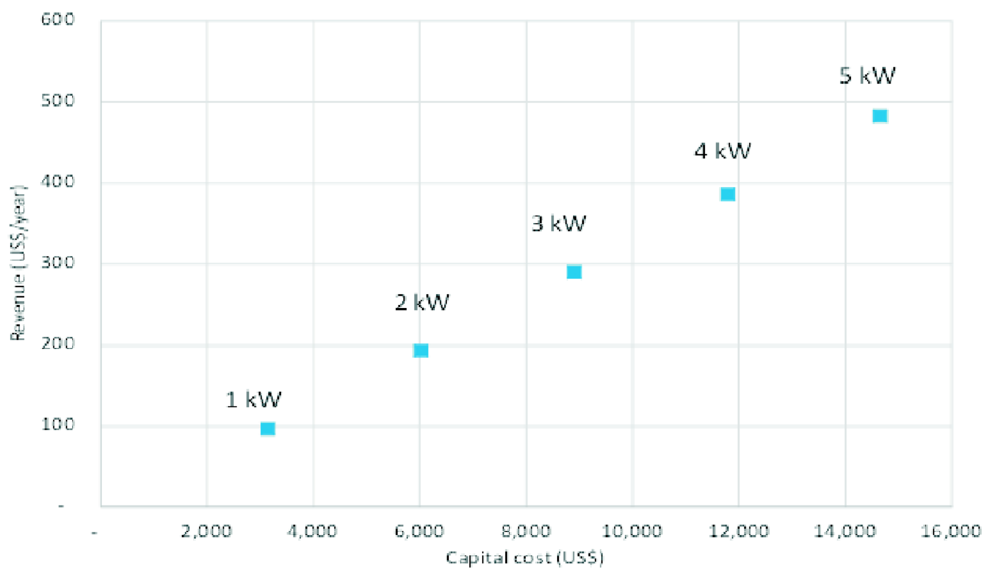

Fig. 1. Capital cost and revenue per year in US$ for 1 to 5 kW PV solar system (assuming US$ 2.5/W for solar panels).

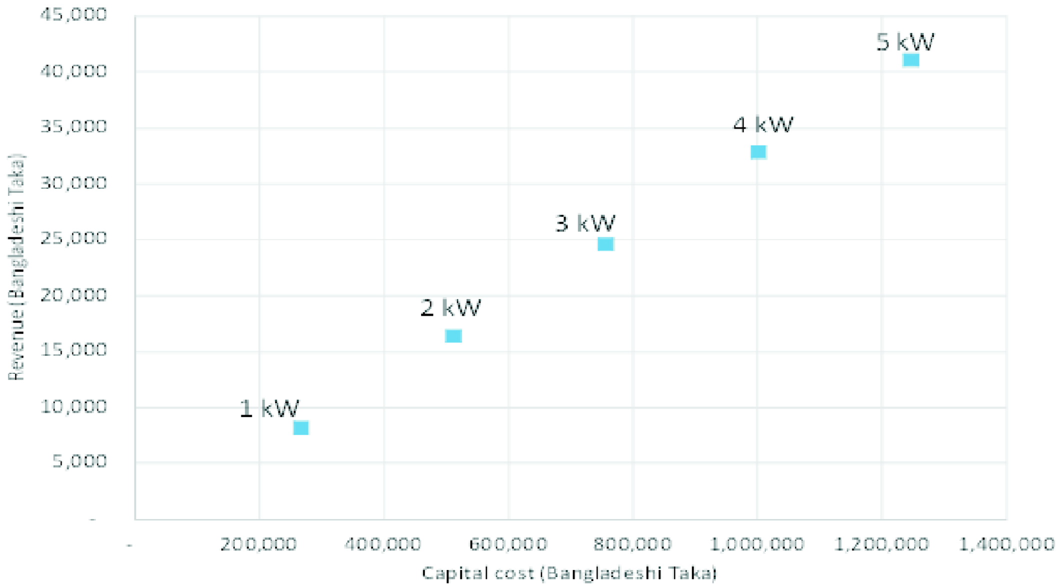

Fig. 2. Capital cost and revenue per year in Bangladeshi currency for 1 to 5 kW PV solar system (assuming 200 Taka/W for solar panels).

Capital cost and revenue is positively and proportionately correlated with the system increase from 1 to 5 kW. The capital cost for such system is estimated to be over US$ 3,000 to 16,000. Such system can generate from $ 100 to US$ 500 per year. The payback period for these systems is very high (e.g. over 30 years) if 5 Taka/kWh tariff is assumed (Fig. 5). This payback period reduces significantly to 6/7 years if 14 Taka/kWh tariff is assumed. Ten (10) Taka/kWh tariff predicts the payback period over 8 years whereas 7 years payback period if predicted for 12 Taka/kWh tariff. The payback period is below 5 years if 60 Taka/W solar panel price which is currently available in Bangladesh and 10.3 Taka/kWh tariff is assumed which is also currently offered by the Government of Bangladesh.

Levelized cost of electricity (LCOE) is calculated for 1 to 5 kW system and is shown in Fig. 3. LCOE is a measure of the cost of electricity generation from a source over its lifetime. The LCOE is calculated using total life cycle cost of an electricity generating plant divided by total energy produced over the lifetime. The LCOE is used to compare different methods of electricity generation cost on a consistent basis. The LCOE is shown for solar panels with two different prices

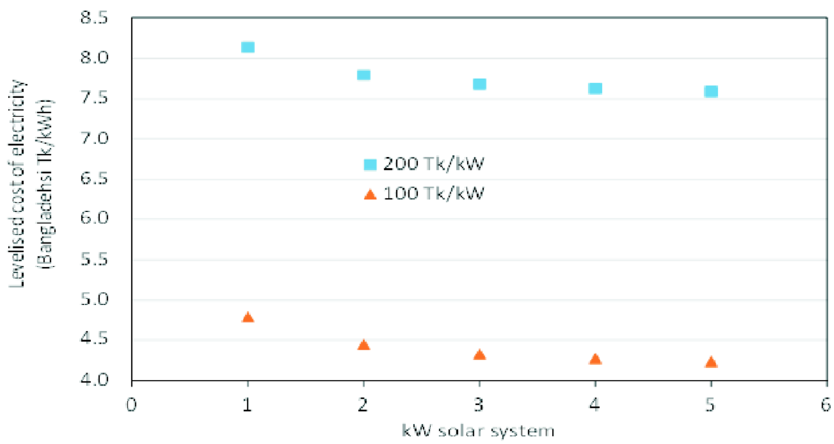

Fig. 3. Levelized cost per unit electricity produced for 1 to 5 kW solar PV system at two prices of solar panels (e.g. 100 or 200 Taka/kW).

in Fig. 3. The LCOE for solar PV system for scenarios presented here is estimated to be 4 Taka/kWh or 8 Taka/kWh. This is equivalent to US$ 0.05/kWh or US$ 0.08/kWh.

Table 3 shows assumptions and indicators for a PV system in Bangladesh. The estimated capital cost for a 5 kW PV system is over 8,700 US$ or 700,000 Bangladesh Taka. This system can generate over 8.2 MWh of electricity per year with over US$ 1,400/y for revenue. The cost of electricity production from such system is over US$ 0.05/kWh. The payback period is less than 6 years and the internal rate of return (IRR) can be up to 17%. The net present value (NPV) is estimated to be about US$ 18,000. This scenario has used conservative assumptions.

However, with current solar panel price (60 Taka/W) and tariff value (10.3 Taka/kWh), the payback period is below 5 years (Table 4). This system can avoid over 7 tonnes of carbon-di-oxide equivalent which is approximately equal to 33 petrol driven cars off the road. The minimum tariff has to be

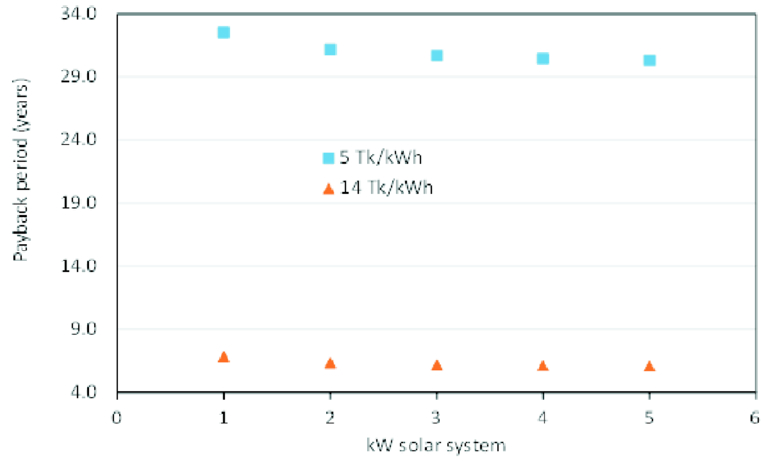

Fig. 4. Payback period for 1 to 5 kW solar system with two different feed-in-tariff regimes.

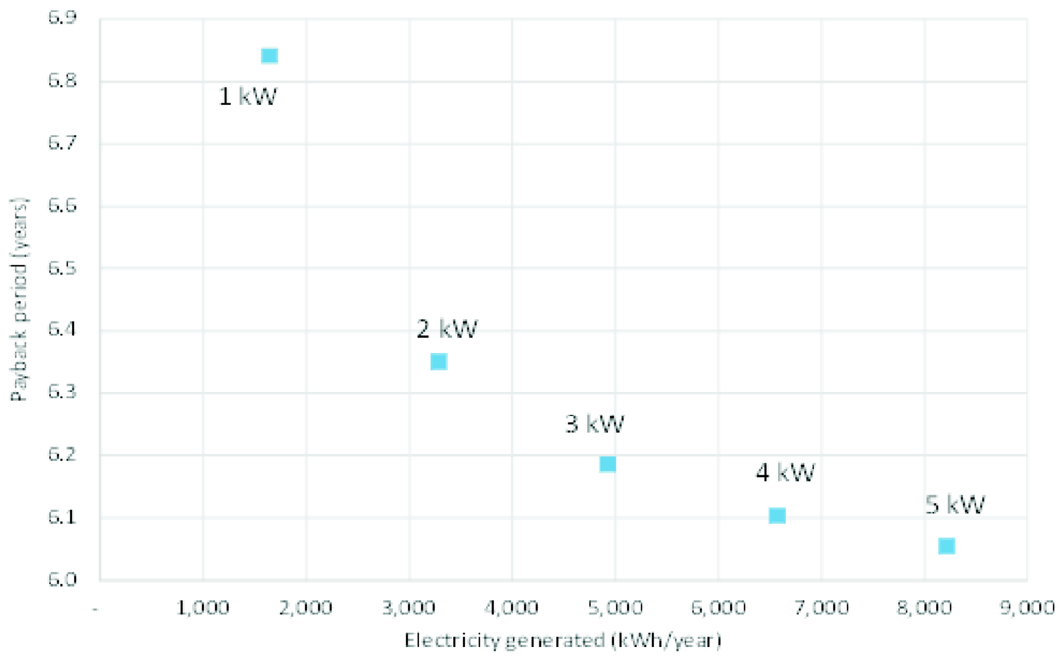

Fig. 5. Electricity produced and payback period for 100 Tk/W solar system with 14 Tk/kWh feed-in-tariff.

Table 3. Techno-economic indicators for a solar PV system installed in Bangladesh – Example 1

Item	Value	Unit	Value	Unit
Capacity	5	kW	Same	Same
Number of solar panels required	20	#	Same	Same
Surface area required	42	m^2	Same	Same
Lifetime	20	Years	Same	Same
Electricity produced	8,213	kWh	Same	Same
Currency conversion	NA	NA	85	Taka/US$
Solar panel price	100	Taka/W	1.25	US$/W
Feed-in-tariff	14	Taka/kWh	0.18	US$/kWh
Capital cost	700,000	Bangladeshi Taka	8,190	US$
Levelized cost of electricity	4.2	Bangladeshi Taka/kWh	0.05	US$/kWh
Revenue	110,000	Bangladeshi Taka/year	1,353	U$/year
NPV	1,420,000	Bangladeshi Taka	16,732	US$
Payback period	5.9	Years	Same	Same
IRR	16.6	%	Same	Same
Avoided carbon-di-oxide emission (based on 0.9 kg/kWh grid emission factor)	7.4	t/year	Same	Same
Number of petrol cars equivalent off the road (based on 15,000 km/y)	33	per year	Same	Same

Table 4. Techno-economic indicators for a solar PV system installed in Bangladesh – Example 2

Item	Value	Unit	Value	Unit
Capacity	5	kW	Same	Same
Number of solar panels required	20	#	Same	Same
Surface area required	42	m^2	Same	Same
Lifetime	20	Years	Same	Same
Electricity produced	8,213	kWh	Same	Same
Currency conversion	NA		85	Taka/US$
Solar panel price	60	Taka/W	0.70	US$/W
Feed-in-tariff	10.3	Taka/kWh	0.18	US$/kWh
Capital cost	440,000	Bangladeshi Taka	5,195	US$
Levelized cost of electricity	2.7	Bangladeshi Taka/kWh	0.03	US$/kWh
Revenue	84,589	Bangladeshi Taka/year	995	U$/year
NPV	1,650,000	Bangladeshi Taka	19,385	US$
Payback period	4.8	Years	Same	Same
IRR	21.6	%	Same	Same
Avoided carbon-di-oxide emission (based on 0.9 kg/kWh grid emission factor)	7.4	t/year	Same	Same
Number of petrol cars equivalent off the road Same(based on 15,000 km/y)	33	per year	Same	

10.3 Taka/kWh to make this system with positive NPV. Assuming a US$ 20/t CO_2-equivalent price, another US$ 140 per year earning is possible under Clean Development Mechanism (CDM) which is an international scheme.

Discussion

Gross domestic product popularly known as GDP is a well-established measurement of the socio-economic condition and the living standard of a country's population. GDP is vigorously affected by the level of energy consumption. Singh *et al.* estimated that 1% increase in per capita energy consumption causes an increase in per capita GDP by 0.23%[42]. However, the GDP growth rate of Bangladesh in the year 2018-2019 was about 6.8%. The GDP growth rate has to be increased to 10% for attaining the long demand dream and economic stability of the country. However, this growth is likely to be highly affected by COVID-19 pandemic as global economy is influenced by this sudden unexpected threat.

The renewable energy resources cannot be alternative to conventional fossil fuel energy resources, they may be supplementary to the long-term energy demand for Bangladesh. As technologies of fuel cells, solar thermal, geothermal, tidal and wave energy require more investigation for their potential in Bangladesh; they have not been covered in this study. However, bio-energy such as biomass and biogas are playing important role for cooking and heating.

The photovoltaic energy is the most promising of all available technologies for Bangladesh. For doubling of each installed capacity of PV system, the cost of manufacturing and installing has decreased by about 20% over the last two decades. As a consequence, SHSs has been upgraded as a sustainable energy supply in rural as well as isolated areas in Bangladesh for meeting household lighting demand. Due to worldwide increase of energy demand and usage, researchers, businessman and policy makers have accepted this seriously to execute future energy demands. As a consequence, introduction of 100,000 roofs program by Germany[43], 700,000 roofs program of Japan[35], about 1 million solar-roof initiative in USA[44] and about 3 million roof-top solar PV systems in Australia are going well. Realizing the advantages of renewable energy (RE), Bangladesh government has formulated a target to produce 10% of its total energy generation and among them, a total 2,100 MW electricity from PV sources by 2021.

Conclusion

To date, photovoltaic energy is experiencing momentum in Bangladesh not only its energy security but also its environmental benign nature. Besides of the PV technology, other sources such as biomass, biogas and hydro-energy have shown the good potentiality for power generation. In fact, this deliberate review work has compiled the latest renewable energy based literatures (i.e. articles, proceedings, and reports). The article also investigated the techno-economic analysis for determining the appropriate and financially feasible PV technology for Bangladesh. The evaluation suggested that small to medium scale solar PV system can economically be attractive for Bangladesh under different scenarios. As the country has not enough natural fossil fuels, as it has sufficient solar radiation and relatively extended sun hour, as the price of photovoltaic technology reducing gradually[45], so it has been concluded that solar photovoltaic energy will be a promising option to meet up the future energy demand.

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