Policy Options While Increasing Share of Renewable Energy: Technology Choices for Peaking Power in the Context of Bangladesh

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Abstract

In Bangladesh, the peaking power plants that serve the peak time loads use conventional fossil fuels for power generation. These power stations remain idle for a good part of their operating life, which therefore results in a high overhead cost. Continuous integration of renewables into the grid is increasing the dependency on these, so far, feasibility of no other less-expensive options has been studied. In this context, this paper aims to analyze the financial feasibility of different alternative options. Three possible options were analyzed and the levelized cost of energy (LCOE) was compared with that of conventional peaking power plants. It was found that Battery-based storage systems are not financially feasible at this moment, while the nation's lone hydro power plant promises financial feasibility if solar PV driven pumped hydro storage is implemented. We also report that if the nation continues to add solar PV power stations even with costly peaking power plants using traditional fuels, this hybrid option was counter intuitively found to be financially feasible.

Keywords

Peaking power · Renewable energy · Solar power · Energy storage system · Grid carbon footprint

1 Introduction

World electricity production industry is predominantly occupied by conventional fossil fuel-based power plants. Since about 1850, the world has commercially depended on conventionally produced fossil fuels such as coal, oil, natural gas, etc. which supply about 75% of energy today (Karim et al., 2018). Total electricity generation all over the world was 25,849.92 TWh in 2020 (Ritchie & Roser, 2020) and the share of renewables is increasing every year as the world leaders are committed to reduce the use of fossil fuels for curbing the detrimental effects of uncontrolled use of fossil fuels especially in producing electricity. The world's dependence on renewable energy sources for electricity generation has increased by more than 10% per year since the late 1970s (Karim et al., 2018). The usage of renewable sources in 2012 contributed 13.2% of global supply, hit 22% of global power production in 2013 and was expected to hit 26% by 2020, which is more than current combined demand from China, India, and Brazil (IEA, 2015). According to Ritchie, in 2020, renewable energy sources accounted for 28.98%

of global electricity, which was higher than forecasted data (Ritchie, 2021). Sweden, Norway, France, Paraguay, Iceland, Nepal, Bhutan, Canada, Ethiopia, Finland, Brazil, for example, get over 90% of their energy from nuclear or renewable sources (Ritchie & Roser, 2020). According to the report "Renewable Energy Capacity Statistics 2021" by IRENA, global renewable energy generation capacity is around 2,799,094 MW (IRENA, 2021). In Fig. 1, we can observe Asia accounts for approximately 46% of total installed capacity. However, it is paramount for the world to make this transition to increasing share of renewable sources without compromising reliability because supply instability will interfere with proper economic performance (Karim et al., 2018).

Bangladesh is also focusing on integrating renewable based power generation facilities into the national power grid. According to Sustainable Renewable Energy Development Authority (SREDA) in Bangladesh, total contribution from renewable energy is 3.24% of total installed capacity. Bangladesh mostly uses hydropower (230 MWp), solar PV (195.01 MWp is connected to the national grid while another 565.16 MWp capacity is in the pipeline) and few wind energy-based projects with a total capacity of 74.9 MWp (SREDA, 2021). In recent times, solar PV systems have been added to a greater capacity than other sources. This proliferation is mainly fueled by the global decreasing trend in the price of energy from solar PV systems. According to IEA, the price of grid-tied solar PV decreased from 1.3 USD/Wp (2011) to 0.2 USD/Wp (2020) shown in Fig. 2. In the near future, the price is expected to fall further. This indicates that there will be more opportunities to build new solar plants at a lower price leading to even lower per unit cost of produced solar energy (IEA, 2020a).

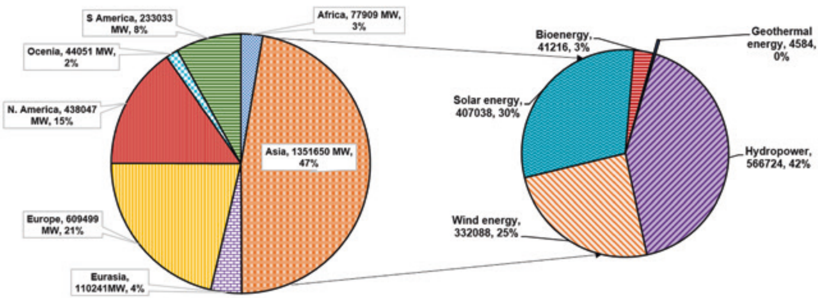

Fig. 1 Grid connected RE capacity in the world, with technology mix shown for Asia. (Source: (IRENA, 2021))

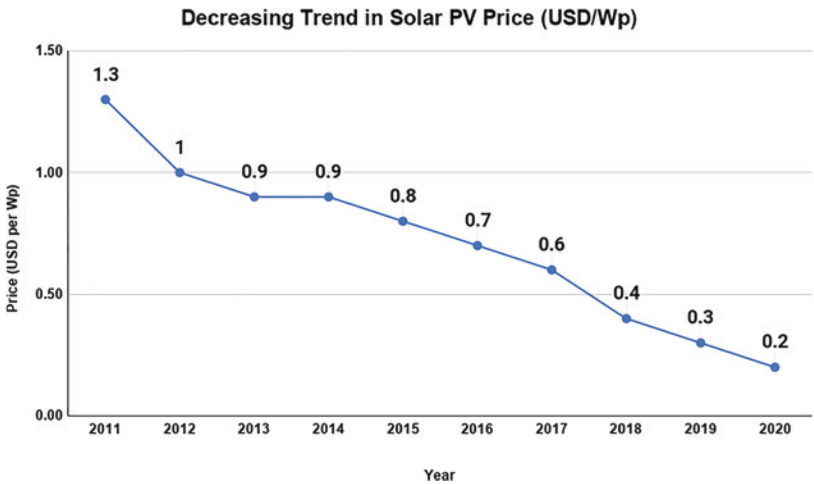

Fig. 2 Decreasing trend in solar PV price (USD/Wp). (Source: (IEA, 2020a))

However, Bangladesh is still heavily dependent on fossil fuel, more specifically on its natural gas resources, for power generation. Figure 3 shows the fuel mix of power generation in Bangladesh. Although, natural gas is the least expensive fuel, its reserve is depleting at a faster rate. If new gas reserves are not explored, it is anticipated that Bangladesh might experience a price hike in gas price as the dependency on imported LNG will increase. In addition to this, the share of other fuels like HFO and coal in power generation is bound to increase. HFO is an imported fuel and we have used locally mined coal so far. Although

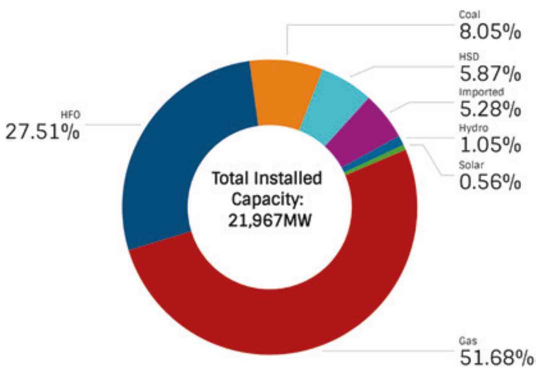

Fig. 3 Installed capacity (in MW) of BPDB power plant by fuel type. (Source: (BPDB, 2021))

the quality of the coal is pretty good, the depth of the coal mines and the soft alluvial soil of Bangladesh makes the coal extraction more expensive compared to the price of coal in the international market (Barapukuria Coal Mining Company Limited, 2021) Bangladesh presently imports about 5% of its power from India, which may also go up in future. The decreasing use of natural gas and increasing use of coal, HFO, LNG, nuclear and renewables have their own concomitant implications.

Meeting time-varying demand, especially during peak periods, is a significant challenge for electric utilities. Small capacity power stations, such as gas or HFO power plants, are commonly used to mitigate the peak demand. Diesel generators are still widely used in isolated power systems to satisfy peak demand (Uddin et al., 2018). However, the cost of operation and maintenance (O&M) for these power plants is high (Chua et al., 2013). Thus, peak load shaving has become an important issue. Peak load shaving is a technique for flattening the load curve by lowering the peak load and moving it to lower load times (Nourai et al., 2008).

Different strategies for peak load shaving have been followed all over the world, such as, Tariff Incentives (TI) and Demand Side Load Management (DSM) (Uddin et al., 2018). It is a common practice to change the tariff during peak and off-peak hours on a daily basis. In some countries, the tariff varies with seasonal demand as well to influence usage patterns of the consumers (Energy Information Administration – EIA, 2021). Since the 1980s, one of the most promising methods for mitigating peaks has been Demand Side Management (DSM) (Gellings et al., 1986). Most research, however, focused on DSM techniques in developed countries, as making DSM more successful necessitates the use of latest technologies like smart grids, which include smart metering systems (Lu, Hong, and Zhang, 2018). Battery technologies in households are also included in some of the DSM schemes. With the development of IoT, the consumers are also using smart systems (e.g., smart home management) to reduce their peak load and energy bill. Companies like Tesla, Duracell, LG Chem, Moixa, Powervault, Solax, Sonnen, VARTA are installing domestic BESS in UK (Department for Business, Energy & Industrial Strategy, 2020). Tesla's "Powerwall" is intended for daily cycling such as for load shifting. Tesla revealed in October 2016 that nearly 300 MWh of Tesla batteries had been implemented in 18 countries. Tesla reported in April 2020 that it had deployed its 100,000th Powerwall. Powerpack is designed for industrial and electric utility grids and has lowered utility bills by 20% in some cases (Wikipedia Contributors, 2021a). To the best of authors' knowledge, no study has been reported that assessed the feasibility of different load shaving techniques and possible options as an alternative to expensive fossil fuel based peaking power plants in the context of Bangladesh.

This study has therefore been conducted to address the high operating cost associated with fossil fuel based peaking power plants by assessing the financial feasibility of three different energy generation options to meet the peak loads. To justify whether the options are feasible or not, the levelized cost of energy from these options are compared to the cost of fossil fuel based peaking power plants.

2 Methodology

According to the report "Renewable Energy Capacity Statistics 2021" by International Renewable Energy Agency (IRENA), global renewable energy generation capacity is around 2,799,094 MW (IRENA, 2021). In Fig. 1, we can observe Asia accounts for approximately 46% of total installed capacity. Bangladesh mostly uses hydropower (230 MWp), solar PV (136.44 MWp is connected to the national grid while another 565.16 MWp capacity is in the pipeline) and few wind energy-based projects with a total capacity of 74.9 MWp (SREDA, 2020). This study has been performed to suggest feasible alternatives to fossil fuel based peaking power plants that are not only expensive but also pose deleterious impacts on environment. To satisfy the objectives of the study, following tasks have been accomplished:

- Analyze the fuel type and LCOE of existing peaking power plants in Bangladesh
- Propose the system layout for three different alternative options to meet the peak loads
- Evaluate the LCOE of the proposed systems
- Compare the LCOE of the proposed systems with that of existing peaking power plants
- Suggest the feasible options so that policy makers can take immediate actions

3 Current Scenario of the Peaking Power Plants in Bangladesh

All the existing peaking power plants are fossil fuel based, except the Kaptai hydro project. The cost of energy varies by a big margin, depending on the type of fuel used, hours of use per year and overall maintenance cost (the cost breakdown can be found in Fig. 4). As per data available on the BPDB website some of the peaking power plants, used for very small hours (2% plant factor), have

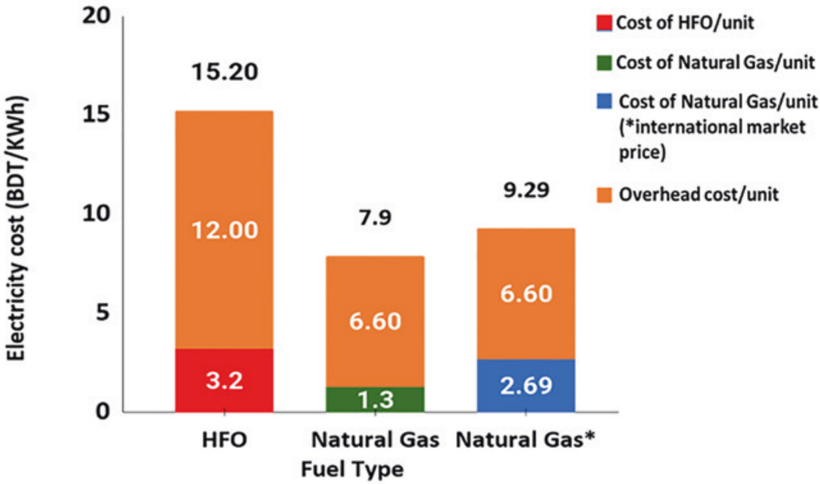

Fig. 4 Per unit electricity greneration cost for different fuel based peaking power plants. (Source: Power Grid Company of Bangladesh Limited (2021))

an energy cost of Tk. 41.60/kWh (for HFO) and Tk. 72.29/KWh (for HSD). The average energy cost of Bangladesh Power Development board (BPDB), including the IPP peaking power plants, is Tk. 17.50/kWh.

BPDB operates 14 peaking power units, one of which is natural gas-fired, three are HSD-fired, and the remaining ten are HFO-fired. Additionally, there are Twelve Quick Rental Power Plants (QRPP) and Nine Rental Power Plants (RPP) with a combined capacity of 1395.89 MW. Between 2014 and 2017, most QRPPs were extended for a further 3–5 years following their initial retirement phase.

4 Possible Technology Options in Bangladesh as Alternative to Conventional Peaking Power Plants

Keeping in mind the technical and financial issues associated with the conventional fossil fuel based peaking power plants; we have proposed three technology options in this paper:

1. Storage battery to store energy during the daytime from grid power and to deliver during the peak hours.
2. Limited pumped hydro facility to pump water from the downstream of Kaptai hydro plant to the reservoir using solar power during the daytime and then discharging the water during the peak hours.
3. Solar PV-HFO hybrid power plants capable of supplying peak load in the evening.

In the following sections, we present an analysis of the three cases mentioned above. The LCOE from these options are then compared with the conventional fossil fuel based peaking power plants. To calculate LCOE we followed the following formula:

$$C_o = C_{in}/\eta + \left(I_{cap} + \Sigma D_i + M\right)/E_{out} \tag{1}$$

where,
C_o is the cost of output energy per kWh
C_{in} is the cost of input energy per kWh
η is the system efficiency
I_{cap} is the annual interest on the capital investment
D_i is the annual depreciation of the ith (i = 1, 2, 3, … etc.) capital investment
M is the annual operation and maintenance cost
E_{out} is the expected energy output from the system.

4.1 Case 1: Battery Storage

We would like to consider two battery storage options to replace the conventional fossil fuel based peaking power plants. One using Lithium-Ion battery and the other using the more conventional Lead Acid batteries. The basic structure of such a system is shown in Fig. 5.

As shown in the Fig. 5, the batteries are charged during the off-peak hours when the load demand is minimum, and the stored energy is delivered to the grid during the peak hours.

4.1.1 Lithium-Ion Battery Storage

The assumptions we considered for energy cost estimation in a Lithium-Ion battery storage system is given below

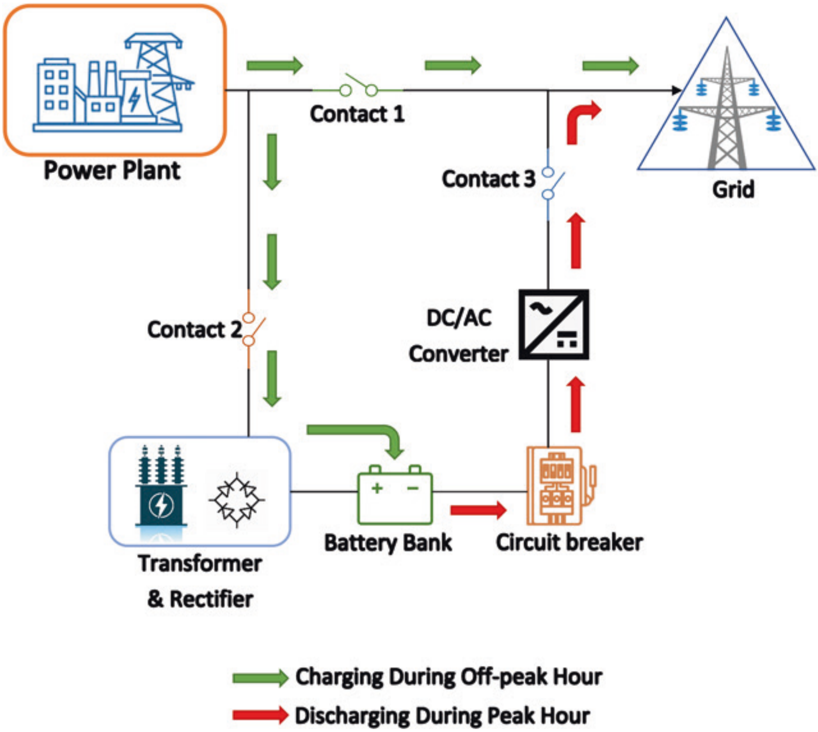

Fig. 5 Schematic diagram for the proposed battery energy storage system. (Source: Own depiction)

Cost of battery/kWh = BDT 20,820
Maximum depth of discharge of the battery = 90%
Cost of inverter/kW = BDT 6940 (including charging unit)
Inverter efficiency = 98%
Expected battery life = 7 yrs
Expected inverter life = 5 yrs
Interest rate = 9%
Battery efficiency = 85%

The stored energy cost, as calculated using the above data, comes out to be BDT 35.95/kWh. The cost breakdown in percentage of the energy cost is shown in

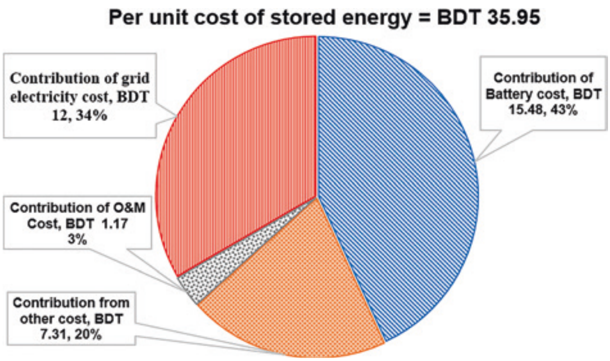

Fig. 6 Cost per kWh and the percentage cost breakdown for Lithium-Ion battery-based energy storage. (Source: Own depiction)

the Fig. 6. If we compare to the average peaking power plant energy cost of Tk. 17.50, it is higher by about 100% and economically not a viable alternative.

4.1.2 Lead Acid Battery Storage

Although Lithium-Ion batteries are getting more popular in recent years due to various improved performance indices (like depth of discharge, efficiency, longevity, weight/kWh storage etc.), lead acid batteries are still quite popular for their low cost. Our assumptions for the cost analysis of the lead acid batteries are given below.

Cost of battery/kWh = BDT. 14,720
Maximum depth of discharge of the battery = 70%
Battery efficiency = 80%
Expected battery life = 5 yrs
Cost of inverter/kW = BDT. 6940 (including charging unit)
Inverter efficiency = 98%
Expected inverter life = 5 yrs
Interest rate = 9%

The results presented in Fig. 7 show that the cost of stored energy for lead acid batteries comes out to be BDT 38.63/kWh. It is interesting to note that the cost of stored energy for lead acid batteries is higher than that of Lithium-Ion battery. Although Lithium-Ion batteries are more expensive, they have a higher depth of discharge and a longer average life that compensates its higher capital cost.

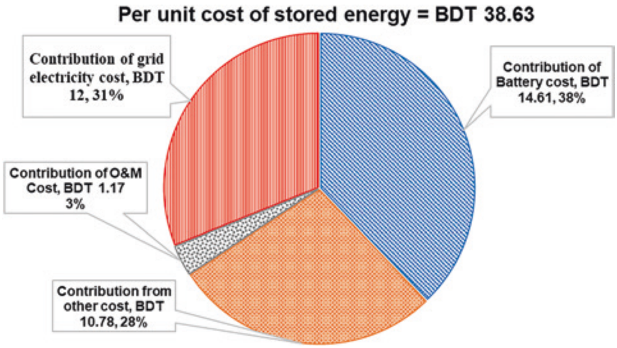

Fig. 7 Cost per kWh and the percentage cost breakdown for Lead Acid battery-based energy storage. (Source: Own depiction)

These energy cost values indicate that battery-based storage is still very expensive and is not yet suitable for replacing the conventional peaking power plants, unless the price of the battery reduces by 50%.

4.2 Case 2: Solar PV with Hydro Reservoir

In this scheme, we consider the possibility of using Kaptai hydro plant as a pumped storage facility. The basic schematic diagram is shown in the Fig. 8. The Kaptai project has a vast area of land still not in use and installing a large-scale PV power generating plant is possible. Government has already installed a 7.4 MWp solar PV plant and there is ample space to install more. In this scheme, we propose to use solar PV energy to pump water from the downstream of Kapati dam back to the reservoir to be used during the peak hours. As solar PV energy cost is lower than the average cost of grid energy, it is expected that the pump storage will be cost effective. Although there is no additional cost needed for the water storage (as it already exists), there are cost involvements in constructing a small water lock downstream to hold the discharged water from the dam during electricity production. The height of the lock should be such that it will only retain the required amount of water and the rest will spill over to the main river. As shown in Fig. 8, the PV is connected to the grid via grid tied inverter and the pump is run from the control station as per requirement decided by the BPDB. So, any surplus power is directed to the grid when the pump is not running.

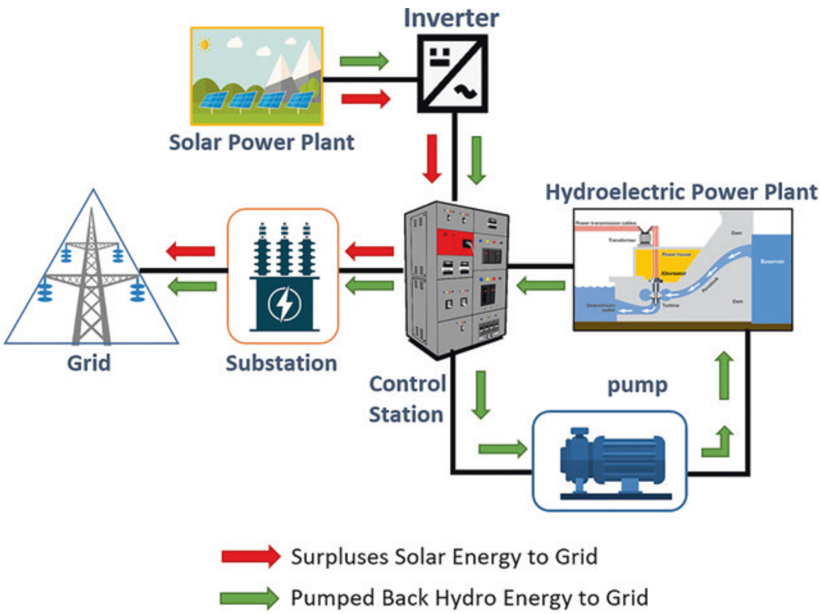

Fig. 8 Flow diagram of the proposed pumped hydro scheme. (Source: Own depiction)

The pump operation is controlled from the control station depending on the following factors.

a) Existing water level of the reservoir
b) Rainfall in the region and water level in the downstream Karnaphuli river
c) Forecast of rainfall in the catchment area

It is expected that there will be times when pumping up of water will not be necessary and under such circumstances, the PV power is supplied to the grid. So, the scheme has the option to supply solar PV power partially or in total to the grid depending upon the reservoir water level and the load demand (Table 1).

In the following paragraphs, we present a study on the cost analysis of an 80 MWp solar PV plant for the pumped storage system. The basic assumptions are

Table 1 Estimated pumping power requirements in different seasons. (Source: Own depiction)

Season	Month	% of pumped energy	Reasons behind variation in pumping scheme
Winter	Nov–Feb	10%	Less peak demand
Summer	Mar–May	80%	High peak demand Scarcity of water in upper reservoir
Monsoon	Jun–Oct	25%	Heavy rainfall Maximum volume of water in upper reservoir

Proposed size of solar PV plant = 80 MWp
Plant factor for the solar plant = 76%
Cost of PV energy (with grid tied inverter) = BDT 5.52 (LCOE)/kWh
Maximum pumping power = 50 MW
Efficiency of the pumping system = 76%.
Cost of the pumping system with accessories = BDT 283,081,150/MW
Civil engineering cost (downstream reservoir) = BDT 366,632,324
Interest rate = 9%.

In calculating the pumped hydro energy cost, we considered the energy production from the solar PV under the prevailing sunshine condition (average of 4.5 kWh/m^2) and estimated pumping power requirements as shown in Fig. 9.

We can see that the pumping power requirement is very low in the months from November to January due to low power demand in the winter season and low water supply from upstream. The pumping power is highest in the months from March to May as it is the peak summertime with low average rainfall when the power demand is high during the peak hours. The months from June to October, there is enough rainfall in the reservoir catchment area and scope of pumping water back to the reservoir is limited.

The calculated cost for the solar PV based pumped hydro, as presented in Fig. 10, comes out to be significantly lower (BDT 12.27) than the average peaking power plant energy cost. However, we need to keep it in mind that Bangladesh has only one hydro-electric plant and we do not have the option to extend it beyond Kaptai. It is possible to build small sized reservoirs on small brooks that run in the valleys in the Hill Tracts to store enough water corresponding to a single day requirement only, but in those cases cost of reservoir and dam will be added to the capital cost and the cost of energy may not be very low.

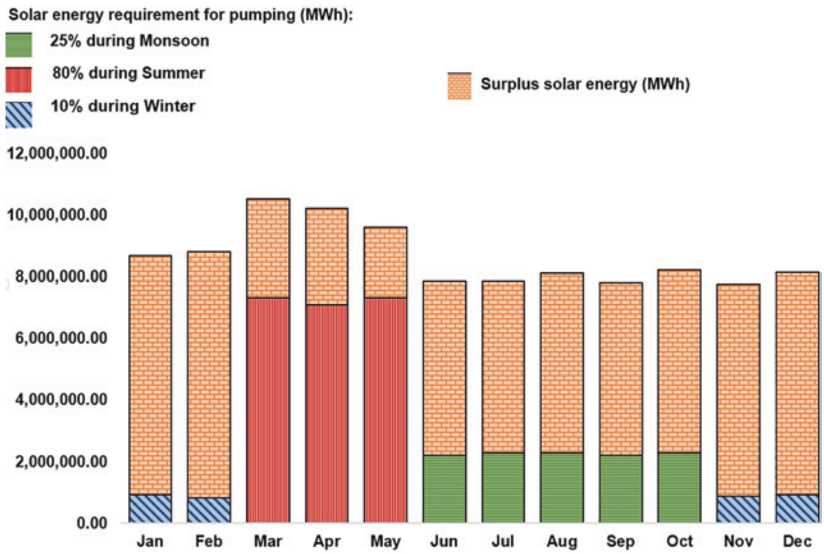

Fig. 9 Seasonal pumping requirement and solar PV output. (Source: Own depiction)

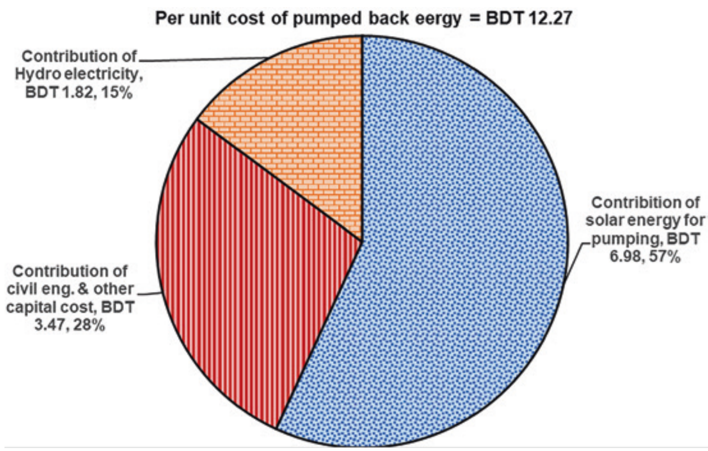

Fig. 10 Cost per KWh and the percentage cost breakdown for pumped back hydro system. (Source: Own depiction)

4.3 Case 3: Solar PV-HFO Hybrid Plant to Address the Peak Load

The option of pumped hydro is very limited in Bangladesh as we have only one hydro project. So, it cannot be a general solution for peaking power plants. In this section, we make a theoretical analysis on the option where solar PV is used for power generation during the daytime and a corresponding HFO plant is established to supply the power during the peak hours. The rationale behind such an idea may look unrealistic, as one can always argue that any HFO based plant established for peaking power can take share of the base load during the non-peaking hours as well and sharing base load will reduce the overall cost per kWh. But the proposal can be justified economically from a different perspective. As it is an established fact that solar PV based electricity has become cheaper than HFO based electricity, generating solar PV based electricity during the daytime will save the generation cost of the HFO plants. If the net cost of energy in a solar PV + HFO hybrid project is less than the cost of generating power using an HFO based plant alone, then we can always justify such a project. Additionally, it will improve the carbon footprint of the power system.

As a test case, we considered a 100 MWp solar PV based power plant and to share the corresponding peak load we consider a HFO based plant in the hybrid system having a power capacity of 80 MW. The cost of HFO in the international market varies and the average price can be assumed close BDT 25/L. However, we took a more conservative approach and assumed the cost of HFO to be BDT 22/L and cost of electricity in a HFO plant to be BDT 9.50/kWh. The annual cost figures for the project are presented below.

Expected energy production form the Solar PV plant = 131.5 GWh
At Tk. 5.52/kWh, cost of solar energy = BDT 726 million
Estimated cost in a HFO plant to generate 131.5 GWh = BDT 1249 million
So, cost saving by using solar PV is = BDT 523 million.
This cost saving would increase to Tk. 622 million if the HFO price is BDT 25/L (see Fig. 11).

Now let us estimate the cost of running the HFO generators to generate peak power only. The running time of the peaking plants vary from 2–6 h depending on the load demand that varies with season and weather condition and the average is close to 3.5 h per day. Based on the BPDB data with seasonal variation of the peaking load, the yearly energy cost of an 80 MW peaking power plant comes

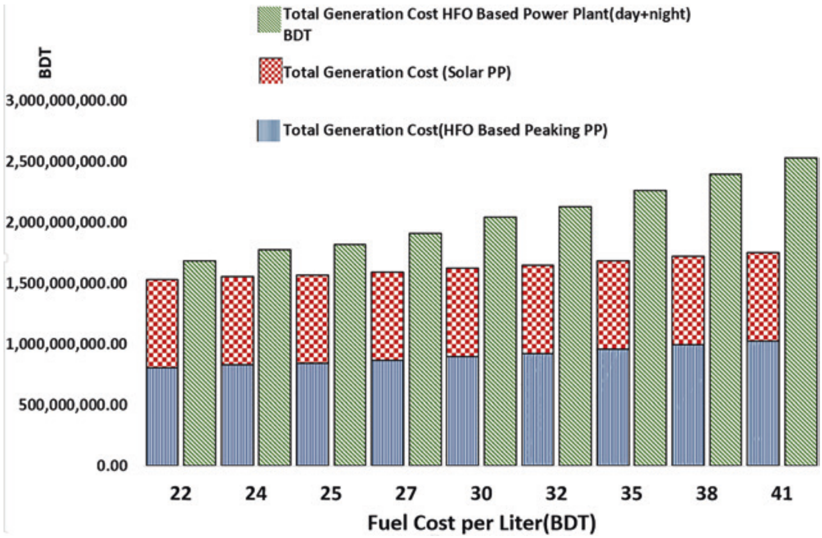

Fig. 11 Generation costs for solar PV-HFO hybrid plant vs. a HFO based plant. (Source: Own depiction)

out to be BDT 809.48 million at a peaking power rate of BDT 17.50/kWh (estimated from BPDB peaking power plant data). So, the total annual cost, including the peaking load, is BDT 1535.48 million. On the other hand, an 80 MW plant generating the same amount of energy will cost BDT 1688.4 (including the peaking hours) at a rate of BDT 9.5/kWh. So, we can see that there is a cost saving of BDT 152.92 when a solar PV-HFO hybrid plant is considered. A comparative energy cost data for solar PV-HFO hybrid plant and a solely HFO based plant is given in Fig. 11 for different HFO prices. It may be mentioned here that we considered an 80 MW HFO plant as an equivalent of the solar PV of 100 MWp. If we look at the sunshine in Bangladesh, which varies from 4.5 to 4.7 kWh/m^2 with a plant factor of 76%, a 50 MW HFO plant should suffice. In that case the cost saving will be even higher (BDT 290 million).

The above analysis gives a very interesting economic option to use solar PV-HFO hybrid power plants to cater for both the daytime load and the peak hour load at a lower cost compared to a solely HFO driven plant. Additionally, the cost of carbon saving in such a scheme is around BDT 70.3 million (at a carbon price of USD 30/ton) per year.

5 Policy Options for Bangladesh and Conclusions

Bangladesh has been slow to adopt renewable energy sources for its power generation needs as it treads its way through the financial challenges the nation faces. It is important to realize that implementation of any renewable energy project needs to be financially feasible with minimum or no subsidy so that it does not put undue pressure on the economy of the country. In some situations, a limited level of subsidy or incentive may be needed to initiate or promote new technologies, but large-scale subsidy is not realistic. The subsidy could be in the form of tax break, reduced import duty or soft term loans with low interest rate. Some of these are already in force, but more may be needed. Any such step can be interpreted as an effort to mitigate climate change and can be used to attract foreign investments and funding from international development cooperation agencies.

Solar PV appears to be the key focus area in Bangladesh's renewable energy sector, while other resources do not appear to be particularly promising. In the absence of solar PV production, an increased percentage of PV energy will necessitate a storage system for power system stability, as well as extra generating or storage capacity to meet peak demand (as peak demand occurs during the evening hours). The results presented here show that we can very effectively use the Kaptai hydro-electric project by using a solar PV based pumped hydro system, as such a peaking power scheme can provide power during peak hours at a cost at least 30% lower than the average existing peaking energy cost. However, such a project is not scalable as we do not have any other hydro power plant. If additional reservoirs were naturally found within the national border, Kaptai experience could be replicated. Joint venture hydropower plant projects in the region (e.g., Indian north-east, Bhutan, Nepal) are an additional avenue that could be pursued to create solar PV power stations plus hydro storage combination.

Solar PV—HFO hybrid plants also offer financial feasibility. This appears to be a promising way to go since, unlike solar PV-hydro storage hybrid plants, it is not constrained by the natural environment. In our analysis, we considered the possibility of using solar PV for power generation during the day hours and set up additional HFO plants to cater to the additional peak load resulting from the unavailability of solar PV power in the evening. It has been shown that the fuel cost saving during the daytime is enough to economically run solar PV-HFO hybrid plants with a generation cost lower than a purely HFO based power plant. This ensures increased renewable energy share without increasing the cost of energy production. This is an important result in the sense that Bangladesh is running out of its own gas reserve and importing natural gas will increase the gas price by a significant margin. Once imported gas is injected in the grid, the price of the natural gas-based electricity will no more be as attractive as it is today. If we consider this scenario, solar PV-HFO hybrid plants seem to be the best possible economic solution.

Using the large-scale battery storage systems as a peak load shaving technique does not look economically viable, as the battery cost is too high. The interest rate in Bangladesh is quite high (~9% has been assumed in the analysis) and it keeps on changing over the years. In most of the developed countries, the interest rate is lower than 5% and the corresponding cost of energy is usually much lower when compared to its cost in Bangladesh. Moreover, the developed countries have the economic resilience to subsidize many of such projects to curb Greenhouse Gas (GHG) emission as a part of their commitment to the reduction of global warming. That level of subsidy will not be possible for a developing country like Bangladesh, but policy makers should encourage small scale grid connected solar PV projects with battery back up to enhance the stability of the power system. In such projects, the size of the battery will not be large enough to reduce the peak load but would be sufficient from a stability point of view.

Financial figures do not point to immediate feasibility for Solar PV—battery storage hybrid power stations. Despite this, Bangladesh's recent transition to middle income country may justify supporting one or more such power stations initially supported by subsidy, research fund or grants as a multitude of change is coming from the technology front (battery technology), financial front (interest rates), knowledge front (learning by doing), global climate change mitigation front (grant) and national energy security front (budgetary support). This could make this battery-based energy storage plant financially feasible as a stand-alone system or in combination with a solar PV power system.

Additional factors are also in play to change the inertia in policy circles that usually favors the use of traditional hydrocarbon sources for electrical power. One of the most important factors in this regard is the increasing concern of sustainability in using hydrocarbon-based energy sources as their price stability cannot be ascertained for the duration of the plant life, particularly for those plants that are on the design table now. Adding to that uncertainty, Bangladesh also faces pressures from different stakeholders to get its green credential in the right place while it pursues funds for climate change mitigation and adaptation purposes. An added incentive to pursue solar as well as other renewable sources for power generation is that it offers the possibility to gain financially from carbon credit and to avoid financial loss that may evolve from direct or indirect carbon tax.

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