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The Impact of COVID-19 Outbreak on the Power Sector in Bangladesh: A Strategic Adoption for Any Pandemic Condition

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Abstract— **In this research all the data sets were gathered during the COVID-19 outbreak. The study presented, however, is applicable to any pandemic scenario in Bangladesh or elsewhere. The lockdown has significantly reduced the demand for power worldwide and altered the makeup of the load and the daily load profile. This is because many offices have switched to home office strategy, which has shortened the operating schedule of many businesses. Considering this, many countries' adoption of lockdown measures to halt the spread of COVID-19 abruptly changed socioeconomic operations, including the power generation industries. To better understand the pandemic's impact on Bangladesh's fossil-fuel based power sector, this study examines renewable energy technologies' roles in creating climate resilient, sustainable energy routes. Research was done for the pandemic lockdown in 2020. Due to the lockdown situation, the power sector witnessed increased overcapacity, and revenue losses. This study looked at the implications on energy demand, load profiles, generation, consumption, generating mix, and expansion of renewable electricity generation. In addition, a suitable generation mix for Bangladesh has been suggested. This sector's resilience has also been assessed to overcome the pandemic crisis and any future pandemic-like emergency. In this research, a well-organized examination of the existing power sector overall plan has also been proposed, focusing on clean energy led power sector development.**

Index Terms— COVID-19, Load Profile, Generation Mix, RES, PSMP, Overcapacity, Capacity Payment, RPP, QRPP, IPP

I. Introduction

SARS-CoV-2 made an appearance in late 2019 in Wuhan, a city with a population of 11 million in the Hubei province. Every day in late January and February 2020, China saw tens of thousands of new COVID-19 cases [1]. Since then, practically every region and industry of the world has seen the disease's devastation. After the initial outbreak on March 8, 2020, Bangladesh was also struck badly.

Many governments have implemented lockdown, travel bans, and work-from-home policies to prevent virus spread. These precautions compelled most people to stay home, affecting normal socio-economic activities. Industries were forced to shut or reduce operations. The travel bans nearly knocked down the aviation industry, small enterprises almost came to a halt and educational institutions went online.

The economic, social, and environmental aspects of the electric industry have also been influenced along with the technical implication. The drop of electricity demand and high penetration of renewable generation have resulted in electricity price fall and reduction in emissions from power generation, respectively. A significant change in electricity demand level, load profile, load composition, generation mix and distribution have been observed due to this transition in working and living style. The power system operation has been facing a higher degree of uncertainty due to anti-epidemic policies.

The impact of COVID-19 on Bangladesh's electricity and energy sector cannot be ignored. The power sector in the country is closely connected to economic growth and the insufficient demand will adversely affect the requirement for electricity. This has led to growing overcapacity and income losses in the power sector. To overcome COVID-19's effects, the country's energy plans and policies will need to shift dramatically. When the country recovers from the COVID-19-induced economic collapse, power consumption will be low and overcapacity will persist for a long time. The current situation emphasizes the necessity to focus on sustainable energy solutions, such as renewable energy sources, which would increase resilience in times of crisis.

Forced lockdowns have had a major impact on the overall power sector globally. However, the influence on developing countries, particularly in the energy sector, has yet to be fully

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studied. The pandemic will undoubtedly hinder progress towards attaining the SDGs by 2030. "Affordable and clean energy for all" is linked to Goal 7. The key to future crisis management and sustainable power sector growth plans is a country-by-country impact evaluation of COVID-19.

A. Objective

This study focuses on providing precise and complete information about the variations in electricity demand, load profiles, energy generation, consumption, and generation mix in Bangladesh's fossil-fuel-dominated power sector over the COVID-19 period. Therefore, the objective of this study is:

- To examine the pandemic's influence on the country's power sector
- Need identification to make policy adjustments to PSMP

II. LITERATURE REVIEW

The present pandemic crisis has significant social, health, and environmental consequences. Energy, particularly the consumption of electricity, is strongly linked to a country's economic activity. There will be short- and long-term effects on the global electricity sector, which will be represented in the future literatures.

Many different aspects of the COVID-19 pandemic and energy systems have been studied recently, including power demand, consumption, electricity prices, emissions reduction, and policy proposals. Over the last few years, several various components of the COVID-19 epidemic and energy systems have been researched. Research showed that the epidemic lowered global electricity usage by 15% [3]. The IEA also expected a 6% drop in global yearly total demand, with non-renewable energy suffering the most [4]. China's energy demand was heavily influenced. The influence of COVID-19 pandemic lockdowns on household energy use in China was also studied [5,6]. Using multivariate time series forecasting with bidirectional long and short-term memory, researchers discovered that throughout the lockdown, electricity demand followed the weekend demand profile [7]. During the epidemic, data visualization and descriptive statistics were used to discover how different European electrical networks behaved [8].

Europe's consumption plummeted by 10% between late March and early April. In Italy, consumption has fallen by around 23% [9]. As reported in the IAEE Energy Forum, which examines the global effects of COVID-19 on the energy industry in terms of demand decreases, supply-side shocks, facility closures, and new electrical demand patterns [10].

Non-residential consumer consumption fell by around 38% during the total lockdown and by roughly 14.5% after the reopening [11]. The impact of COVID-19 pandemic lockdowns on energy consumption and peak demand in residential aged care (RAC) facilities was studied, and it was discovered that the reduction pattern depends on the facility's location. The biggest reduction in peak demand and energy use was reported in warm-climate facilities [12].

Carbon dioxide (CO_2) emissions from electricity generation are one example of how COVID-19 affects the environment [13]. Global fossil CO_2 emissions declined 5.8% in Q1 2020, with the electrical sector contributing for 131.6 Mt [14]. The IEA reported that individual country emission reductions are positively connected with epidemic severity and length, with the US (9%) China (8%), and the EU (8%). The 2020 full year reduction is predicted to be 2.6 Gt (8%), more than six times the 2009 record of 0.4 Gt [15].

III. METHODOLOGY

The proposed study aims to look into the impact on Bangladesh's power industry, as well as possible solutions to the COVID-19 problem and pandemic-like scenario. It takes a lot of data to fully investigate and assess the pandemic's effects, as well as uncover industry challenges. The study used secondary data.

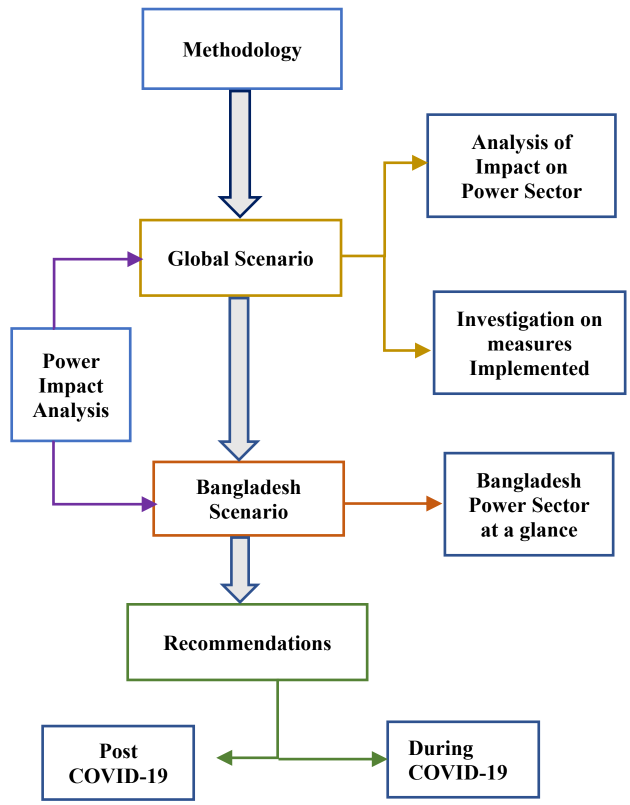


Fig. 1. Approach to the study

A pandemic centered around characteristics that obstruct investment and planning is the focus of this research. Figure 1 depicts the study's methodology.

The PGCB website [16] provided daily maximum load served by substations in different energy generating zones. The data was collected from March 26th to April 26th, 2020, and compared to data collected from the same time period in 2018, 2019, and 2021.

Daily (half-hourly) load profile data were downloaded from the PGCB website [16]. Data were considered for four years from 2018 to 2021, from 26 March to 26 April, so that the lockdown period can be compared to the baseline situation.

Furthermore, two representative load curves for 2019 were considered, one for a regular weekday and the other for a weekend. These load curves were compared to the shutdown period in 2020.

Daily records of actual energy generating data were acquired from the PGCB website [16] to conduct the total electricity generation study and average electricity consumption comparison. Data from March 26 to April 26 of 2020 were compared to data from the same period in 2017, 2018, 2019, and 2021 in order to make a comparison between the lockdown period and the baseline scenario.

For the generation mix analysis, data from March to July for four years from 2018 to 2021 were used for comparison as stated above.

To calculate the contribution of renewable energy sources (solar and hydro) to our energy generation, total monthly RES (solar and hydro) data were used from 2018 to 2021 for comparison purpose.

All data files were moved to spreadsheets to create simulation plots. Power BI structured and modified the data before moving it to MATLAB. The plots were created using the MATLAB default coding language. Excel was also used to generate graphs.

Both economic and environmental values were considered while forecasting an ideal future generation mix for power generation in Bangladesh. A discounted cash flow (DCF) analysis was used to calculate the generation mix analysis presented here. The capital costs ($/kW), fixed operation and maintenance costs ($/kW-year), variable operation and maintenance costs ($/MWh), heat rate (Btu/kWh), CO2 emission (lb/MMBtu), and CO2 emission cost rate of various electric power generating technologies are taken as reference values from Annexure-5. The CO2 price was set at 125 dollars per ton of CO2 in the environmental cost calculation, based on the assumptions in the IEA World Energy Outlook 2015 [17]. BPDB's current kWh bulk tariff is BDT 5.82/kWh (1$ = BDT 86.00), according to BPDB.

A. Equations Used [18] to Calculate Electricity Generation Cost in Different Generating Technologies

$$Electricity\ cost\ per\ unit = \frac{Capital\ cost + Environmental\ cost}{Total\ KWh\ power\ generation\ per\ year} \quad (i)$$

Where,

$$Capital\ Cost = Fixed\ O\ \&\ M\ cost + Variable\ O\ \&\ M\ cost + Interest\ on\ Capital\ Cost \quad (ii)$$

$$Fixed\ Operation\ \&\ Maintenance\ Cost = (Installed\ Capacity\ in\ MW\ x Fixe\quad d\ Operation\ \&\ Maintenance\ Cost\quad 24\ x\ 365\ x\ Fixed\ O\ \&\ M\ Cost) \quad (iii)$$

Now,

$$Interset\ on\ Capital\ Cost = Capital\ Cost\ \left(\frac{\$}{KW}\right) \times Installed\ Capacity\ in\ KW \times Interest\ rate \quad (iv)$$

$$Environmental\ Cost = Cost\ of\ CO2\ emission\ \left(\frac{\$}{tCO_2}\right) \times tCO2\ emission\ by\ each\ power\ plant\ type \quad (v)$$

Where,

$$CO2\ emission\ by\ plant\ type = 0.553592 \times Btu\ required\ in\ KWh \times CO2\ emission\ in\ KWh \times CO2\ emission\ in\ lb/MMBtu \quad (vi)$$

$$Total\ KWh\ power\ generation\ per\ year = [Installed\ Capacity\ (MW) \times Plant\ Utilization\ Factor] = [Installed\ Capacity\ (MW) \times \frac{Actual\ operating\ hours\ in\ a\ year}{Total\ hours\ in\ a\ year}] \quad (vii)$$

By 2030, Bangladesh's net power consumption is estimated to reach 40000 (MW). The proportion contributions of various fuel types were changed to get the 40000 MW. The interest on capital cost was calculated using a 10% interest rate. Different plant usage factors (0.92, 0.85, 0.50, 0.30, and 0.05) were used to calculate annual power generation in KWh. Annual performance reduction was considered @1.5%.

A. Financial Analysis

To assess the commercial viability of solar, wind, biomass, and hydro plant projects, the most commonly used financial indicators have been calculated:

- Payback period (PBP)
- Discounted payback period (DPBP)
- Net present value (NPV)
- Financial internal rate of return (FIRR)
- Financial benefit-cost ratio (FBCR)

Based on the following viability indicators: capital cost of the plant, fixed operation and maintenance cost, variable operation and maintenance cost, cost of fund, and revenue from the sale of electric power were calculated assuming that the considered power plant will be operational for a period of 20 years.

B. Formula and Correction for Project S

- PBP = The year in which investment is near to recover + (initial investment – cumulative cash flow of the year in which investment is near to recover)/cash flow of the year in which investment is fully recovered

➢ If the PBP calculated is less than 20 years, the plant will be accepted and if not, it would be rejected.

- For DPBP, cumulative discounted cashflows and $PVIF_{10\%,n}$ were derived.

- For NPV, the present value of all future inflows was calculated by discounting the cashflows @ 10%

➢ If the NPV shows a surplus value the plant would be considered for investment. Since it would be financially viable.

- To find the FIRR, it is required to find out two NPV's where one is positive and the other is negative. Here, $NPV_{40\%}$ and $NPV_{10\%}$ were considered.

FIRR = Lowest interest rate + [(Higher rate -Lower rate) x NPV_{LR}]/(NPV_{LR} -NPV_{HR})

- If FIRR ≥ cost of capital; project accepted
  FIRR ≤ cost of capital; project rejected

- FBCR = PV of benefit expected from project/PV of the cost of the project

C. Economic Analysis

Electricity generation cost per unit was taken into consideration for economic analysis of the power plants.

IV. A GLANCE AT POWER SECTOR OF BANGLADESH

A. The State of the Power Sector

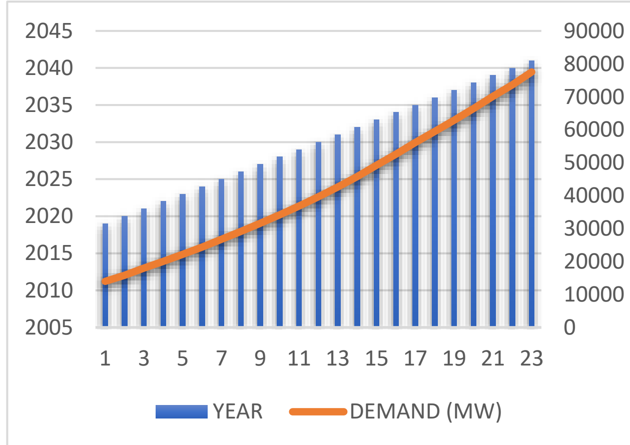
The power sector is one of the key areas of success over the last decade. And this success has been described in terms of installed capacity, per capita generation, and access to electricity, and system loss, among other things. Table I depicts the determinants of last three years [15].

TABLE I. GENERATION OF ELECTRICITY IN FY2020 & FY 2021

Determinant	Actual (MW)			% Δ between FY19 & FY20	*% Δ between FY20 & FY21*
	2019	2020	2021		
Generation Capacity	18610	20383	22023	9.5	8.04
Maximum Demand	12100	13300	14,097	9.9	5.99
Maximum Generation	12893	12738	13792	-1.2	8.2
Per Capita Generation (kWh) (Grid)	426.05	426.23	512	0.04	20.1

B. Demand-Supply Scenario

Power generation capacity has been escalated eyeing towards growing demand. Despite the progress, electricity consumption did not increase as predicted by the Power System Master Plan. As of today, the real scenario differs drastically from what was previously predicted. According to the revised PSMP, forecasted peak demand in 2019, 2020 and 2021 was 13,975 MW, 15,809 MW and 18,023 MW respectively (Fig.2) [19]. However, reported maximum electricity generation so far was 12,893 MW as on 29 May 2019, 12,738. The fact is that our power supply now exceeds demand due to faulty demand-supply calculations. COVID-19 has further aggravated situation.



Source: PSMP 2016 (Revisiting)-Published in November 2018

Fig. 2. Year-wise peak demand forecast (MW) (base case)

C. Power Transmission and Distribution Systems

Not surprisingly, power generation has outpaced transmission and distribution. The distribution and transmission systems are underfunded. Even though half of its capacity is idle due to delayed transmission line connections, the almost-completed Payra Coal-Fired Power Station reportedly receives monthly capacity payments totaling Tk160 crore ($19 million) [20].

D. Local Industry Transportation

In order to increase the capacity of the country's electricity generation on a short-term basis (but at a high cost), the government turned to some rental or quick rental power projects under private ownership as a short-term option. In addition, favorable legislative backing, easy borrowing from banks, high profit margins, and a short payback period of investment, as well as tax exemptions, have enticed most private company groupings to grow their footprint in the electricity industry [21]. As a result, the private sector's contribution is increasing. Table II illustrates the various ownerships of the Bangladeshi power plants.

TABLE II. POWER PLANTS UNDER DIFFERENT OWNERSHIP

Ownership	Actual (MW)			*Actual (MW)*		
	No. of Plants	*Electricity Generation (MW)*	*Electricity Generation (%)*	*No. of Plants*	*Electricity Generation (MW)*	*Electricity Generation (%)*
Public PP	76	9568	46.94	57	10146	46.07
Joint Venture	1	771	3.78	1	1244	5.65
IPP	49	7583	37.2	71	8172	37.12
Rental PP	21	1301	6,38	20	1301	5.91
Imported		1160	5.69		1160	5.27
Total	147	20383		149	22023	

E. Current Position of Energy Resources

Indigenous natural gas, coal, imported oil, LPG, imported LNG, imported electricity, and hydro-electricity are all known commercial energy resources in Bangladesh.

Furthermore, power is generated in both on-grid and off-grid places by utilizing Solar Home Systems (SHS). Solar power generation now stands at around 532.81 megawatts (MW).

F. Primary Energy Mix for Power Generation

Figure 3 depicts the composition of the primary energy mix for electricity generation in FY 2019-20.

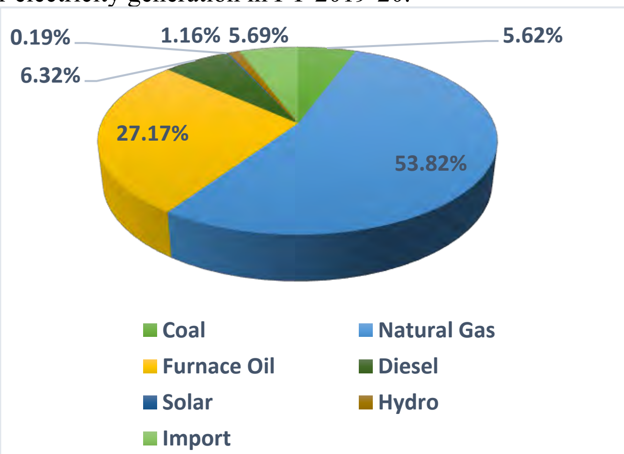


Fig. 3. Power generation by fuel type (2019-20)

In 2019-20, 60.6 percent of the total electricity generated came from domestic fuels (natural gas, coal, and hydro), 33.5 percent from imported petroleum fuels (diesel and furnace oil), and 5.69 percent came from electricity imported from India as part of cross-border energy exchange [22].

G. Consumer Segmentation

In the fiscal year 2019–2020, Bangladesh's total retail electricity consumption was 63364 GWh. Figure 4 depicts the various contributions of consumption to each sector in Bangladesh during the 2019-2020 fiscal year. Due to the COVID-19 outbreak and the resulting general holidays of more than two months in 2019, the share of residential users has increased while the share of industrial and commercial users has decreased.

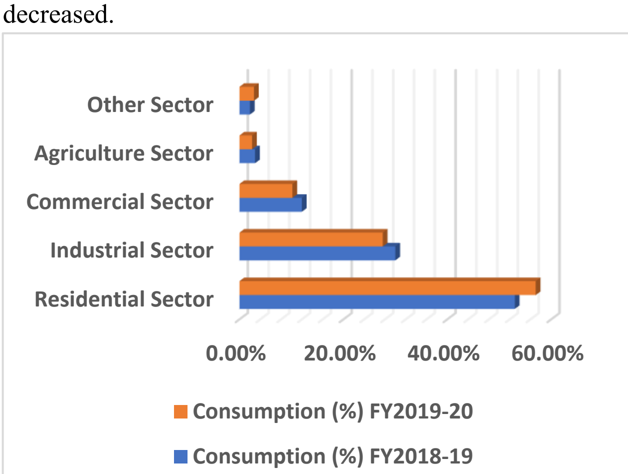


Fig. 4. Consumer segmentation in Bangladesh

H. Primary Energy Resources Utilization in Electricity Generation

The following describes the status of Bangladesh's indigenous energy resources and their potential as a primary fuel for electricity generation [23]:

For energy, the country has been primarily reliant on domestic natural gas. Natural gas is responsible for most of the grid's electrical generation. Natural gas use has declined from 83 percent in 2010 to 53.86 percent in 2020.

In FY 2020, coal accounted for 5.62 percent of total energy production. The government planned to boost coal consumption and decrease domestic natural gas use for electricity generation under PSMP-2016.

Bangladesh imports the majority of its liquid fuel. Power sector consumed 6.84% of liquid fuel in 2019-20.

The government is now focusing on imported LNG as a low-cost, long-term energy source for power generation, as LNG imports can bridge the demand and supply gap.

Bangladesh now imports 1,160 MW of power from India via the Bangladesh-India Regional Grid.

I. Resource for Renewable Energy in Bangladesh

Currently, Bangladesh uses three types of renewable energy sources (Fig.5).

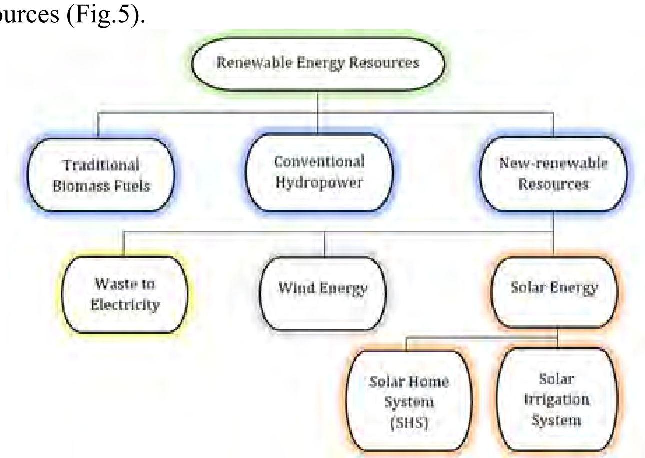


Fig. 5. Renewable energy resources used in Bangladesh

Biomass fuels are used for cooking in areas where there is no access to natural gas or the electric grid. In Bangladesh, biomass accounts for 27% of total primary energy consumption.

At Kaptai (1000 MKWh/year), the country's total hydropower potential was reported to be 1500 MkWh/year. Sangu (200MKWh/year) and Matamuhury (300MkWh/year) (GOB 1996). In 2018-19, the 5 hydropower units installed at Kaptai had a total generation capacity of 230MW, generating 8934 MKWh of energy [24].

Solar energy: In Bangladesh, the amount of solar energy available is substantial, ranging from 4 to 7 kWh/m2/day, which is sufficient to supply the country's need. Rural populations are increasingly accepting solar photovoltaic (PV) systems for supplying electricity to homes and small enterprises in off-grid locations.

The Rural Electrification Board (REB), a government body, has been working to commercialize solar energy for home, commercial, and irrigation purposes in rural areas.

Solar Home Systems (SHS) are being distributed by IDCOL and BREB to people living in off-grid locations. IDCOL has already given around 55 lakh SHS (with a capacity of 250 MW) through various partner organizations, and BREB has distributed about 30,000 SHS across the country.

Solar Irrigation System: IDCOL has installed a total of 1158 solar irrigation pumps as of June 2019.

Bangladesh is looking at wind power's potential. Windmills with a capacity of 2.9 MW are in service along Bangladesh's coast.

Electrical Energy from Waste: The government is implementing a waste management and electricity generation from solid wastes program to save the city from pollution.

J. Challenges Confronted by the Power Sector

Overcapacity in Power Generation: Bangladesh has already been dealing with the problem of overcapacity (Table III) within the power sector, COVID-19 has definitely widened the gap between power demand and current power plant generation capacity [25].

TABLE III. OVER CAPACITY IN TERMS OF GENERATION

Year	*Total installed capacity (MW)*	*Overcapacity (as per max. generation)*	*% of share of overcapacity of installed capacity*	*Year*
2000-01	4005	972	24.3	2000-01
2010-11	7264	2374	32.7	2010-11
2015-16	12365	3329	26.9	2015-16
2018-19	18610	6068	32.6	2018-19
2019-20 (17 June,20)	20383	10216	50.1	2019-20 (17 June,20)
2020-21	22023	8231	37.4	2020-21
2021-2022	24223	2231	32.3	2021-22

According to the BPDB annual report, overall power system usage fell to 40% in FY 2020 from 43% in FY 2019.

Our power system has a huge spare capacity, as evidenced by our 40% usage rate. With 56.37 percent, 53.87 percent, and 46.32 percent over-capacity in January, February, and March 2020 (during COVID-19) (Fig. 6). A large reserve capacity goes against the PSMP's goal (25 percent). This is far more than most developing countries' 10% reserve capacity (IEEFA, 2020).

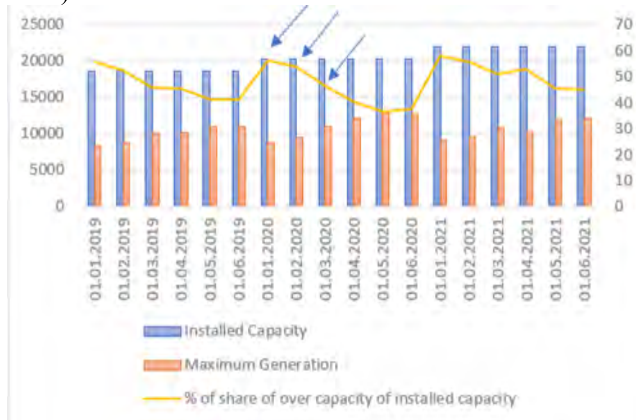


Fig. 6. Overcapavity in power generation: Pre-COVID & CVID period

Un-utilization and under-utilization of power plants: Unbalanced growth in generation capacity and lack of proportional growth in electricity consumption forced many power plants to remain idle, especially during the COVID-19 period. On June 17, 2020, 45 of the 147 power plants in the C-19 time period were not used at all. This number was just 19 a year before (17June, 2019). In the Dhaka, Comilla, and Chittagong zones, more power plants were left running because there wasn't enough demand for them.

Payment of Capacity Charges: The Bangladesh Power Development Board (BPDB) requires paying IPPs for unused/underutilized capacity. Meanwhile, many power plants are either idle or producing at half capacity. Because nearly half of our generation capacity is idle (reserved), BPDB must pay a capacity charge to each of those plants to keep them compliant with the power purchase agreement. Capacity payment is the payment which the BPDB has to make as a penalty to the individual power producers (IPPs) from whom it is contractually obliged to buy electricity, but does not because of a lack of demand for power [26]. The payout has increased dramatically over time, rising from Tk.1,790 crore in FY10 to Tk.8,929 crore in FY19 (a 398 percent increase) (Fig 7).

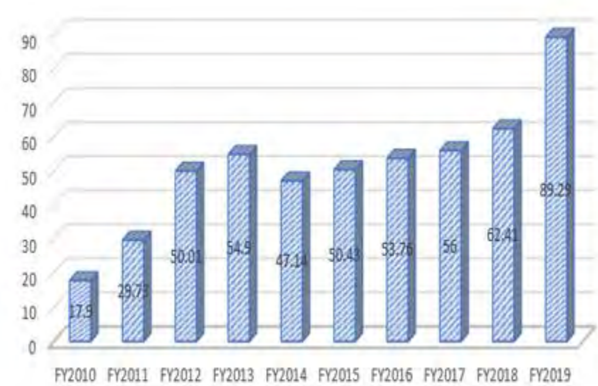


Fig. 7. Capacity payments to power plants (billion Tk)

COVID-19 caused a delay in the installation of transmission lines: Despite considerable surplus capacity, insufficient transmission and distribution systems leave rural and even some urban areas without reliable energy supply. Covid-19 has slowed the upgrade of the transmission and distribution systems, causing unused capacity to linger even longer.

V. Results Analysis & Discussion

A. Electricity Demand Variations

The lockdown period of 26 March to 26 April 2020 was considered to check the demand variations of nine electricity generation zones of Bangladesh. For comparative reasons, the same calendar days from 2018, 2019, and 2021 were used. Increased lockdown measures resulted in a continuous decrease in energy usage, as shown in the profiles [25].

If the daily electricity consumption in the Dhaka zone (Fig 8) decreased dramatically from 3000-3800 MW in 2019 to 2300-2900 MW in 2020 between March 26 and April 1.

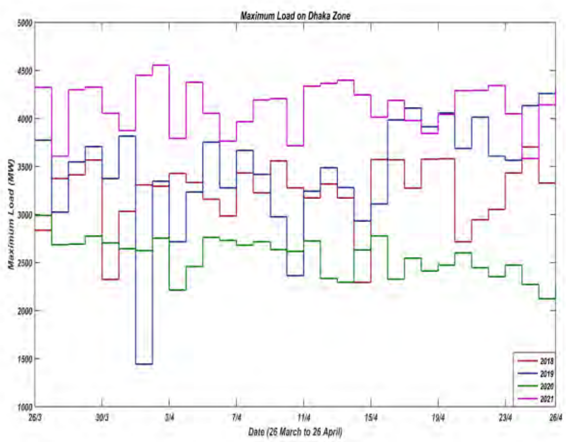


Fig. 8. MATLAB plot for maximum load on Dhaka Zone

The Dhaka zone's (Fig.8) demand decreased more and more between April 16 and April 26, 2020, and fell below 2500 MW. During the 2020 shutdown, demand swings on weekdays and weekends were virtually nonexistent.

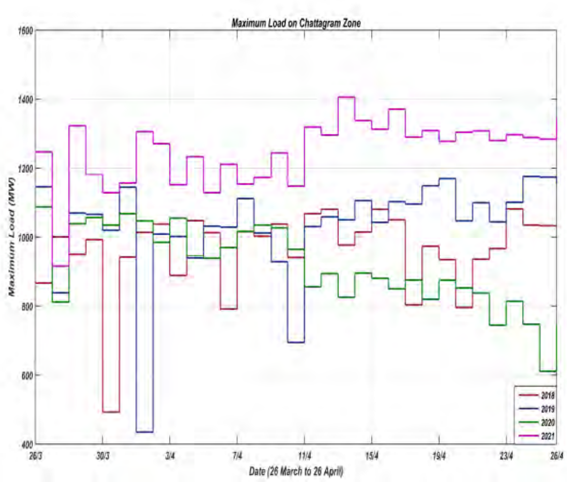


Fig. 9. MATLAB plot for maximum load on Chattogram Zone

In 2020, between April 16 and April 26, demand in Chattogram zone (Fig. 9) was less than 1000 MW, compared to more than 1000 MW the previous year for the same calendar days.

In the Sylhet zone (Figure 10), between April 16 and April 26, demand was less than 300 MW.

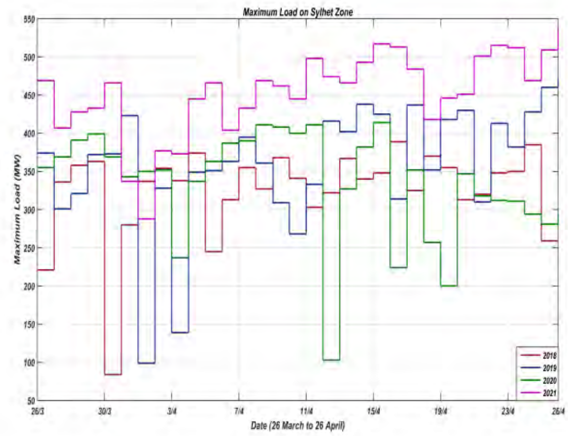


Fig. 10. MATLAB plot for maximum load on Sylhet Zone

In Table IV the demand changes in MW along with their (%) changes for Dhaka, Chattogram & Sylhet zones are summarized.

TABLE IV. ELECTRICITY DEMAND CHANGES

Zone	Demand in 2020 (MW)	Average Demand in 2018-19 (MW)	Changes (%)
Dhaka	81758	107373	-31.3303
Chattogram	29215	31995	-9.5156
Sylhet	10688	10952	-2.47

The results of all nine electricity reveal that

- Total demand reduction -2.2362%
- Maximum drop in Dhaka one, then Chattogram & Sylhet zone
- In other zones variances were minor, possibly due to variances in residential demand.

B. Daily Load Profile Analysis

The contour of the electrical load over time is known as the load profile. The load profile for a specific region differs significantly depending on the types of users, such as commercial, residential, and industrial. Peak electricity demand varies depending on the season and holidays. Fig. 11 & 12 depicts a typical Bangladesh load profile for the winter (January) and summer (April) weekdays and weekends in 2019.

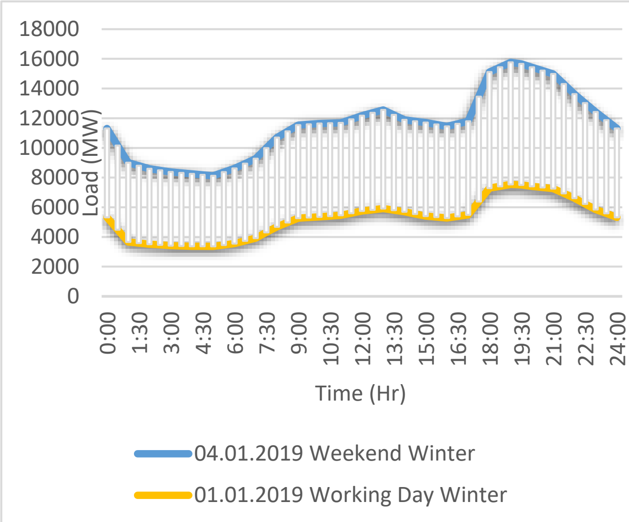


Fig. 11. Load profile: Weekday/Weekend (January/Winter)

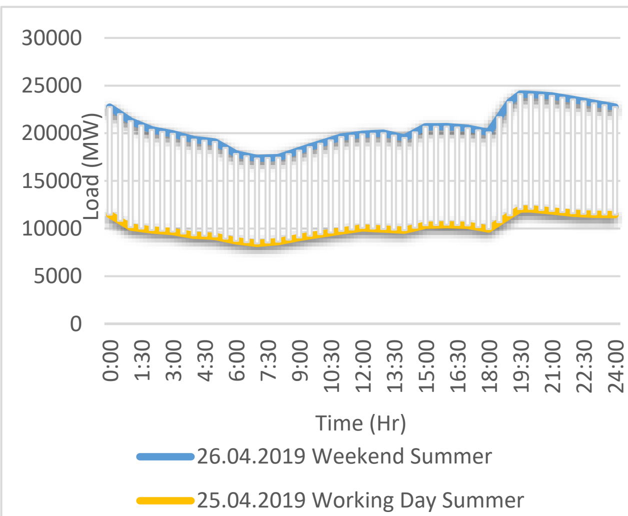


Fig. 12. Load profile: Weekday/Weekend (April/Summer)

The three main dates in Bangladesh's lockdown sequence were:

- 16th March 2020: closing of all educational institutions,
- 26th March 2020: General Holidays started and transport ban,
- 29th March 2020: the first available Sunday after the lockdown declared

During COVID-19 epidemic limitations, the forced closure of educational institutions, public facilities, industry, and office activities reduced consumption trends during daily working hours. When the daily load profile of the days 16th (Fig. 13) and 26th (Fig. 14) (for 2020, 29th, the first available Sunday) March is compared to the previous two years (2018-2019), a reduction in consumption is observed, despite weather variances and other relevant economic difficulties.

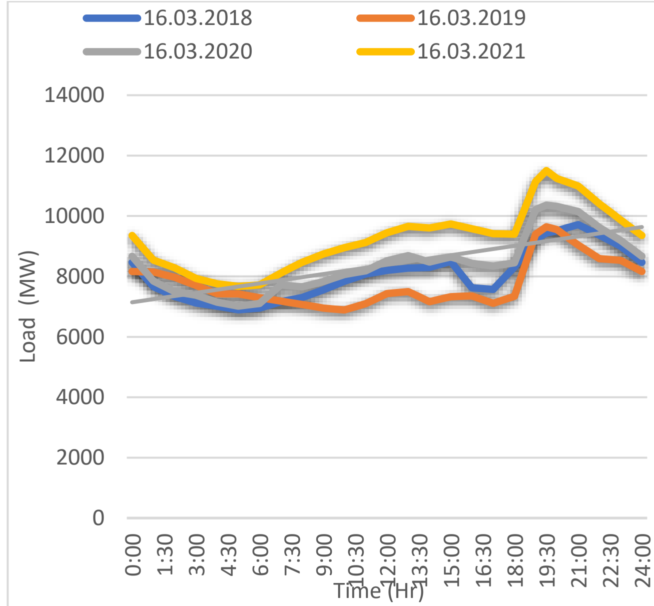


Fig. 13. Load profile comparison 16th March (2018-2021)

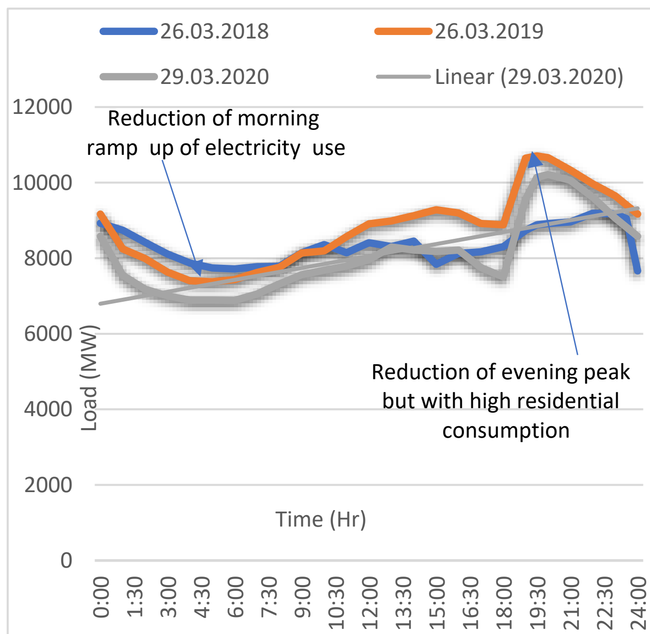


Fig. 14. Load profile comparison 26th (2018-2020) & 29th March 2020

The daily consumption curve changed its usual trend as a result of the lockdown.

Electricity consumption increased more slowly in the morning, and evening peaks are prolonged.

Bangladesh's power demand consumption is primarily dominated by the residential sector. COVID-19 initiatives have had a significant influence on energy consumption, as evidenced by our daily profiles. As described and shown in 'consumer segmentation' of this paper that the residential demand increased by 4.02%, and industrial and commercial demand decreased by 2.42% and 1.81% respectively. In comparison with the daily pre-lockdown consumption curves in prior years. The forced closure of industrial and commercial activity has changed the working hour consumption curves slightly.

The lockdown has changed the regularity of consumption as well as the hours and demand values of peak consumption periods. The greatest drop in electricity demand happened during the morning and evening peaks, despite the fact that it happened at all hours of the day.

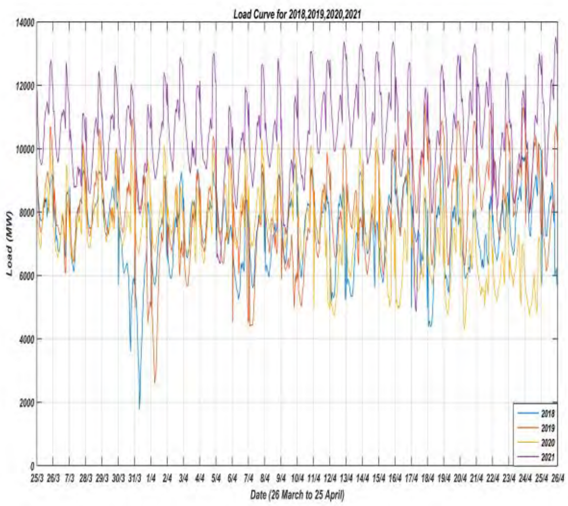


Fig. 15. MATLAB plot for load curve (2018-2021)

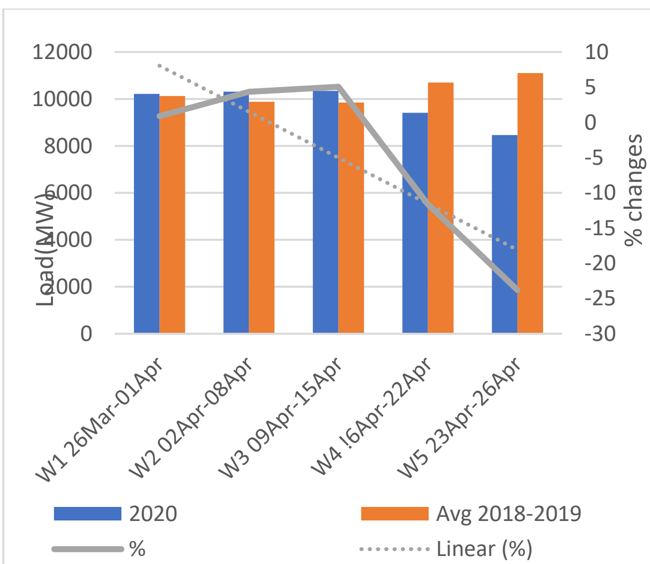


Fig. 16. Number equations consecutively with equation numbers in pa Five-week peak comparison between average value of 2018-2019 & 2020

To better clarify the phenomena, in Figure 15, a comparison is shown between the average value of 2018-2019 and 2020 of the peak load variation profiles in Fig. 16 which shows an evident gradual reduction in consumption that reached -23.788% less consumption in the last week of the stipulated period than the average in the previous two years (2018-2019).

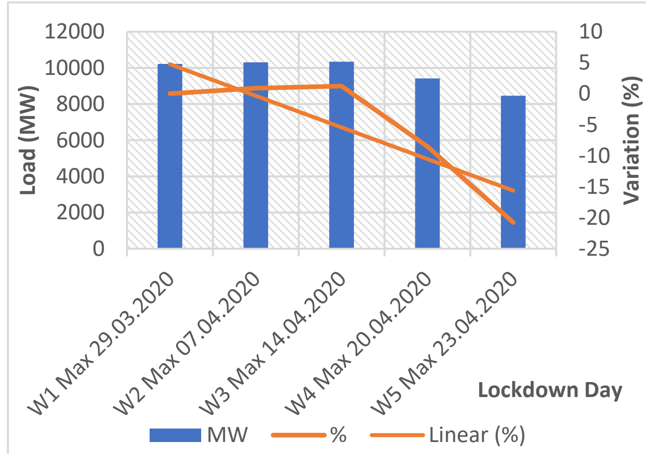


Fig. 17. Week-wise load profile changes (26 March to 25 April 2020)

In Figure 17 the volatility of the peak in the demand on weekly basis is analyzed from 26 March to 25 April 2020. Increased lockdown measures resulted in a consistent drop in national energy usage, as shown in the profiles. Following the closure of several production facilities, a drop in load was seen starting on April 11th. The considered period was divided into five weeks, with the first week's peak demand value serving as the baseline, and peak demand variations of 0.88 percent, 1.22 percent, -8.53 percent, and -20.75 percentage were found for the next consecutive four weeks, respectively.

C. *Generation Analysis*

Figure 18 depicts total daily energy generation in MWHr in Bangladesh from 26 March to 26 April, 2020, as well as average daily load curve shape for the past three years (2017-2019).

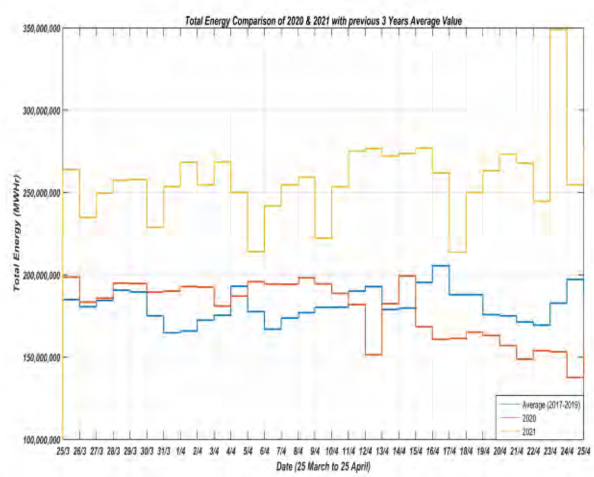


Fig. 18. Five-week load profile, (26 March to 25 April, 2020)

Fig. 19 shows the percentage variance in consumption on each of the days in the time represented. Consumption was somewhat higher than the three-year average for the first three weeks depicted in the graph (4.55 percent higher on average in these three weeks). However, starting on Thursday, April 15, there was a huge drop in demand. Consumption was 18.42

percent lower from April 15 to April 25, compared to the previous three-year average, reflecting weaker activity in the industrial sector and a major portion of the service sector. The reduction in total electricity consumption from the commencement of the lockdown to Saturday 25 April was 2.607 percent.

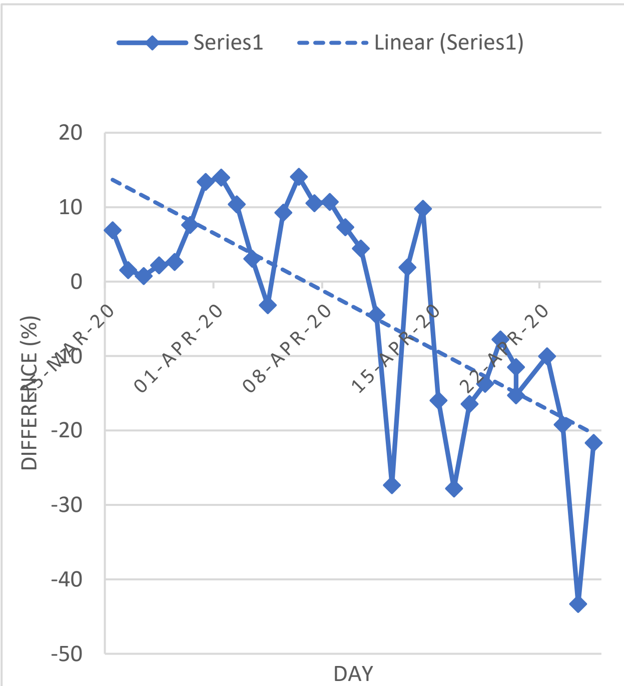


Fig. 19. Difference (%) between the electricity consumption in 2020 & the average values in three previous years (2017-2019)

Working days and weekends have been separated in the fig. 20 and 21, illustrating the percentage decline in demand for each type of day in 2020 compared to the average value of demand for the previous three years.

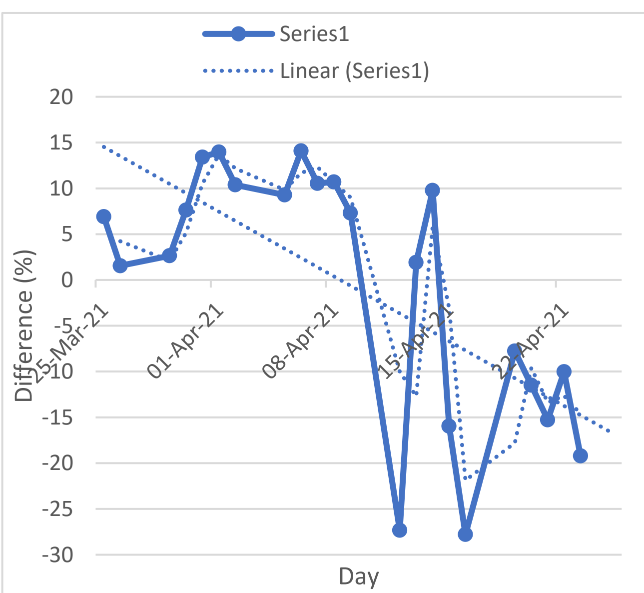


Fig. 20. Difference (%) between the electricity consumption in 2020 & the average values in three previous years (2017-2019), on weekdays

Between March 25 and April 25, electricity usage fell 0.66 percent on working days, compared to the same time the previous three years, and fell 9.22 percent on weekends.

Fig. 21. Difference (%) between the electricity consumption in 2020 & the average values in three previous years (2017-2019), on weekends

Analyzing the demand-supply scenario during COVID-19 period in Bangladesh, the combined effect of under-utilization and overcapacity would increase until 2025 if the power demand consumption growth does not catch up quickly and remains at a very low level throughout the period. Due to the negative economic impacts of COVID-19 in our country, the rate of power generation growth was only 1.26 percent in 2019-20, according to BPDB.

However, according to the Bangladesh Power Development Board's (BPDB) latest annual report for 2020, the country's overall power system utilization fell to 40.0% from 43.0% the previous year (Figure 22). As per data, 40% utilization means the power system has significant spare capacity.

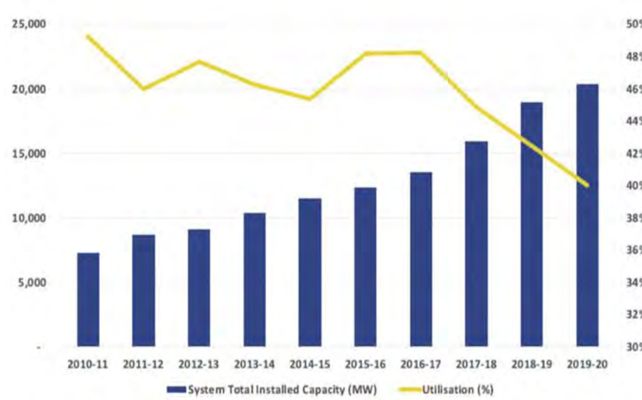


Fig. 22. Bangladesh power capacity (MW) & overall capacity utilization (%)

On the basis of power generation growth assumptions and BPDB reported capacity additions and retirements through 2025, IEEFA forecast future capacity utilization. Even if generation growth returns to 10% in FY21, overall capacity utilization will fall below 40% in the early 2020s before rising to 40% in 2025-26. (Fig. 23).

If annual generation increases by 8%, utilization will fall to 36% by 2025-26. By the end of the year, 2/3 of the country's power capacity will be idle due to generating growth of 7%. (Fig. 23).

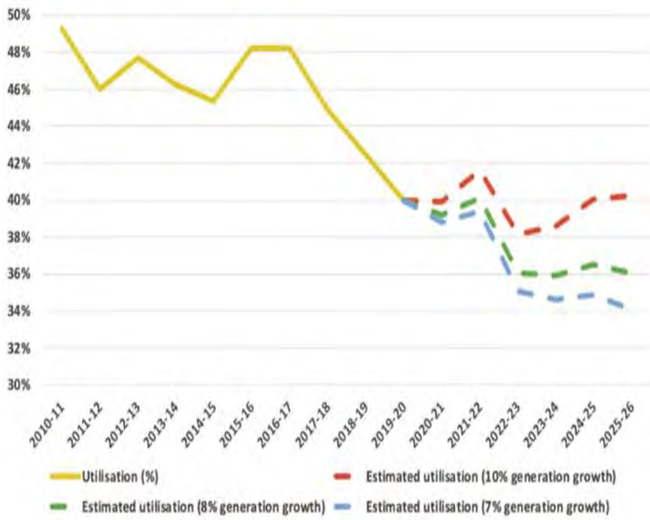
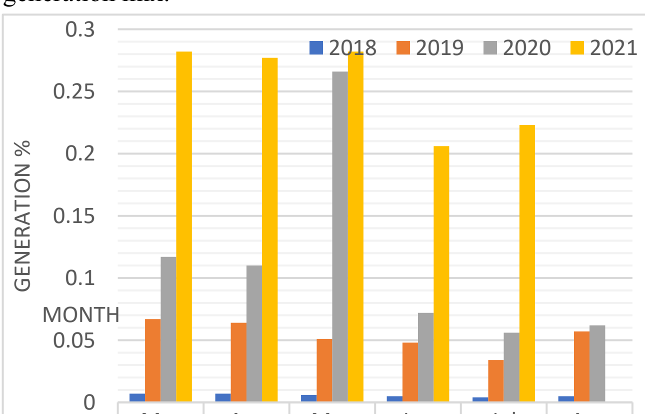


Fig. 23. Actual & estimated future total system capacity utilization

Overcapacity has severe financial and tariff repercussions for the BPDB. Capacity payments to power plants that are increasingly idle enhance the per unit cost of generation, resulting in higher government subsidies and/or raising power bills for consumers.

D. Generation Mix

Developed countries' energy mix with renewables changed considerably during the lockdown. The most significant factor for those countries is that non-renewable electricity output has decreased due to lower demand. However, renewable energy sources like solar plants have increased their share of the generation mix.

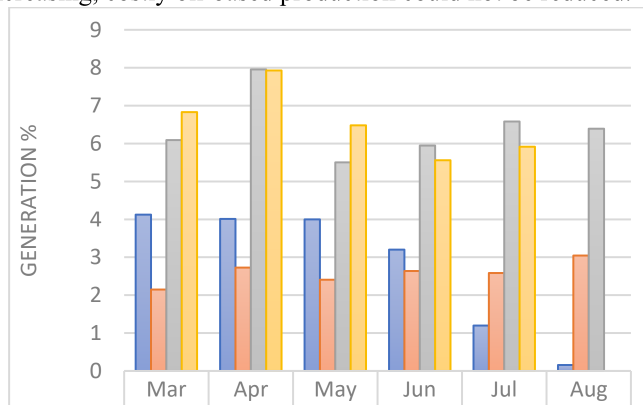


	Mar	Apr	May	Jun	Jul	Aug
2018	0.007	0.007	0.006	0.005	0.004	0.005
2019	0.067	0.064	0.051	0.048	0.034	0.057
2020	0.117	0.11	0.266	0.072	0.056	0.062
2021	0.282	0.277	0.282	0.206	0.223	

Fig. 24. Fuel wise generation-gas

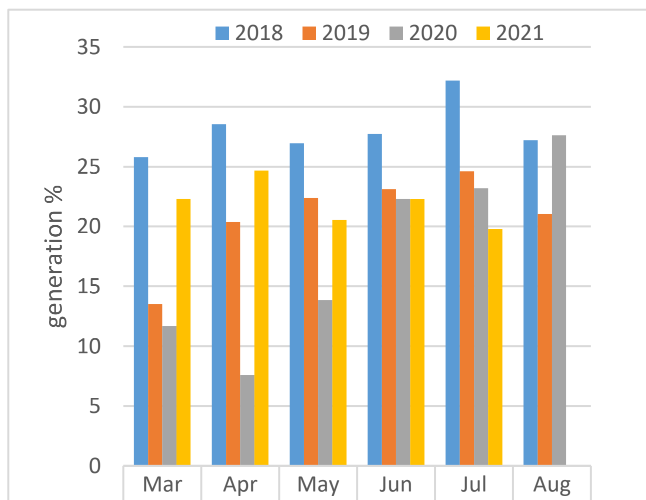
However, in this case, the generation mix is different. The RES share in Bangladesh's generation mix is negligible. Bangladesh's power system relies heavily on natural gas and oil (diesel, HFO and HSD). Fig 24 shows that the reliance on gas increased during the lockdown period in 2020, compared to the same months in the previous two years (2018-2019).

During the lockdown, the country's reliance on oil decreased due to a steady supply of imported electricity (Fig. 25). Unfortunately, with few alternatives and seasonal demand increasing, costly oil-based production could not be reduced.



	Mar	Apr	May	Jun	Jul	Aug
2018	4.124	4.011	3.999	3.201	1.198	0.157
2019	2.148	2.727	2.407	2.637	2.584	3.045
2020	6.091	7.954	5.503	5.946	6.581	6.391
2021	6.829	7.927	6.48	5.559	5.916	

Fig. 25. Fuel wise generation -oil



	Mar	Apr	May	Jun	Jul	Aug
2018	25.781	28.54	26.949	27.722	32.194	27.207
2019	13.526	20.366	22.374	23.113	24.607	21.033
2020	11.69	7.605	13.852	22.292	23.184	27.613
2021	22.297	24.675	20.556	22.274	19.782	

Fig. 26. Fuel wise generation-coal

During the 2020 lockout period, however, some large-scale coal power plants were connected to the natural gas grid. As a result, coal's share of the generating mix has increased in comparison to the same months in the previous two years as shown in Fig. 26.

Even though grid-tied renewable electricity generation is essentially non-existent in Bangladesh's power system, the contribution of solar peaked during the FL period, as seen in Fig. 27.

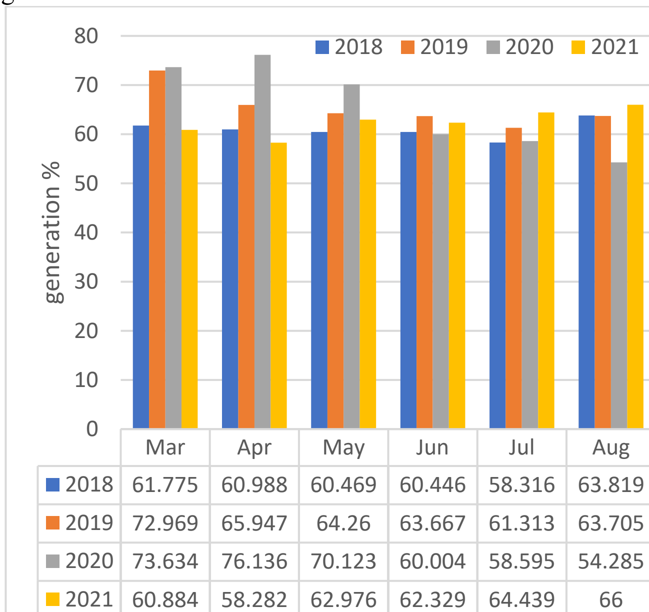


Fig. 27. Fuel wise generation-solar

Figure 28 illustrates the participation of hydro in generation mix was also higher compared to the same months May-June 2019.

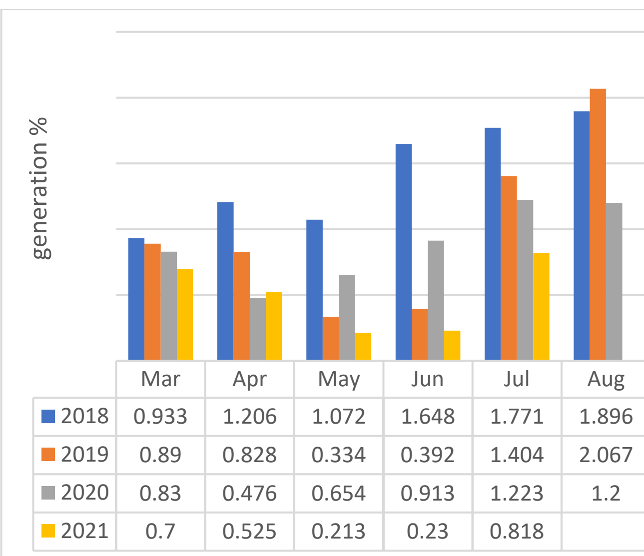


Fig. 28. Fuel wise generation-hydro

Figure 29 illustrates how the participation of solar and hydro in generation mix in such a negligible portion (Fig.27 & 28) have brought down the per unit fuel cost. This highlights the importance of greater participation of RES in the electricity generation mix in future.

For a power system like Bangladesh's with little renewable capacity, generation mix and fuel cost per unit are interrelated.

Table V demonstrates both diesel and oil-fired capacity utilization decreased significantly from the previous year, with diesel falling from 16.8% capacity utilization in FY19 to just 1.2 percent in FY20. As a result, the loss of Tk. 43.5 billion

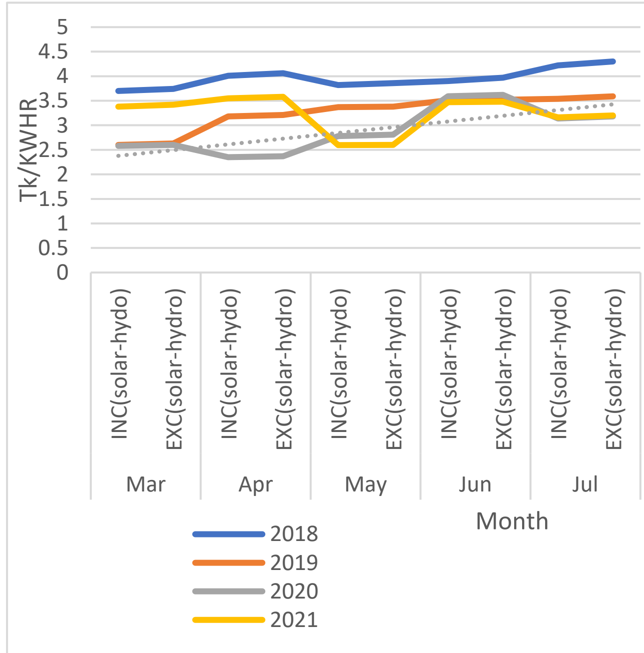


Fig. 29. Per unit fuel cost comparison

(US$514 million) was 14.0% lower than the previous year. This was achieved by reducing dependency on oil and diesel-fired electricity (Table V). This resulted in a 16.0% reduction in the cost of fuel per unit for thermal power plants, to Tk 1.64/kWh.

TABLE V. POWER CAPACITY, GENERATION, & CAPACITY UTILIZATION

Source	FY 2019-20			FY 2018-19		
	Capacity (MW)	Generation (GWh)	Utilization (%)	Capacity (MW)	Generation (GWh)	Utilization (%)
Coal	1146	2968	29.60%	524	1230	26.80%
Gas	10979	51290	53.30%	10877	48306	50.70%
Hydro	230	825	40.90%	230	725	36.00%
Utility scale solar	38	62	18.60%	30	39	14.80%
Furnace oil	5540	9461	19.50%	4770	11426	27.30%
Diesel	1290	139	1.20%	1370	2022	16.80%
Imports-India	1160	6674	65.70%	1160	6786	66.80%
Total	20383	71419	40.00%	18961	70534	42.50%

E. From a Financial Standpoint, the Viability of Power Sector

Government subsidies in the electricity sector: In the last decade, the government has subsidized the power sector by BDT 522.60 billion. The government's emphasis on short-term, high-cost power generation projects has driven up average unit costs. The BPDB is getting increasingly concerned about the financial burden of accumulating excess generation capacity. For years, BPDB has been losing money since retail power rates are lower than the cost of producing or acquiring electricity from private facilities.

Moreover, Long-term power consumption will be lower than projected as industrial expansion deteriorates because of the COVID-19 epidemic. By making capacity payments to power producers, the pandemic-induced economic crisis is threatening to reduce the BPDB's income even further.

New power plants fueled by imported coal and LNG are expected to come online to meet rising demand and replace retiring plants. These new coal and LNG-fired power plants will gradually replace Bangladesh's cheapest source of electricity, natural gas. BPDB's domestic gas-fired facilities generated Tk 3.0/kWh in 2019-20, much less than the estimated cost of imported coal and LNG-fired power. As local gas is replaced by imported coal and LNG, Bangladesh's power generation costs will rise eventually.

Coal and LNG will reduce costs where they replace Bangladesh's most expensive power sources, oil and diesel-fired power, but they will raise costs where they replace local gas. According to the BPDB's 2019-20 annual report, domestic gas powers 3,604 MW (66.0%) of the 5,501 MW of capacity scheduled for retirement, with diesel powering 1,140 MW (21.0%) and oil powering 757 MW (14.0%).

Aside from imported coal and LNG, the BPDB is expected to face significant cost increases in the coming years from new oil-fired power generation. The BPDB estimates that by the end of 2021, over 1,000 MW of new oil-fired electricity will be operational.

While the number of coal and gas-fired power plants has decreased, the number of HFO-fired power plants has increased, as shown in Table VI.

TABLE VI. ENERGY MIX IN POWER GENERATION: FY2020 & FY2021

Energy-mix	2020		2021	
	No. of Plants	MW generated	No. of Plants	MW generated
Coal	4	1146	3	1768
Gas	71	10979	67	11402
HFO	56	5540	61	6044
HSD	10	1290	10	1290
Hydro	1	230	1	230
Solar	4	38	7	129
Power Import	0	1160	0	1160
Total	146	20383	149	22023

Due to these increasing number of installed HSD and HFO based plants average power supply costs increases. Currently, the average cost of producing electricity for HFO-based rental plants is BDT 13-14, BDT 25-30 for HSD-based QRPPs is BDT 25-30, and BDT 2.5-3 for gas-based plants is BDT 2.5-3. As a result, it's possible to estimate how much money has been lost only because of these oil fired power plants.

Transmission and distribution: Investing in the transmission and distribution system is another key component of a successful response to Bangladesh's overcapacity problem. This would not only allow for the installation of larger renewable energy capacity, but it would also help in the greater utilization of current thermal power capacity, reversing the country's declining capacity utilization, and reducing the impact of capacity payments on electricity per unit.

Extending certain plants increases the cost burden unnecessarily: Despite the governments declared commitment to gradual phase-out of QRPPs, several expensive power plants are still in service, and a number of RPPs and QRPPs have been handed extensions of 3-15 years, with the stipulation that if the units remain inactive, they will continue to receive capacity payments. Moreover, in private PP, there are a lot of outdated and inefficient power plants. These plants must gradually be phased out. Furthermore, the actual plant factor remained significantly lower than the country's installed generation capacity, and the continuation of costly projects has resulted in growing power division losses. QRPPs had a normal agreement duration of 3 to 5 years, whereas RPPs had a term of 15 years, after which they were to be phased out and replaced with more cost-effective big power units. Despite having extra capacity, various types of power plants are used to generate electricity under varied ownerships. This study reveals that the rental power plants have a capacity of 1301 megawatts (MW) (Table II). Only 440 MW of power was consumed in FY2020, out of a total capacity of 1301 MW, accounting for only 1/3 of QRPP capacity. In my opinion, private investment in RE-based power generation would be unviable without providing scope by phasing out plants.

Public power production plants that are inefficient: Most public power generation firms cannot recover their own costs while generating electricity for end-users as such plants are in constant demand and cannot shut down. Moreover, many of the country's plants are obsolete, producing less power (low plant load factor) and consuming more fuel.

Power imports despite overcapacity: Despite domestic overcapacity, the government has gradually increased power imports from neighboring countries. Even after paying capacity charges, importing power is still cheaper than generating it at most private facilities (mostly HFO-fired). For most local rental plants, the cost of power import is Tk 15-30/kWh.

F. *Opportunity for Renewable Energy*

Bangladesh offers a great chance for renewable energy development without jeopardizing the country's economic and financial prosperity. Nonetheless, considerable development efforts in Bangladesh have met with limited success and are currently facing a variety of issues, most of which are financial, technological, and regulatory in nature.

Utility-scale renewable energy has struggled to take momentum in Bangladesh due to land problems. Similar to India, Bangladesh's utility-scale solar and wind power development might be expedited by utilizing land set aside for coal-fired power plants.

The Bangladesh Sustainable and Renewable Energy Development Authority (SREDA) has stated that there are solutions to land constraints. The draft SREDA Roadmap aims for a 30,000 MW high-deployment solar installation program by 2041 [27]. A 25-year lease on property in char (island) areas would help establish a green and clean Bangladesh. This would also help Bangladesh fulfill its 25% renewable energy target by 2050.

SREDA expects rooftop solar to account for 12,000 MW of the 30,000 MW objective [28]. IDCOL (Infrastructure Development Company Ltd.) predicts that 5,000 MW might be put on readymade garment, textile, and other industrial buildings in Bangladesh. Similarly, 2,000 MW of solar power

TABLE VII. ENERGY MIX

Energy Mix-1	1	2	3	4	5	6	7	8	9	10
Types of Fuels	Coal	Gas	Nuclear	F. Oil	Solar	Solar + Storage	Hydro	Biomass	Offshore Wind	Offshore Wind
Percentage Contribution (%)	5	30	5	5	10	10	5	20	3	2
Installed Capacity (MW)	2000	12000	2000	2000	4000	4000	2000	8000	1200	500
Capital Cost ($\frac{\$}{KW}$)	3676	1084	6041	6700	1313	1755	3123	4097	1265	1677
Projected Capital Cost ($ in billions)	7.352	1.3008	1.2082	1.34	5.252	7.02	6.246	3.2776	1.518	1.3416
Fixed O&M Cost ($\frac{\$}{KW-yr}$)	40.58	14.1	121.64	30.78	15.25	31.27	5	125.72	26.34	35.14
Fixed O&M Cost ($ in billions)	0.711	1.4822	2.1311	0.5393	0.5343	1.096	0.0876	8.811	0.277	0.246
Variable O&M Cost $\frac{\$}{MWhr}$)	4.5	2.55	2.37	0.59	0	0	0	4.83	0	0
Variable O&M Cost ($ in billions)	0.711	0.2681	0.0415	0.0103	0	0	0	0.3385	0	0
Interest on Capital Cost ($ in billions) [Projected Capital Cost × 0.1]	0.7352	1.30	1.21	1.34	0.525	0.702	0.625	3.278	0.1518	0.134
Total Annual Capital Cost ($ in billions) [Fixed O&M Cost+ Variable O&M Cost+ Interest on Capital Cost]	1.525	3.051	3.38	1.89	1.0596	1.798	0.7122	12.427	0.4287	0.3804
Annual GWhr Power Generation	14892	89352	16118.4	10512	17170	17170	14892	59568	2733	3644
Per Unit Cost ($) [$\frac{Total\ Annual\ Capital\ Cost}{\text{Annual KWhr Power Generation}}$]	0.102	0.034	0.210	0.180	0.062	0.105	0.048	0.209	0.157	0.104
Heat Rate ($\frac{Btu}{KWhr}$)	8638	6431	10608	6469	0	0	0	13300	9	0
Required Btu in TWhr Generation [Annual KWhr Power Generation× Heat Rate]	128637	574623	170984	68002	0	0	0	792254	0	0
CO_2 Emission ($\frac{lb}{MMBtu}$) (ref)	206	117		117				206	0	0
CO_2 Emission (tons)	12017797	30490185		3608276				74015603		
Total CO_2 Emission Rate ($ in billions) [125$\frac{\$}{tons}$ × CO_2 Emission]	150.22	381.13	0	45.1	0	0	0	925.195	0	0
Environmental Cost ($\frac{\$}{KWhr}$) [$\frac{\text{Total CO2 Emission Rate}}{\text{Annual KWhr Power Generation}}$]	0.101	0.043	0	0.043	0	0	0	0.155	0	0
Per Unit Cost ($\frac{\$}{KWhr}$) [$\frac{\text{Total Annual Capital Cost+ Total CO2 Emission Rate}}{\text{Annual KWhr Power Generation}}$]	0.203	0.077	0.210	0.223	0.062	0.105	0.048	0.364	0.157	0.104
Per Unit Cost ($\frac{\text{USD cents}}{KWhr}$)	20.328	7.680	20.975	22.266	6.171	10.470	4.782	36.393	15.685	10.439
Per Unit Cost ($\frac{BDT}{KWhr}$)	17.482	6.605	18.039	19.149	5.307	9.004	4.113	31.298	13.489	8.978

atop government buildings' roofs has been proposed.

Wind power is a valuable resource. In 2018, the US National Renewable Energy Laboratory found Bangladesh's wind power potential to be substantially higher than expected (NREL).

Small-to-medium-sized renewable energy projects are most effective in rural and remote places where traditional fossil fuel-based energy sources are difficult to reach. Aside from faster building periods, wind and solar power facilities offer for more flexible capacity expansions to meet rising demand.

Wind and solar energy costs would fall in Bangladesh if a concerted renewable energy development effort were made. Moving away from coal and LNG-fired energy can help reduce overcapacity by slowing capacity additions per megawatt (wind and solar plants are smaller than typical coal- and LNG-fired projects).

G. Outcome of this Study

As Bangladesh's indigenous natural gas reserves may be drained by 2031, according to statistics assessing the current reserve-to-production ratio of fossil fuels so Bangladesh's existing energy mix must be modified immediately in order to meet future energy demands and achieve long-term economic growth. Bangladesh must recognize this and change its emphasis to renewable energy sources.

In this work, a comprehensive study of Bangladesh's existing energy environment was offered, taking into account the numerous clean energy resources while also offering an optional energy mix solution for the country's long-term development. To help Bangladesh identify its future analysis of the feasibility indicators of several renewable energy sources was conducted [29].

Every mega project requires a Development Project Proposal (DPP), which is based on a Feasibility Study (FS), which assesses the project's technical and commercial viability. Then the Executive Committee of the National Economic Council (ECNEC) of Bangladesh reviews and approves it (GoB). Like any other planning project, this one required a commercial viability examination.

According to the calculations, Bangladesh's optimal energy mix would include 5% coal, 30% natural gas, and 50% renewable energy (including solar 20%, hydro 5%, biomass 20%, and wind 5%), as well as 5% F. oil and 5% nuclear fuel. This study thoroughly examined the performance matrices of all existing energy supplies, and the findings may pave the way for a long-term sustainable energy solution in Bangladesh's energy market.

TABLE VIII. SUMMARY OF DIFFERENT GENERATION MIX OPTIONS

Options of power generation capacity	Gas	Coal	Fuel	Nuclear	Renewable Energy Sources	Import	Total cost per unit (BDT/kWh) incl environmental cost	Total cost per unit (BDT/kWh) excl environmental cost
Energy MIX-1	30	5	5	5	50	5	13.346	10.41
Energy MIX-2	30	10	10	5	40	5	18.103	15.161
Energy MIX-3	20	25	15	5	30	5	18.285	15.944

Table VIII shows that as the percentage of gas and renewable energy sources decreases in the energy mix, the per unit cost of electricity rises. Energy Mix-1 (calculation) shows how different renewable energy sources (solar, hydro, biomass, and wind) were weighed in proportion to their availability and technical viability in the context of Bangladesh. Energy Mix-2 and Energy Mix-3 (calculations) are attached to as annexure-6.

Table IX demonstrates that hydro is the cheapest renewable energy source, solar is the second cheapest renewable energy source, and gas is the cheapest fossil fuel. The table illustrates two distinct prices for all fuels; one takes into account environmental costs, while the other does not.

TABLE IX. GENERATION COST COMPARISON OF DIFFERENT NON-RENEWABLE & RES PLANTS

Types of Fuels	Capital & operational cost per unit ($/KWh)	Environmental cost per unit ($/kWh)	Total cost per unit (BDT/kWh) incl environmental cost	Total cost per unit (BDT/kWh) excl environmental cost
Coal	0.102	0.101	17.482	8.772
Gas	0.034	0.043	6.605	2.924
Nuclear	0.21	0	18.039	18.039
F.Oil	0.18	0.043	19.149	15.48
Solar	0.062	0	5.307	5.307
Hydro	0.048	0	4.113	4.113

Different RES power plants' capital costs, payback periods, discounted payback periods, Net present value, financial rate of return, and financial benefit cost ratio are shown in Table X to XIII.

TABLE X. SUMMARY OF FINANCIAL ASSESSMENT RESULTS IN THE BASE CASE OF SOLAR PLANT (ANNEXURE-1)

SL	Viability Indicator	Financial
1	Capital cost (incl. O & M cost, cost of fund)	$5252000000
2	PBP	4.134
3	DPBP	5.247
4	NPV (NPV @ 10%)	$8904132059
5	FIRR (FIRR @ 10%)	33.45
6	FBCR (FBCR @ 10%)	1.69

TABLE XI. SUMMARY OF FINANCIAL ASSESSMENT RESULTS IN THE BASE CASE OF HYDRO PLANT (ANNEXURE-2)

SL	Viability Indicator	Financial
1	Capital cost (incl. O & M cost, cost of fund)	$6246000000
2	PBP	6.071
3	DPBP	10.461
4	NPV (NPV @ 10%)	$1365680053
5	FIRR (FIRR @ 10%)	30
6	FBCR (FBCR @ 10%)	1.23

TABLE XII. SUMMARY OF FINANCIAL ASSESSMENT RESULTS IN THE BASE CASE OF BIOMASS PLANT (ANNEXURE-3)

SL	Viability Indicator	Financial
1	Capital cost (incl. O & M cost, cost of fund)	$32776000000
2	PBP	6.135
3	DPBP	25.82
4	NPV (NPV @ 10%)	$664982429
5	FIRR (FIRR @ 10%)	27.72
6	FBCR (FBCR @ 10%)	0.94

TABLE XIII. SUMMARY OF FINANCIAL ASSESSMENT RESULTS IN THE BASE CASE OF WIND PLANT (ANNEXURE-4)

SL	Viability Indicator	Financial
1	Capital cost (incl. O & M cost, cost of fund)	$1518000000
2	PBP	6.126
3	DPBP	26.239
4	NPV (NPV @ 10%)	$16350959
5	FIRR (FIRR @ 10%)	10.11
6	FBCR (FBCR @ 10%)	0.933

H. *Financial Assessment Results*

The financial assessment results reveal that solar plants have the highest FIRR (33.45%), the shortest discounted payback period (5.247 years), and the highest financial benefit cost ratio (1.69) of all the options. As a result, it is believed that solar power is more commercially viable in our country than other renewable energy sources.

The estimated financial indicators reveal that the solar power project has a positive IRR and NPV, and hence is regarded viable in general. Governments invest in such development projects because they believe that investments in the power sector have direct and indirect multiplier effects across the economy, e.g., effective management of power shortages, replacement of expensive fuel-based plants, and the ability to exit from expensive and quick rental power plants.

TABLE XIV. PLANT UTILIZATION FACTOR VS PER UNIT COST (BDT) OF ELECTRICITY

SL	Utilization Factor	Gas	Coal	F.Oil	Nuclear	Solar	Hydro	Biomass	Wind
1	0.85	0.85	6.605	17.482	14.602	19.524	3.059	4.113	31.298
2	0.50	0.5	8.66	23.647	22.241	33.191	5.201	6.992	43.856
3	0.30	0.3	11.989	33.628	34.608	55.318	8.668	11.653	64.189
4	0.05	0.05	53.59	158.39	189.199	331.91	52.01	69.919	318.347

Table XIV shows how underutilized power plants cause an increase in the average unit price of electricity generation of up to BDT 189.199 (in the case of fossil fuels) and BDT 331.91 (in the case of renewables). With such a large expense load, the BPDB will find it increasingly difficult to accommodate its loss and will be forced to seek government assistance. It is critical to investigate the causes of plant underutilization or idleness.

I. *Analysis of the Lowest Cost*

Table XV shows the average cost of production.

TABLE XV. ELECTRICITY GENERATION COST PER UNIT (TK/KWH) IN BANGLADESH

Source	BPDB Plants	Rental/QRP Plants (RPP/QRPP)	Public Plants	IP Plants (IPP)
Gas	3.0	4.0	3.0	3.0
Coal	6.30			
HFO	19.28	9.5-13.0	13.0-16.0	9.0-14.0
HSD	35.84			
Diesel	37.35	23.0-33.0	15.0-32.0	
Solar	10.36-16.11			
Hydro	1.49			
Wind	25.45			

Source: BPDB

Table XV reveals that Hydropower is the most cost-effective option, followed by gas-based generating. The overall economic cost of gas-based generating exceeds the financial cost when the financial cost of gas-based generation is coupled to the economic cost of restricted gas availability and power outages. The next cheapest source of electricity is domestic coal. According to Table 5.20, the most expensive energy sources in 2020 are diesel, HSD, wind and HFO respectively.

The benefits of investing in renewable energy projects, particularly solar power projects, will accrue to Bangladesh through incremental benefits to new customers and increased domestic consumption demand by existing customers as a result of additional supply during specific periods; studying the electricity demand pattern in Bangladesh, it is clear that the peak demand occurs every day between 6 p.m. to 11 p.m. Solar power plants with energy storage systems are now the best answer for fulfilling power demand. The additional supply will replace HFO–based QRPPs in the short term, until 2022, imported LNG–based plants from 2022 to 2025, and imported coal–based power from 2025 onwards in the domestic economy, among other non-incremental benefits from direct resource cost savings.

VI. CHALLENGES AND LIMITATIONS

A large amount of data is required to adequately comprehend the epidemic's consequences and the underlying issues in the electrical industry. This investigation relied heavily on secondary data. Because only a small number of companies have publicized data that can be relied upon. Majority of the power generating companies especially the private sector companies do not want to disclose their business data which being a key factor on the unavailability of primary reliable data being a major constraint of this study.

The study was conducted during the COVID -19 outbreak, and it was limited to using only short-term data. The results of the same analyses performed over different time periods are likely to differ. It is critical to assess the long-term impact of COVID-19 on the electric power industry.

VII. FUTURE SCOPE

The outcomes of this study can stimulate further research into the resilience of power systems with increasing RES penetration. Overall, testing data will help refine scenario-based analysis, leading to more precise planning phases and procedures.

VIII. RECOMMENDATIONS

Due to the unusual scenario, virtually every country's electricity and energy sectors have been hit badly. To keep the power sector working properly, the following procedures must be recognized and implemented swiftly. Figure 30 depicts a summary of the suggested changes.

The following are some suggestions:

- Transmission and Distribution System Improvement: The Power Division must improve the transmission and distribution system immediately.

- Re-estimation of Forecasted Demand: The Power Division requires a re-estimation on future power demand due to slow investment being expected in the post-COVID period. This would aid the power sector plan for the future, with a focus on clean energy.

- Overcapacity reduction: The Power Division should focus on reducing overcapacity. The goal should be to gradually reduce overcapacity as a percentage of total installed capacity. Due to massive overcapacity, both public and private power generation projects must adopt a "go-slow" policy.

- Redirecting the Power Sector towards RES Based Projects: For the public and private sectors, the power division must shift its focus away from fossil fuel-based electricity generation and toward renewable energy generation. In this case, the government could renegotiate with development partners and the private sector. Hydro, solar, wind, roof-top, biomass, and other renewable energy sources may be the future of energy.

- Exit Strategy for QRPPs: The government should develop a clear exit strategy for quick rental power plants. Furthermore, the contract agreement must include sub-clauses governing efficiency level or minimum plant factor maintenance requirement, or the clause "provision of future extension of the contract duration" must be removed.

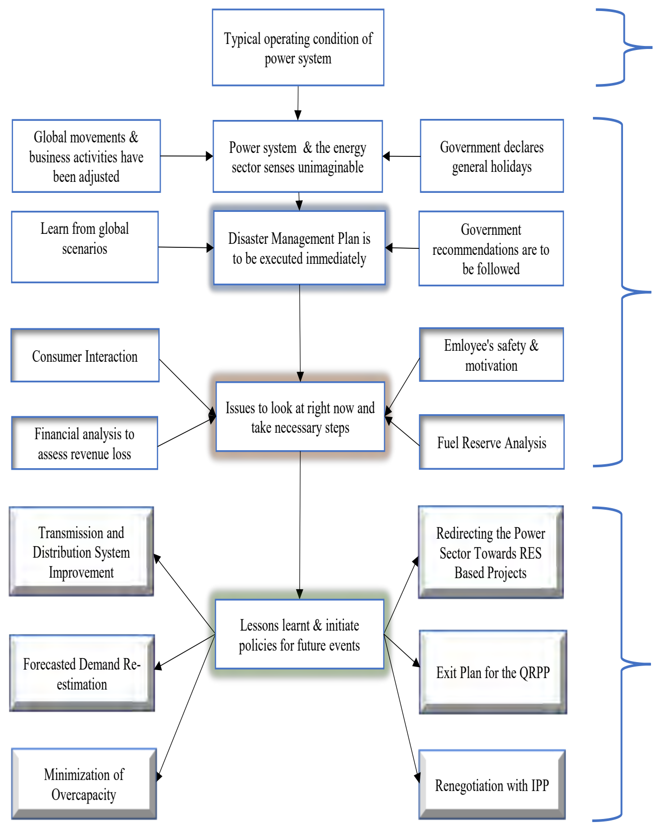


Fig. 30. Flow chart displaying ideas for operational & policy-oriented management of energy & power industry

- Renegotiation with IPPs: Given the shifting power demand, the government should renegotiate with IPPs concerning the terms and conditions for various forms of payments, including capacity payments, energy payments s, especially during COVID-19 and the post-COVID period. The contract between BPDB and IPPs "force majeure' clause can be examined and renegotiated.

IX. CONCLUSION

Bangladesh, like all developing countries, felt the effects of the lockdown. A decline in energy demand coupled with a shift in generation mix and idle peaking power units have put financial strain on the system. Dealing with this in a heavily subsidized power sector as of Bangladesh is challenging.

Meanwhile, the country must examine its power policy and renegotiate with private sponsors, mainly in planned coal and LNG projects, to set more appropriate prices, abolish capacity payments, or insert "force majeure" clauses in contracts while maintaining both sides' interests.

Deploying local gas and focusing on renewable energy sources are also required to reduce power generation costs. Bangladesh also needs to reform its renewable energy policy to attract development partners and private sector finance for mega-projects based on RES.

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