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The COVID-19, power generation and economy – Case study of a developing country

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ABSTRACT

The global COVID-19 pandemic created profound impact on every nation’s economy, education, healthcare, social and cultural life, domestic and international mobility at an unprecedented level. Since the start of the COVID-19 pandemic in early 2020, most nations are undergoing through frequent full or partial lockdowns, resulting in significant economic losses, and unprecedented suffering of hundreds of millions of people worldwide. Given the crucial role of electric power in economic activities, the purpose of this study is to investigate the impact of COVID-19 pandemic on power sector and economy in a developing/emerging country as a case study. The study examined electric power generation and consumption, GDP growth, export, import, remittances, and various government measures undertaken during the COVID-19 pandemic in Bangladesh. Autoregressive distributed lag (ARDL) model was used to investigate correlation between COVID-19 cases and power consumption during full and partial lockdowns. The research revealed a long-run negative relationship between COVID-19 cases and power consumption during partial lockdowns. The study also revealed that the targeted and partial lockdowns accompanied by nation-wide mass vaccination programme can steer the economy along the power sector with minimal or no impact during the COVID-19 pandemic.

1. Introduction

The COVID-19 pandemic has caused unprecedented havoc and disruptions to the economy, public health and life, education, national and international mobility, supply chain and logistics, energy and power, and many other areas of the global ecosystem. As of 11 February 2022, there were over 402 million people infected with COVID-19 and 5.7 million deaths world-wide (World Health Organisation, 2021). Most countries were forced to implement full and/or partial lockdown to slow the virus spread and minimise the fatality. Fig. 1 shows the ratios of infection to population, death to infection, and double-dose vaccination for highly affected 45 countries and 8 less affected countries from Asia, Europe, North America, South America, and Africa (World Health Organisation, 2021; World Population Data, 2021). The figure illustrates that up to 57% of the entire population of some countries were infected with the COVID-19 virus. The pandemic hindered global Gross Domestic Product (GDP) growth in 2020, 2021 and continues hindering in 2022. The GDP growth rates of pre-COVID-19 pandemic in 2019 and during the pandemic in 2020 and 2021 for major developed, emerging and developing nations are shown in Fig. 2. The COVID-19 pandemic induced economic disruption reduced the global GDP growth by 4.4% in 2020 compared to pre-COVID year 2019. This reduction is much higher than the Global Financial Crisis (GFC) in 2009. The GDP reduction was only 0.1% in 2009. The economic data for 194 countries by International Monetary Fund (IMF) showed that only 27 countries’ GDP grew higher than 0% and the remaining 167 countries experienced negative GDP growth (International Monetary Fund, 2020; Bajpai, 2020). The COVID-19 pandemic created a disproportionate impact on world-wide health and economy especially low-income and emerging countries as they have less resources to protect themselves against the dual (health and economic) crisis. The COVID-19 pandemic rendered over 255 million people jobless mostly in South America, Asia, Southern Europe, and Africa in 2020 (US Global Leadership Coalition, 2021; International Labour Organisation, 2021; IMF Briefing, 2020). Developing economies lost at least US$220 billion in income in 2020 and nearly half a billion people were driven to live below the poverty line (1.9 US dollar a day) (UNDP, 2020; Sawada and Sumulong, 2021). It is feared that the COVID-19 pandemic would reverse years of gains in the reduction and alleviation of poverty, thereby undermining global efforts to meet the Sustainable Development Goal (SDG) deadline to eliminate extreme...
The growth of GDP and electric power consumption have a linear correlation for all economies (Zhang et al., 2020; Lu, 2017; Hirsh and Koomey, 2015). Normally, 1% electric power consumption growth can enhance almost 2% GDP growth based on a country’s industrial and economic activities (i.e., intensity of industrialisation and manufacturing, household income, climate condition, access to reliable and quality power and cost, etc.) (Abdoli et al., 2015; Kasperowicz, 2014; Acaravci, 2010). Nevertheless, the relationship between electric power consumption and GDP growth shows a solid (one-to-one) correlation for emerging and developing economies compared to fully developed and matured industrialised nations as less electric power is required to produce each unit of GDP in developed nations (Hirsh and Koomey, 2015). A growing economy needs higher energy and electric power to generate products and services. Thus, the demand for electric power and the rate of economic growth are interdependent. This vital power sector was severely affected by the COVID-19 lockdowns reducing nearly 2% global power demand in 2020 (International Energy Agency (IEA), 2020b). Fig. 3 shows the absolute term power consumption reduction in selected countries in emerging and developing nations in Asia. The relative consumption changes in selected countries for the financial year of 2018–2019 and 2019–2020 are shown in Fig. 4. Three countries (Vietnam, China including Chinese Taipei- Taiwan and Bangladesh) recorded relative positive power consumption (World Nuclear News, 2020; International Energy Agency (IEA), 2020b). All other countries led by Australia, Japan, South Korea, India, and Indonesia experienced significant reductions in relative power consumption during the same period.

Interestingly, till now, there is scant information available on the effect of lockdowns on electric power generation, consumption, and economy in the open literature. It is well established that the reduction of power generation and consumption affects the economic output (i.e., the rate of GDP growth) especially in emerging and developing nations. As our understanding of COVID-19 impact on power generation and economic growth is rather limited due to unavailability of research findings on developing economies, there is a need for research to investigate and understand the impact of COVID-19 pandemic induced full and partial (flexible) lockdowns on power generation, consumption, and economic growth in order to develop strategy, policy, and roadmap to mitigate the impact. Moreover, the emergence of Delta and Omicron variants of COVID-19, and potentially more new variants are expected to continue the havoc as the efficacy of existing COVID-19 vaccines on new and emerging variants is yet to be known and fully investigated. Therefore, the likelihood for full or partial lockdowns are expected to continue. The available reports by the World Bank, IMF and Asian Development Bank and other research organisations indicate that the lockdown causes economic losses more in emerging and developing countries than the developed and high-income nations (Sawada and Sumulong, 2021).

Therefore, the objective of this study is to investigate the impact of full and flexible (partial) lockdowns on electric power generation, consumption and economic activities, and their interrelation through the GDP growth, export, import, and inward remittances for an emerging nation as a case study. The selected country for the case study is Bangladesh. It was one of several countries that experienced positive GDP growth in 2020 (3.5%) and 2021 (5.5%) (Trading Economics, 2022). The study is based on primary and secondary data related to power generation, consumption, economic activities (export, import, remittances). Autoregressive distributed lag (ARDL) modelling was applied to estimate the short term and long-term impacts of COVID-19 on power consumption at different levels of lockdowns (full and partial) imposed in Bangladesh in 2020 and 2021. The following is the study layout: a) power generation and consumption scenario during COVID-19 pandemic, b) ARDL modelling of COVID-19 impact on power and economy during full and partial lockdowns, c) impact of COVID-19 on export, import and remittances, d) discussion of research findings, and e) conclusion and implication of the study.
2. The COVID-19 lockdowns and power generation in Bangladesh

Along with all other countries, Bangladesh has also been experiencing the impact of the COVID-19 pandemic. Bangladesh, a country of 160 million people with an estimated GDP of 330 billion US dollar, has recorded 1,894,535 COVID-19 infections and 28,744 deaths as of 12 February 2022. An infection to death ratio is 1.5 (World Health Organisation, 2021; World Population Data, 2021). To lower the spread and control the pandemic, Bangladesh imposed its first lockdown as ‘general holiday’ from 26 March 2020 to 30 May 2020 shortly after the announcement of first death caused by the COVID-19 virus (Institute for Energy Economics and Financial Analysis (IEEFA), 2021; Sajid, 2021). After the relaxation of lockdown, the economic activities were gradually resumed. However, in 2021, the 2nd lockdown was imposed from 5 April to 11 August to control the second wave of infections by delta variants and minimise the casualties. The educational institutions (schools, polytechnics, and universities) were closed from 26 March 2020 to 18 September 2021 (nearly 18 months long closure). During lockdown periods, the economic activities were disrupted. Numerous industries and commercial spaces were temporarily closed affecting the power generation, consumption and economic activities.

Nearly 99.5% Bangladesh’s population has access to electric power through grid and off-grid connections. Despite the significant power generation capacity increase over the decade, the consumption demand outstrips the generation of power by over 10%. As of 31 December 2021, the installed power generation capacity was 25,235 MW (including captive power) which is 6 times higher than the installed capacity in 2009. Bangladesh is considered an emerging nation as it has witnessed accelerating economic growth in industrial, agricultural and technological sectors with an improving Human Development Index (HDI) over the decades. It may be noted that countries with no appreciable economic growth and HDI improvement are considered developing nations (World Population Review, 2022; Art of Smart, 2022).

To examine the impact of lockdowns on power generation, the monthly power generation in 2019, 2020 and 2021 has been studied here. Furthermore, daily load curves during working days, weekends, full lockdown, and partial lockdown were analysed. The monthly maximum power generation in 2020 was benchmarked against the power generation in other years. The total power consumption was also studied. The daily maximum power generation for 2019, 2020 and 2021 (till September) is shown in Fig. 5. The first COVID-19 lockdown was imposed in Bangladesh at the end of March 2020 which was lasted till early July 2020. The effect of lockdown on power generation is visible from early April to June 2020. During this time, the power generation was reduced. Shutdown of industries, commercial spaces/activities, educational institutions, social, cultural, and religious places attributed to the reduction. A reduction of 40% power generation was found in May and June 2020 compared to the generated power of corresponding months in 2019. The reduction was attributed by the strictly enforced COVID-19 full lockdown and super cyclone ‘Amphan’ (the first super cyclone in the Bengal Sea between 1999 and February 2022). Apart from the reduced generation and consumption caused by the full lockdown, the Amphan also contributed to the reduced power generation and consumption. The power infrastructures (transmission and distribution
systems) in Southern Bangladesh were severely damaged thereby limiting the power supply capability to the consumers. However, the maximum power generation recovered to pre-COVID-19 level from July 2020 once the power supply infrastructures in southern Bangladesh were restored and the full lockdown was withdrawn. It is interesting to note that the maximum power generation and consumption were exceeded by 14% in May and June 2021 when no lockdown was imposed compared to the corresponding months in 2019. The daily power load during full and partial lockdowns, and year before the full lockdown on weekdays and holidays for Dhaka city is shown in Figs. 7 and 8. Dhaka is the capital and largest city of Bangladesh. The city is the country’s largest power consumer. It generates nearly 25% of Bangladesh’s GDP. The days in the graph are chosen in such a manner that the ambient temperatures of those days are similar. The power uses in weekday was reduced by up to 20% at peak hours during the full lockdown period (Fig. 6). The power demand during a day of partial lockdown is substantially higher than that of during the full lockdown, despite these two days are two months apart. It indicates that the strict (full) lockdown had more impact on power consumption than that of the partial (flexible) lockdown. It can also be noted that power demand during daytime on partial lockdown is identical to pre-COVID-19 demand level, indicating the recovery of power demand when lockdown is relaxed or withdrawn.

The power demand in holidays is considerably lower during the full lockdown (Fig. 7). As economic activities were restricted and people were confined at home, outdoor activities including short stay tourism, commercial and community activities and engagement were stopped, the power demand for these activities was reduced drastically. Our initial focus was on the comparison of different daily generations with the previous year. The investigation on monthly maximum generation and daily load clearly indicates that there is an impact of lockdown on power consumption. However, the effect of lockdown on the growth of power usage is a more significant indicator. Therefore, the overall growth of maximum power generation and energy consumption have been investigated to comprehend the impact of lockdown in a broader context.

The monthly maximum generation for 2017, 2018, 2019, 2020 and 2021 (up to September) are plotted in Fig. 8. It is apparent that the
overall power generation has been growing every year from 2017 to 2021. The power generation trend from years 2017 to 2021 depicts that the maximum generation starts to increase from the beginning of the year and decreases at the year-end. But for the year 2020, the maximum generation increases until March and then sharply falls in April due to the strict (full) lockdown. It is also noted that the maximum generation in April 2020 is less than that of the previous month. On the other hand, the maximum generation is nearly 33% more in April 2021 compared to the previous year. Hence, this reduction in power generation is certainly caused by the strict (full) lockdown culminated with the super cyclone ‘Amphan’.

Whilst, as observed from previous year’s data (Fig. 8), the maximum generation increased from March to April. The maximum monthly power generation in 2020 follows a similar trend as 2021, 2019, 2018 and 2017. However, the power generation was higher in October and November in 2020 compared to 2019. This rise is due to higher economic activities occurred immediately after the COVID-19 restrictions were relaxed and higher than normal economic activities took place to recover the losses incurred during the full lockdown.

In Fig. 9, the total and per capita power consumption are shown over a twelve-year period to illustrate the historic trend of power uses in Bangladesh. The power consumption data presented in the figure is determined for the period of 1 July to 30 June of next year. The data indicates that the total power consumption has been increasing steadily. To assess the lockdown’s impact on power consumption, the actual power consumption in 2019–2020 is compared to the power consumption of previous years as well as the power consumption of the following year (excluding captive power generation by industries and off-grid renewable energy).

Despite having grid-connected power access to nearly 99.5% of the population, the per capita power consumption is still low in Bangladesh compared to countries with similar economies, climate conditions and per capita GDP. However, it is evident that the per capita power consumption is progressively increasing with the increase of per capita GDP growth. The Compound Annual Growth Rate (CAGR) is used to determine the annual growth rate as it takes into consideration the fluctuating values over a period. The CAGR formula shown in Eq. (1) incorporates the initial value, final value and number of compounding years and
The CAGR of total power consumption is 9.58% for the last decade. The projected total power consumption for 2019–20 using CAGR value is roughly 67,977 million kwh. Whereas the actual total power consumption of 2019–20 is 63,364 million kwh (Bangladesh Power Development Board, 2021). That implies the actual growth rate between FY 2018–19 and 2019–20 is 2.14%. It is mentioned earlier that the general lockdown came into effect on 26 March 2020. So, for the sake of determining growth rate during the lockdown period, it could be assumed that the growth rate was 9.85% from 1 July 2019 to 25 March 2020 and the actual impact of lockdown on power consumption lies between the period of 26 March 2020 and 30 June 2020 of the fiscal year 2019–20 with the imposition of COVID-19 lockdown. With this assumption, the growth rate of three months (April–June) of 2019–20 financial year is calculated as – 18.42% (Table 1).

The determined loss is shown in Table 2. The bulk rate of power was obtained from Bangladesh Energy Regulatory Commission (BERC) (2021). With the assumptions mentioned earlier, it is found that the estimated loss of revenue from sales of electric power due to 66 days’ lockdown in 2020 is 23,849 million Bangladesh Taka-BDT (equivalent to 281 million USD).

Despite Bangladesh being an energy deficient country, over 60% of its power generation is undertaken by indigenous natural gas and around 35% of remaining power is generated by imported liquid fuel. It also imports power (5%) from neighbouring India. Power generation using different fuel types from February 2020 to December 2020 is shown in Fig. 10 using a 100% stacked area plot. The figure clearly indicates that the power generation by natural gas was highest in the earlier part of the lockdown period. The power import remains constant since June 2020. Coal-based power generation has also remained steady during the larger part of lockdown period, except in late May 2020 when there was a sudden drop in coal-based power production due to scheduled maintenance of the power plant. However, the power generation by all fuel types quickly recovered from late June 2020.

### Table 1

**Estimated growth rate during lockdown period (26 March 2020–30 May 2020).**

| Period                | Days  | Growth Rate (%) | Remarks             |
|-----------------------|-------|-----------------|---------------------|
| 01 July 2019–30 June 2020 | 365   | 2.14            | Actual growth rate  |
| 01 July 2019–25 March 2020 | 268   | 9.58            | Assumed (CAGR)      |
| 26 March 2020–30 June 2020 | 97    | -18.42          | Calculated growth rate during lockdown |

**3. ARDL modelling of the COVID-19 impact**

To examine the effect of COVID-19 imposed lockdowns on Bangladesh’s electrical power consumption, the Autoregressive Distributed Lag (ARDL) model developed by Pesaran et al., (2001) was used for the following three phases:

- **Phase 1:** COVID-19 induced General Holiday and Strict Lockdown (26 March 2020–30 May 2020).
- **Phase 2:** Partial Lockdown to stem the spread of COVID-19 prior to Vaccination Drive (31 May 2020–6 February 2021).
- **Phase 3:** Partial Lockdown with COVID-19 Vaccination Drive (7 February 2021–30 September 2021).

The ARDL model was used because the data sample size was small. When the sample size is small, the ARDL model is effective as it avoids issues with auto-correction and omitted variables. The impact on daily electrical power consumption in GWh (EnCons) has been investigated as a function of independent variables such as daily COVID-19 cases (CovCase), and max. ambient temperature of the day (AmbTem) in the capital city.

As a pre-condition of applying ARDL model, Unit Root Tests have been carried out by using Augmented-Dickey-Fuller (ADF) method to check the stationarity of the variables to avoid having spurious regression results. Each of variables has been tested both for Trend and Intercept. Probability values of the unit root test are given in Table 3.

The unit root tests suggest that all variables are stationary either at level or first difference at 5% level of significance. Hence, all test variables are statistically significant for all three phases of the period and satisfy the precondition of the ARDL model.

The Eq. (2) has been used for ARDL modelling:

\[
\text{EnCons}_{it} = c + \sum_{i=1}^{m} \gamma \text{EnCons}_{i-1} + \sum_{j=1}^{n} \alpha \text{AmbTem}_{t-j} + \sum_{k=1}^{m} \delta \text{CovCase}_{t-k} + \delta X_t + \epsilon_t
\]

In Eq. (2), X comprises the fixed variables and factors that are likely to have influences on energy consumption, and \( \epsilon_t \) is the error term. Model selection method to determine optimum lag of the dependent variable and regressors was Akake info Criterion (AIC). The short-run coefficient and probability of the variables from ARDL model for all three phases are given in Table 4.

The results of statistical test of the model are shown in Table 5. The \( R^2 \) value, adjusted \( R^2 \) value for all three phases indicate that the model is well fitted. The probability of F-statistic is 0.00% for all phases and thus the overall model is significant. The model has also been tested for Stability Diagnostics by using Cusum test and the cumulative sum of the recursive residuals was found within 5% critical line for all three phases. It is apparent from Table 4 that the COVID-19 Cases have negative impact on energy consumption in the short run for both Phase 1 and Phase 2 periods. However, for Phase 3 after the start of vaccination...
drive, correlation with COVID-19 cases and power consumption is not
evident as the result is statistically insignificant. Thus, this model con-

Table 2
Estimated loss due to strict lockdown of 66 days (26 March 2020–30 May 2020).

| Period      | Projected energy consumption (MkW h) | Actual energy consumption (MkW h) | Bulk rate (BDT/kW h) | Projected revenue (Million BDT) | Actual revenue (Million BDT) | Estimated loss (Million BDT) |
|-------------|-------------------------------------|----------------------------------|----------------------|--------------------------------|----------------------------|----------------------------|
| 2019–20     | 67,977                              | 63,364                           | 5.17                 | 351,441                        | 327,592                    | 23,849                     |

![Power Generation Fuel Mix (Feb 2020 to Dec 2020)](image)

**Fig. 10.** Power generation fuel mix from February 2020 to December 2020.

Table 3
Unit root tests results.

| Variables | Phase 1: 26 Mar 2020–30 May 2020 | Phase 2: 31 May 2020–06 Feb 2021 | Phase 3: 07 Feb 2021–30 Sep 2021 |
|-----------|----------------------------------|----------------------------------|----------------------------------|
| Level     | Intercept | Trend & Intercept | Intercept | Level | Intercept | Trend & Intercept | Intercept | Level | Intercept | Trend & Intercept | Intercept |
| EnCons    | 0.0043     | 0.0223            | 0.0000    | 0.8501 | 0.7026    | 0.0000            | 0.0002    | 0.0000 | 0.0000    | 0.0000            | 0.0000    |
| AmbTem    | 0.0045     | 0.0243            | 0.0000    | 0.0079 | 0.0001    | 0.0000            | 0.0000    | 0.0000 | 0.0000    | 0.0000            | 0.0000    |
| CovCase   | 1.0000     | 0.0025            | 0.0150    | 0.9130 | 0.4636    | 0.0000            | 0.0000    | 0.3257 | 0.7590    | 0.0081            | 0.0255    |

Table 4
Short-run coefficient and probability of the variables.

| Variables | Phase 1 | Phase 2 | Phase 3 | Phase 1 | Phase 2 | Phase 3 |
|-----------|---------|---------|---------|---------|---------|---------|
| EnCons (1) | 0.801826** | 0.798685** | 0.422819** | 8.070283 | 22.05807 | 6.768848 |
| EnCons (2) | -0.306639** | – | 0.168410** | -3.220650 | –2.908660 | –2.908660 |
| AmbTem    | 5.558343** | 2.570752** | 4.450293** | 6.471542 | 6.266587 | 8.863096 |
| CovCase   | -0.010243 | -0.006461* | 0.001790 | -1.131437 | -1.979923 | 1.830975 |
| CovCase (1) | 0.024341** | -0.005027 | -0.001711 | 2.479658 | -1.741855 | -1.743068 |
| CovCase (2) | -0.040239** | 5.56E-05 | – | -3.538467 | 0.018974 | – |
| CovCase (3) | -0.019405 | 0.001076 | – | -1.687548 | 0.367265 | – |
| CovCase (4) | – | -0.005263 | – | – | -1.837569 | – |
| CovCase (5) | – | 0.008870** | – | – | 3.790888 | – |

** denotes 1% significance level and * denoted 5% significance level.

Table 5
Statistical test of the model.

| Variables | Phase 1 (%) | Phase 2 (%) | Phase 3 (%) |
|-----------|-------------|-------------|-------------|
| R² Value  | 80.26       | 92.82       | 79.37       |
| Adjusted R² Value | 77.34       | 92.49       | 78.83       |
| Probability of F-statistic | 0.00       | 0.00       | 0.00       |
were persisting, the industrial and commercial demand of power fallen sharply, and the residential loads (mostly ambient temperature sensitive cooling, appliances, and lighting loads) were predominant. Thus, the ambient temperature had strongest correlation with the energy consumption during Phase-1 lockdown.

To estimate the long run relationship between the dependent variable and independent variables, ARDL Long Run Form and Bounds Test were carried out. The results are given in Table 6. From the Bounds Test, it is found that the F-statistic value is higher than I(0) and I(1) at 5% level of significance for each of the Phases 1, 2 and 3. Thus, it can be summarised that there is a long run relationship between the dependant variable and independent variables. Moreover, for both independent variables (AmbTem & CovCase), the probability values are less than 5% and t-Statistics are more than 2 in absolute form and thus the regressors are statistically significant for Phases 1 and 2 but for Phase 3 only the AmbTem is statistically significant but not the CovCase.

Since there is cointegration relationship between independent variable (Power Consumption) and independent variables, Conditional Error Correction ARDL estimations were applied using Eq. (3). Results of Error Correction ARDL estimate are shown in Table 7.

\[
\Delta \text{EnCons}_t = \beta_0 + \beta_1 \Delta \text{AmbTem}_t + \beta_2 \Delta \text{CovCase}_t + \epsilon_t
\]

Where \( \Delta \) is the first difference operator and \( \Delta \text{ECT}_{t-1} \) is the error correction term, which captures the long-run relationship between dependent variable and regressors. The residual series (ECT) analysis for Phases 1, 2 and 3 were estimated and the series were found stationary at level from the unit root test, which also suggest that long run relationship exists.

From the Error Correction Regression, the coefficient of one period lag ECT is negative (between 0 and –1) and the probability value is statistically significant. Hence, the model will adjust towards long run equilibrium. The coefficient of ECT (–1) for Phase 1 is –0.386770 which shows the speed of adjustment towards equilibrium. Here, the speed is 38.68% per unit time; that means 38.68% adjustment per day as daily data is used. Similarly, for Phase 2, the speed towards long-term equilibrium is 16.21% per day and that is 30.0% for Phase 3.

### 4. Effect of COVID-19 lockdowns on export, import and inward remittances

Bangladesh is an export-oriented manufacturing nation. Having over 160 million people, it possesses an abundance of unskilled and semi-skilled labour force. Some excess labour force seeks work opportunities abroad especially in the Middle East, South-East Asia, North Asia, Oceania, Europe, North America, South America, and Africa. At present, over 14 million expatriates from Bangladesh work temporarily and/or permanently abroad, and send remittances, making Bangladesh the world’s 8th largest remittance recipient nation (World Bank Report, 2020). Economic activities such as, inward remittance, export, and import are strongly intertwined in Bangladesh.

#### 4.1. Export, import and inward remittances

In April and May 2020, a significant decline in foreign trades and inward remittances occurred due to strict (full) lockdowns in Bangladesh and its major export destinations in Europe and North America. However, once the lockdowns were lifted in Bangladesh and its export destination countries, the export, import, and inward remittances returned to pre-COVID-19 levels as shown in Figs. 11 and 12 (Bangladesh Bank, 2021; Mahmud, 2021). Despite a decline during the lockdown months, the inbound remittances increased substantially once the lockdown restrictions were withdrawn. Surprisingly, the inbound remittances were higher in 2020 and 2021 than that of the prior years (Fig. 13). Bangladesh and Pakistan are only two countries that received higher remittances during the COVID-19 pandemic (International Monetary Fund, 2020; World Bank Report, 2020; Saeed and Chami, 2020). The reasons for higher remittance flow is due to: a) Bangladesh government’s cash incentives (2%) and fees remediation for remittances sent through legitimate financial systems (i.e., discouraging cross border money laundering and hundi), b) International travel restriction due to COVID-19 made remittance transactions harder through hundi and other illegitimate systems, c) Continuing financial support to families located in rural Bangladesh to minimise their financial hardship. The unskilled and semi-skilled migration patterns in Bangladesh differs from other South Asian countries. Over 85% of 14 million Bangladeshi migrants overseas are from the rural Bangladesh where 65% of the country’s total population (160 million) live. This remittance inflow was critical to keep the rural economy vibrant.

Regarding yearly inward remittances, as shown in Fig. 13, the remittances were increased by 10.9% in FY 2019–20 and further 35.8% in FY 2020–21 despite the global COVID-19 pandemic. A declining trend of inward remittances is noted from June 2021 which is assumed to be a belated impact of COVID-19 as expatriate workers faced a major layoff at different stages of the COVID-19 crisis and informal channel of remittance inflow reopened once the travel restrictions were eased (Mahmud, 2021). The relative drop of inward remittances in 2016–2017 was due to the fall of oil prices in the middle east forced some layoffs where most Bangladeshi expatriates work.

#### 4.2. Export and import

Yearly category-wise export and import performance for the last 12 years are shown in Fig. 14. It is evident that the export of ready-made garment products (Bangladesh’s major export item) was consistently increasing up to FY 2018–19. In FY 2019-20, this vital export sector experienced 10.96% shrinkage due to COVID-19 pandemic. The growth of other export sectors was relatively smaller compared to ready-made garments. Total export in FY 2019–20 was reduced by 11.45% compared to FY 2018–19, whereas in the previous year (2018–19) the growth rate was 8.58%. The lowest monthly export and import were recorded in April and May 2020. The trend of yearly import is akin to export. Total import was growing rapidly from FY 2016–17 up to FY 2018–19 as seen from Fig. 14. The reduction of imported goods was 13.45% in FY 2019–20 compared to 5.77% in FY 2018–19. As Bangladesh economy is export oriented, the import reduction was associated with the export reduction. For the export of ready-made

### Table 6

ARDL Long Run Form and Bounds Test results.

| Variables | Coefficient | t-stat |
|-----------|-------------|-------|
|           | Phase 1 | Phase 2 | Phase 3 | Phase 1 | Phase 2 | Phase 3 |
| AmbTem    | 11.01070** | 5.028819** | 10.88708** | 6.135569 | 3.484681 | 10.35173 |
| CovCase   | -0.090224** | -0.024488** | 0.000194 | -3.562585 | -3.001810 | 0.275439 |

** Statistically significant at 1% level.

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garments, raw materials (e.g., textile articles, cotton, yarn, fabrics, dyeing materials, etc.) and capital machinery are required to import. However, both export and import were increased to pre-COVID level in FY 2020–21 with 12.78% growth in export and 12.0% growth in import once the COVID-19 lockdown is eased. The nation-wide COVID-19 mass vaccination programme was commenced from early February 2021. As of 12 February 2022, over 41% eligible population was fully vaccinated, and national target is to achieve 80% fully vaccinated population by

### Table 7
The Error Correction ARDL estimates.

| Variables   | Coefficient  | t-stat   |  |  |  |
|-------------|--------------|----------|  |  |  |
|             | Phase 1      | Phase 2  | Phase 3 | Phase 1 | Phase 2 | Phase 3 |
| Intercept   | 0.446698     | -0.028063| 0.198370 | 0.219714 | -0.042760 | 0.178191 |
| D(AmbTem)   | 3.779897**   | 2.689609**| 3.983853** | 3.75337 | 6.581791 | 6.838269 |
| D(CovCase)  | -0.012814    | 0.000639 | 0.001146 | -1.378767 | 0.276602 | 1.153004 |
| ECT (– 1)   | -0.386770**  | -0.162110**| -0.300031** | -4.090129 | -5.114907 | -6.680228 |

** Statistically significant at 1% level.

### Fig. 11. Monthly export and import of goods and services from July 2018 to June 2021.

### Fig. 12. Monthly inward remittances from January 2018 to December 2021.
April 2022. With the increase of vaccination rate, it was possible to ease lockdown restriction for resuming full economic activities with certain COVID-19 safety conditions (e.g., social distancing at public places, offices, and wearing mask, etc.).

4.3. Annual development program (ADP) implementation and GDP growth

As an emerging nation, Bangladesh is currently investing in infrastructure development, education, health, and social safety network as part of its annual development program (ADP). The ADP expenditure is a significant determinant of the country’s GDP growth. Last 12 years’ ADP expenditures are shown in Fig. 15 (Implementation Monitoring & Evaluation Division (IMED), 2021). During the initial phase of COVID-19 pandemic, Bangladesh experienced 4.1% shrinkage of ADP expenditures, creating a slowdown in the implementation of development projects. The outbreak of COVID-19 pandemic triggered ‘force majeure clause’ of most contracts for the development projects. During the pandemic, the supply chain was disrupted, optimum labour forces could not be utilised, and there were other direct and indirect impacts for which contractual obligations could not be fully enforced and or/ executed. Consequently, the major development projects were being delayed and ADP implementation was reduced in 2019–20. However, the ADP expenditures increased in 2020–21 by 6%. With the continuing growth of inward remittances (that kept rural economic activities vibrant) and stable domestic agricultural production, Bangladesh achieved 3.5% GDP growth in 2019–2020 and 5.5% in 2020–2021. The rate of GDP growth for three major economies in South Asia, India, Bangladesh, and Pakistan for the last six years, published by Asian Development Bank (ADB), are shown in Fig. 16 (Asian Development Bank, 2021a; Asian Development Bank, 2021b). Bangladesh is the only country in South Asia that achieved positive GDP growth during the COVID-19 pandemic. As per Bloomberg’s COVID-19 resilience ranking, Bangladesh was positioned 17th out of 53 global economies worth over USD 200 billion (The COVID Resilience Ranking, 2021).

5. Discussion

Power generation and consumption, GDP growth, inward remittances, export, and import are interrelated especially for Bangladesh. The power consumption and GDP growth also depend on relative level of development, access to power, industrialisation, economic makeup, and income levels (US Energy Information Administration, 2017). Power consumption plays a crucial role in economic development. Studies undertaken on power consumption and economic growth for developed and developing countries over the period from 1960 to 2020 show a long-run equilibrium relationship and a bi-directional Granger causality between power consumption and economic growth (World Nuclear News, 2020; Saveh and Chami, 2020; Hu and Wang, 2015; Chang, 2010). Generally, an increase of 1% power consumption can boost the annual GDP growth by up to 2% (Bayar and Ozel, 2014; Shahbaz and Feridum, 2012; Nazlioglu et al., 2014). However, the power consumption and annual GDP growth vary between developed and developing countries. For example, countries of the Organization for
Economic Cooperation and Development (OECD) gradually move from manufacturing economies towards service economies. The service-based economies tend to use less energy/power than economies with high levels of industrial activity. Commercial services are less energy-intensive compared to manufacturing. OECD countries with sizable manufacturing are shifting toward advanced manufacturing, which uses energy efficient technologies (i.e., less energy intensive). Therefore, additional economic activity can be generated without requiring high power use in developed industrialised nations. In contrast, emerging nations including Bangladesh use labour and energy intensive technologies for their industrialisation and economic development. Hence their power consumption is relatively higher than industrialised developed countries even with the same annual GDP production.

According to International Energy Agency (IEA2020), the world average sector-wise power consumption: industry – 40%, residential – 30%, commercial and public services – 20%, transport – 2% and others 8% (International Energy Agency (IEA), 2020a; World Bank, 2020). In Bangladesh, the residential sector consumes the highest percentage – 56.4% followed by the industrial sector – 28.4%, commercial and public services – 10.6%, agricultural sector – 2.4% and others – 2.2% as shown in Fig. 9 for FY 2020–21. Comparing Bangladesh with similar per capita nominal annual GDP nations such as India, Pakistan, Uzbekistan, the residential sectors of those countries consume 25%, 42%, 23% respectively compared to the world average of 30% and Bangladesh’s 56.4%. The industrial sector in Bangladesh consumes 28.4% compared to 41% in India, 30% in Pakistan, 40% in Uzbekistan. The per capita GDP and annual power consumption for Bangladesh, India, Pakistan and Uzbekistan are shown in Table 8. The compound annual power generation growth of nearly 10% in Bangladesh since 2010. This growth is mainly driven by the residential sector in rural and urban areas and a lesser extent by the commercial sector. Bangladesh has undertaken massive electrification in rural areas where nearly 65% of its 160 million people live. Power access in rural Bangladesh accelerates economic activities by creating employment and consumption. The power consumption by small industry and cottage industry in rural areas is classified as residential power consumption which is one of reasons for the higher residential power consumption figure in Bangladesh.

Around a decade ago, due to unreliable grid-connected power supply, over 2905 large industries and enterprises in Bangladesh built captive power plants with a generation capacity of 3700 MW. Furthermore, 2389 small industrial units possess captive power plants (less than 1 MW) with approximately 1000 MW generation capacity. The total industrial captive power generation capacity is 4700 MW (i.e., nearly one-quarter of the current grid-connected installed capacity (19,788 MW)) (Sajid, 2021; Bangladesh Energy Regulatory Commission, 2021). Current per capita power consumption does not include the captive power generation and consumption. If it is accounted, the per capita power consumption would increase by another 100 kW h (i.e., 435 + 100 = 543 kW h). Therefore, it is difficult to estimate the impact of COVID-19 on power consumption by industrial sector in Bangladesh. However, most captive power plants in Bangladesh use natural gas to generate power. Monthly gas supplied to captive power plants in 2019,

### Table 8

| Country   | GDP/Person in 2021 (USD) | Yearly power consumption kWh/Person |
|-----------|--------------------------|------------------------------------|
| Bangladesh | 2122                      | 435                  |
| India     | 2191                      | 1100                 |
| Pakistan  | 1260                      | 550                   |
| Uzbekistan | 1750                      | 1700                 |

* Excluding Captive and off-grid solar power.
2020 and 2021 (up to June) is shown in Fig. 17 (Bangladesh Energy Regulatory Commission, 2021; Petrobangla, 2021). Gas supply to these power plants can be considered a reference for the captive power generation. In April 2020, when full lockdown (general holiday) was imposed, the gas supply was decreased by more than 63% compared to the previous month. Many factories were temporarily closed during this time, resulting in a reduction of gas for captive power generation. Gas demand rebounded to pre-COVID-19 levels once strict lockdown was eased (Fig. 17). Apart from three months (April–June 2020) strict lockdown, the economic activities continued as like pre COVID-19 period, boasted by domestic consumption of 160 million people with the government’s timely and targeted fiscal stimulus packages (nearly 22 billion US dollars), and increased inflow of remittances from abroad. Export losses due to COVID-19 lockdown are comparatively higher as the cumulative export dropped by more than 11% in FY 2019–20 compared to pre-COVID-19 period due to the global disruption of supply chain and COVID-19 impact on export destinations. However, the overall foreign trades in FY 2020–21 recovered well with only 2% shortfall, compensated by higher remittance flow and lower import cost. As determined by the ARDL modelling, the number of COVID-19 cases has had a negative influence on Bangladesh’s power consumption in both the short and long run. It is evident that the stringent (full) lockdown has severe effect than the partial or flexible lockdown. During the first phase of lockdown (26 March 2020–30 May 2020), Bangladesh experienced a decline in power consumption, even though COVID-19 cases were relatively low at the time. Power generation and consumption returned to normal as economic activity gradually resumed in the second phase of (partial and or targeted) lockdown, starting on 31 May 2020. Thus, the impact on power generation and consumption was minimal. Finally, during the third stage of partial and flexible lockdown along the nation-wide COVID-19 vaccination campaign, the power generation and consumption were irresponsible to COVID-19 pandemic, despite having more severe Delta variant outbreak, and later contagious Omicron variant occurrence.

Bangladesh with one of the world’s highest population densities per square kilometre area (1265 people/km²) learned and managed well the COVID-19 lockdowns since March 2020 to minimise the impact of COVID-19 on economy and health. It has developed a so called Bangladesh model of lockdowns to advance its economy during the COVID-19 pandemic. The Bangladesh model constitutes the following:

a) Full lockdown was strictly enforced across the nation by engaging all law enforcement agencies including ansar-village defence party, police, border guard Bangladesh, coast guard Bangladesh, and armed forces (army, navy, and air force) to slow down the virus spread and take time to prepare medical facilities including constructing field hospitals and recruiting additional doctors (4000), nurses (6000) and other medical staff (over 3000) to deal with the COVID-19 emergencies. Vulnerable people were provided food and other essentials free of cost. Export oriented industries were given financial support to keep people employed.

b) Flexible and targeted lockdowns were enforced with the nation-wide vaccination campaign to keep running all economic activities. A total of 22 billion US dollar stimulus packages was disbursed to all economic sectors (industrial, agricultural and commercial), vulnerable communities and various professions.

c) Export and import facilities (seaports, river ports, land ports, airports, customs, banks, logistics and transports, etc.) were kept fully functional during full (stringent) and partial (flexible) lockdowns. The medical safety was ensured for all people working in these facilities, processes. These people were vaccinated as per other COVID-19 frontline people. Expatriates were encouraged to remit more money to Bangladesh by providing cash incentives for upholding the domestic consumption and economic activities especially in rural Bangladesh where over 65% population live.

The above-mentioned Bangladesh model directly enabled continuing the power generation and consumption with minimal impact. During the full lockdown period, a small number of industries was temporarily closed. However, the industrial consumption of power was not reduced much compared to commercial and community consumers. During the flexible lockdowns, the power consumption by commercial sector, charitable institutes, community centres, cultural centres, religious worshipping places (mosques, temples, churches, pagodas, etc.), and temporary connections to construction sites was started again. The cumulative power consumption was increased in 2020 compared to 2019 due to the ongoing and new connections to construction sites offsetting the consumption by others within this category throughout the year. Overall, the power consumption in industrial, commercial, agricultural, and other sectors showed an upward trend in 2020–21 and 2021–22 after introducing the flexible and targeted lockdowns.

6. Conclusion and policy implications

The COVID-19 pandemic affected the power generation and consumption in Bangladesh. The severity of impact depended on the type of lockdowns (full/strict or partial/flexible). The full lockdown impacted severely the power generation and consumption. However, the partial lockdown along with the vaccination programme has no or negligible impact on power generation and consumption due to the resumption of economic activity to its pre COVID-19 level.

During the full lockdown, the total power generation and consumption were reduced by 30–40% for a very short time. The commercial sector’s consumption was reduced by 14% which was offset by the increased residential sector’s consumption as the residential sector is the largest power consumer (57%) in Bangladesh.

The COVID-19 pandemic influenced the fuel used in power generation. During the full lockdown, the liquid fuel-based power generation was reduced resulting in lower greenhouse gas emission and the cost of import. However, with the relaxation of lockdown and nation-wide vaccination programme, the liquid fuel use in power generation has progressively been increased with the higher power demand created by economic activities.

The effect of COVID-19 pandemic on rural power consumption and economy is negligible during the lockdown as the production and consumption were remained as pre COVID-19 level thanks to inflow of higher power demand by ex-patriates, higher agricultural production, and government financial stimulus packages. However, the urban population (35% of the total population) is slightly affected due to temporary job losses in informal sectors and some service sectors during the full lockdown period.

Overall, the COVID-19 pandemic reduced Bangladesh’s GDP growth to 3.5% in 2020 and 6% in 2021 from 8.2% in 2019 (prior COVID-19 outbreak). In 2021, all economic indices (consumption, government expenditure, inward remittances, and net export), power generation and consumption have exceeded pre-COVID-19 levels.

The ARDL modelling indicates that the prudent lockdown (flexible and targeted) along with the nation-wide vaccination campaign helped to minimise the COVID-19 pandemic’s impact on power consumption. The targeted, selective, and flexible lockdowns with the vaccination programme and preparation for COVID-19 emergency healthcare services is vital for creating economic confidence and sustainable development.

The policy implication of the case study of Bangladesh is that the full lockdown without the vaccination programme would severely harm the power generation and consumption resulting in significantly lower economic activities and GDP growth. It is especially important for emerging and developing countries as the lower economic activities can push millions of people below poverty line ($1.90 per day). Therefore, the emerging and developing nations can follow the Bangladesh model to minimise the COVID-19 impact on their power generation, consumption, economic activities, and health. As the world-wide mass
vaccination would require several years, therefore, the havoc of various COVID-19 variants (Delta, Omicron, etc.) is expected to continue for many years to come. Hence, the Bangladesh model (targeted, selective, and flexible lockdown with the mass vaccination campaign and financial stimulus support) instead of full (strict) lockdown would be effective way to live the COVID-19 pandemic emergency.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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