Estimating Costs of LNG-based Power Generation and Devising Alternatives Pathways towards Green & Clean Energy

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Acronyms

3P	*Proven, Probable, and Possible*
AIT	*Advance Income Tax*
BACQ	*Base Annual Contract Quantity*
BAPEX	*Bangladesh Petroleum Exploration and Production Company Limited*
BCM/Year	*Billion Cubic Meters per Year*
BDT	*Bangladeshi Taka*
BEPZA	*Bangladesh Export Processing Zones Authority*
BERC	*Bangladesh Energy Regulatory Commission*
BGDCL	*Bakhrabad Gas Distribution Company Limited*
BIDA	*Bangladesh Investment Development Authority*
BOOT	*Build Own Operate and Transfer*
BPDB	*Bangladesh Power Development Board*
CCPP	*Combined Cycle Power Plant*
CIF	*Cost, Insurance and Freight*
CO2	*Carbon dioxide*
COP	*Conference of the Parties*
CVF	*Climate Vulnerable Forum*
EE	*Excelerate Energy*
EEBL	*Excelerate Energy Bangladesh Limited*
EGCB	*Electricity Generation Company of Bangladesh*
EMRD	*Energy and Mineral Resources Division*
ENOC	*Emirates National Oil Company*
EU	*European Union*
FGD	*Focus Group Discussion*
FLNG	*Floating Liquefied Natural Gas*
FO	*Furnace Oil*
FSRU	*Floating Storage Regasification Unit*
FY	*Fiscal year*
G to G	*Government to Government*
GHG	*Greenhouse Gas*
GIIGNL	*International Group of Liquefied Natural Gas Importers*
GOB	*Government of Bangladesh*
GSMP	*Gas Sector Master Plan*
GTCC	*Gas Turbine Combined Cycle*
GTCL	*Gas Transmission Company Limited*
GW	*Gigawatt*
GWP	*Global Warming Potentials*
HSD	*High Speed Diesel*
IDCOL	*Infrastructure Development Company Limited*
IDRA	*Insurance Development and Regulatory Authority*
IEA	*International Energy Agency*
IEA	*International Energy Agency*
IEPMP	*Integrated Power Sector Master Plan*
IFC	*International Finance Corporation*
IOCL	*Indian Oil Corporation Limited*

IPP	*Independent Power Producer*
JGTDSL	*Jalalabad Gas Transmission and Distribution System Limited*
KGDCL	*Karnaphuli Gas Distribution Company Limited*
KII	*Key Informants Interview*
KWH	*Kilowatt Hours*
LCA	*Life Cycle Assessment*
LNG	*Liquefied Natural Gas*
MCM	*Million Cubic Meters*
MCPP	*Mujib Climate Prosperity Plan*
MLNG	*Maheshkhali Liquefied Natural Gas*
MMBtu	*Metric Million British Thermal Unit*
MMcfd	*Million Cubic Feet per Day*
MMscfd	Million Standard Cubic Feet per Day
MRIO	*Multi Regional Input Output*
MSPA	*Master Sales and Purchase Agreement*
MT	*Metric Ton*
MTOE	*Million Tonnes of Oil Equivalent*
MTPA	*Million Tons Per Annum*
NBP	*National Balancing Point*
NG	*Natural Gas*
Nox	*Nitrogen Oxides*
PGCL	*Pashchimanchal Gas Company Limited*
PV	*Photovoltaic*
RE	*Renewable Energy*
RFP	*Request for Proposal*
RLNG	*Regasified Liquefied Natural Gas*
RPGCL	*Rupantarita Prakritik Gas Company Limited*
SANEM	*South Asian Network on Economic Modelling*
SCC	*Social Cost of Carbon*
SDG	*Sustainable Development Goals*
SGCL	*Sundarban Gas Company Limited*
SHS	*Solar Home Systems*
SO2	*Sulphur dioxide*
SOSCL	*Summit Oil & Shipping Company Limited*
SPA	*Sale and Purchase Agreement*
SREDA	*Sustainable and Renewable Energy Development Authority*
Tcf	*Trillion Cubic Feet*
TGTDCL	*Titas Gas Transmission and Distribution Company Limited*
TWh	*Terawatt Hour*
US	*United States*
USAID	*United States Agency for International Development*
USD	*United States Dollar*
VAT	*Value Added Tax*

Executive Summary

The power and energy sector of Bangladesh is currently being challenged by newer obstacles imposing its inherent structural and institutional vulnerabilities despite of notable achievements. Volatility in the global energy market, notably from the Russia-Ukraine conflict, pressures the government budget which is evident from the financial pressure on the BPDB. As domestic gas reserves deplete, leading to plans for expanded LNG imports and infrastructure development, the country becomes more vulnerable to fluctuations in global energy prices. In this situation, a comprehensive assessment of alternatives is crucial for an optimal energy mix. Amidst this backdrop, this report explores and assesses the cost-effectiveness of the available options thoroughly to understand and select the optimal energy mix available for the country.

In terms of energy sources, Bangladesh heavily relies on fossil fuels, with gas accounting for the majority. While the country has potential in solar and wind energy, their contribution remains low, prompting initiatives to expand renewable capacity. Bangladesh's development journey has witnessed a growing demand for electricity in industrial and agricultural sectors, resulting in a significant increase in electricity generation capacity over the past decade. Nonetheless, despite having addressed generation shortages as a blackout cause, load-shedding due to transmission constraints and distribution network overloads remains a frequent obstacle to economic activities. The country has also felt the impact of the recent global energy crisis, which has been further exacerbated by the ongoing dollar crisis within the economy. Even after adding 669 MW in FY2021-22, demand remains unmet due to rapid urbanization and industrialization. Notable issues include high-capacity payments for underutilized coal plants, overcapacity despite idle facilities, and cancelled coal projects amid global trends. The dependence on imported energy, insufficient renewable options, inadequate investment, and burdening subsidies pose further hurdles. Frequent tariff increases, outdated technology, and workforce skill gaps accentuate the sector's complexities.

The global LNG market is witnessing increased demand from both emerging and developed markets, leading to substantial investments in LNG processing and transport infrastructure. Global LNG investments are expected to peak at $42 billion in 2024, driven by the escalating global energy crisis. LNG supply is projected to nearly double by 2030, from 380 million tons per annum (MTPA) in 2021 to about 636 MTPA. Despite fluctuations in LNG trade due to factors like the Russian-Ukraine conflict and COVID-19, Europe's LNG demand surged, impacting global supply and causing price volatility. While the focus on energy security shifts LNG trade patterns, future markets predict varying prices influenced by global events, such as China's energy demand growth.

Bangladesh has been affected significantly by the global energy crisis and global LNG price and supply volatility. Despite attempting to continue imports, the country had to halt at a certain point in 2022, leading to the government's adoption of precautionary load-shedding measures. The escalating reliance on imported fossil fuels for power generation exacerbates energy sector volatility, compounding the nation's fiscal strain and precipitating hikes in fossil fuel prices. The impacts extend to foreign currency reserves and substantial subsidy burdens. Compounded by declining foreign reserves, the feasibility of government-led projects becomes a concern, eroding companies' trust in the state's capability to finance spot market LNG imports. The energy crisis also holds political economy implications, fostering a focus on short-term gains over long-term stability. Consequently, the government faces a heavier subsidy burden, necessitating increased allocation of funds to the power and energy sector. Concurrently, overcapacity issues hinder substantial investments in the renewable energy sector's expansion in the near future.

Given the inherent volatility in the LNG market, it is imperative to evaluate the economic cost of LNG imports for Bangladesh, encompassing both accounting and opportunity costs. The accounting cost was calculated to be 1.43% of the total GDP at constant prices. However, when considering the opportunity cost while the alternative is the existing energy mix, the comprehensive economic cost rises to 2.45% of total GDP at constant prices. If we consider the opportunity cost while the alternative is domestic gas, the economic cost becomes 2.778% of GDP as domestic gas is the cheapest fuel. Our analysis also considers an alternative energy mix proposed in the draft IEPMP, projecting an accounting cost of 8.097% of future GDP in 2030 for predicted LNG use and an overall economic cost of 10.88% of GDP at constant prices. This considerable economic impact of LNG is further supported by the substantial price difference in generating 1 kWh of power. According to our calculations, the LNG cost for Bangladesh is 41.50 BDT per kilowatt-hour, while solar energy costs stand at 12 BDT per kilowatt-hour. Furthermore, our assessment of the social cost of LNG, using the global warming potential method (GWP) and the social cost per unit of emission, reveals this cost to be 0.366% of GDP at constant prices indicating significant environmental impact created by LNG import last year.

Though depleting, the domestic gas resources demand thorough evaluation to understand their actual potential and the challenges impeding exploration efforts. The current gas shortage is expected to worsen in the near future which has led the government to prioritize gas distribution to power plants while cutting back on supply to industries, households, and other sectors. The energy mix is also shifting towards coal and increased import of liquefied natural gas (LNG) to supplement the supply. Despite ongoing gas scarcity, exploration efforts haven't been effective in covering unexplored areas of the country. Predictions indicate a rise in gas demand, with the gas sector's master plan outlining different scenarios involving varying levels of gas use and integration of renewable energy. While some scenarios anticipate less gas use in the power sector, residential and industrial demand is expected to grow. In this demand context Petrobangla and its subsidiaries have proposed long-term gas production scenarios (2016-2041) with variations in forecasts and uncertainties showing steady to slightly declining production from existing fields, with a sharp decline after 2022.The recent data support this declining trend and projected 67% and 76% import dependency in gas sector in 2030-31 and 2040-41 respectively.However, experts' opinions differ to some extent from those of the government bodies. According to them, gas exploration involves three stages: Bangladesh primarily focuses on first step which is working on easily identifiable fields, neglecting other two stages involve studying complex areas. Two-third of the country's total area is lacking sufficient exploration. Offshore exploration lags behind neighboring countries due to offering low gas prices and bureaucratic issues which is prevalent in onshore exploration also. Gas supply to the gas grid faces challenges with a 500-700 million gap between production and demand, leading to under-utilization and pressure issues. The central grid's underutilization results in a significant gas deficit. There is also a cost-effectiveness issue due to low wheeling charge for transmission and significantly higher cost of setting up grid line.

Given the reliability of renewable energies, leading global nations are intensifying their investments in response to ongoing geopolitical uncertainties. In accordance with this trend, presently, the draft IEPMP (Integrated Energy and Power Master Plan) suggests a 40% clean energy composition by 2040, incorporating nuclear, hydro, solar PV, wind, CCS, ammonia, and hydrogen. In contrast, the Mujib Climate Prosperity Plan (MCPP) in 2021 envisioned achieving the same 40% solely through renewable sources.To meet these target requirements, Bangladesh possesses several renewable resources like solar, wind, hydro, biomass, and biogas. Among these, solar power has undergone the most significant advancements. Surpassing all other solar systems, solar parks hold the highest capacity at 2470.66 MWp. Nonetheless, the opportunity cost of solar parks are higher than others as each unit of land has alternative use of food cultivation or housing. Subsequently, rooftop solar systems offer a significant avenue for industrial consumers to tap into idle roof spaces for energy generation. The government's introduction of net metering guidelines to incentivize rooftop solar power has yielded results but still unlocking the full potential of rooftop solar faces challenges such as the absence of domestically manufactured high-quality solar inverters, high import duties on inverters, inadequate testing facilities, the prevalence of sub-standard solar accessories, and information asymmetries concerning promotional schemes. Another substantial renewable energy initiative is solar irrigation contributing to the uninterrupted supply of electricity ensuring continuous water availability. With the World Bank assistance, IDCOL and other government bodies deploying solar PV-based irrigation systems in regions with the potential to cultivate three types of crops year-round with a target to install 10,000 solar irrigation pumps by 2030. Among small scale solar projects Bangladesh's Solar Home Systems Program faced challenges due to grid expansion, quality issues, and parallel projects while the off-grid mini-grid has made significant progress.

Bangladesh's wind energy potential is significant, exceeding prior estimates, with over 20,000 km2 of land showing a gross wind potential of 30,000 MW at wind speeds of 5.75–7.75 m/s. The coastal regions, notably Bay of Bengal, Kuakata, Sandwip, and Saint Martin, offer the highest potential, especially at hub heights of 140-160 meters. The government has initiated wind power projects, including a 55 MW plant in Mongla and a 60 MW project in Cox’s Bazar. The Bangladesh Power Development Board (BPDB) is advancing grid-connected and hybrid wind power plants, emphasizing coastal areas with a 724 km coastline. Ongoing repairs and enhancements are underway for the existing 900 kW grid-connected Wind Power Project at Muhuri Dam and the 1000 kW Wind Battery Hybrid Power Project at Kutubdia in Bangladesh. Further analysis is needed for efficient wind turbine electrification. According to key-stakeholders, nine potential land areas in Bangladesh, including Chittagong - Cox's Bazar, are identified for wind turbine installation, with a critical 60 MW plant under construction. Future wind power success relies on achieving a minimum yearly average of 20% output and securing external funding for Bangladesh to potentially reach to 17,000 MW wind power generation by 2050, predicted by the academicians though the BPDB predicts a more conservative 500-600 MW capacity without additional funding.

Bangladesh, despite its riverine landscape, faces limitations in harnessing hydroelectricity due to geographical and geopolitical factors. Collaborative studies have identified limited opportunities for small-scale hydro projects, urging comprehensive feasibility assessments. The nation's hydroelectricity production is comparatively low, hindered by administrative barriers like land acquisition complexities and equipment costs. While exploring diverse renewable sources like biofuel and geothermal energy, Bangladesh's transition to renewable energy encounters challenges needing strategic solutions.

Challenges like inefficient load management and limited renewable capacity hinder progress towards ambitious renewable energy targets. The current approach of adopting Independent Power Producer (IPP) plan involves private entities establishing renewable projects, leading to mixed outcomes due to funding and land acquisition issues. Feasibility studies are crucial, particularly for sites identified in long-term plans. Solar energy stands as a cost-effective electricity source, with its potential to meet Bangladesh's energy demands. Despite the country's substantial solar resources, solar energy utilization remains under-optimized, with a mere 500MW produced against a potential of 3500MW. Efforts to integrate renewable facilities in economic zones and utilize unused lands reflect steps towards advancing the renewable energy landscape.

The failure in achieving the Renewable Energy Policy's target of 10% renewable energy by 2021 stem from multifaceted challenges. Land scarcity, competition with cost-effective alternatives, and concerns regarding nighttime solar power availability and grid stability hinder progress. Current renewable energy generation accounts for 6% of peak capacity and merely 4% of overall capacity. A proposed solution involves allocating a portion of arable land for solar projects, striking a balance between energy and food security. Battery storage, crucial for renewable energy, faces space and cost limitations. Moreover, the challenge of surplus solar energy impacting base-load power plants requires meticulous demand analysis and system optimization. Fully transitioning to 100% renewable energy proves impractical in Bangladesh due to costs and nighttime usage constraints, making grid enhancements essential to maximize the output.

On the basis of the cost estimation, comparison and energy sources’ analysis our study suggests that Bangladesh's pursuit for energy security amid frequent power outages need a strategic shift. The vulnerabilities of imported fossil fuels underscore the need for self-reliance. A focus on domestic gas exploration is necessary to curtail costly LNG imports, while uncharted deep offshore exploration holds untapped potential. About renewables, harnessing Bangladesh's abundant 4.5 hours of daylight efficiently and tapping into wind resources can significantly reduce load shedding and reliance on fossil fuels, aligning with clean energy goals. Comparing LNG and solar investments reveals solar power’s long-term cost-effectiveness and environmental advantages. Furthermore, repurposing inefficient plants into solar facilities could alleviate financial burdens and aid workforce transition. To incentivize solar, exemptions on accessories, enhanced quality checks, and expanded rooftop solar installation capacities are vital. Formulating a comprehensive funding roadmap and aligning policy plans with short-term goals can accelerate renewable energy projects. Smart grid implementation, subsidies shift, and public financing collaboration emerge as key strategies, while feed-in-tariff schemes encourage distributed energy production. Bangladesh's energy security journey requires a multifaceted approach anchored in policy alignment, financial commitment, and embracing renewables

1. Introduction

The power sector holds immense significance within the economy of Bangladesh, serving as an indispensable cornerstone for overall development and growth. It plays a crucial role in the economy as it is closely linked to several other sectors and contributes significantly to overall economic growth and development. The sector has undergone significant transformation and expansion over the years, contributing immensely to the lives of its citizens. Over the last decade, both the installed capacity and maximum generation have risen almost by three folds (Bangladesh Economic Review, 2023). Bangladesh has made substantial progress in expanding its power generation capacity and improving access to electricity by almost 100%. Concurrently, the reduction in electricity system losses of approximately 7.78% (Power Cell, 2023) and the notable enhancement of system reliability, as indicated by fewer and shorter outages, have been other noteworthy achievements. Despite these achievements, the momentum of reform has decelerated in recent years, and the sector now confronts newer challenges that have confronted it with underlying structural and institutional weaknesses. In order to prepare for the future, Bangladesh must undertake further reforms, addressing these weaknesses and instigating structural changes within the electricity system.

Bangladesh, with a primary fuel import-dependent energy and power system, relies heavily on natural gas as the primary fuel source. It uses more than half of the electricity generated by domestic natural gas and imported Liquefied Natural Gas (LNG). The rest of the power generation is sourced from coal, diesel, furnace oil, hydro, solar and power import (BPDB, 2022). According to Bangladesh Economic Review (2023), the overall power capacity of the country has increased by 1000 MW in FY 2023 than FY 2022, representing an increase of 4.45% over the previous year. Power generation in total rose by 6.45% than the previous year. The distribution system loss has been mentioned to fall by 0.40% but that couldn't help the net earning as 32.33 billion net loss occurred. In fact, last year's net profit was only taka 1.29 billion (BPDB, 2022) which indicates that the net earning condition in the previous year was not favourable either. A large amount of government subsidy was required to avoid a net loss. With BPDB's financial sustainability under growing pressure, it looks likely that the tariff on imported coal, oil, and LNG will continue to grow, which in turn, will put a burden on households and firms. Moreover, the international primary energy market is gradually being highly volatile, especially due to the Russia-Ukraine war last year. As a result, the high cost of primary energy in the international market has created tremendous pressure on the government budget.

Bangladesh has increasingly relied on liquefied natural gas (LNG) for power generation for the last few years, marking a significant shift in its energy landscape. With the initiation of LNG import in 2018, the current LNG import supplies around 22% of the total gas supply to the national gas grid (BERC, 2022). The domestic natural gas reserve has been claimed to be depleted completely within 11 years (TBS, 2022). This fuel crisis will induce further LNG import expansion according to the existing proposals and on-going development of LNG infrastructure. There are concerns that Bangladesh's power capacity overexpansion, along with growing reliance on LNG imports is jeopardizing the financial sustainability of the country's power system. Bangladesh's heavy dependence on imported LNG has exposed the country to significant vulnerabilities in the face of global energy prices and supply disruptions.

This vulnerability materialized in 2021 and 2022 when global LNG prices skyrocketed due to events such as Russia's reduction in gas exports to Europe and its subsequent invasion of Ukraine.

In contrast, Bangladesh, being one of the signatories of the Paris Climate Accord, is committed to reducing carbon emissions. The country holds the Presidency of the Climate Vulnerable Forum (CVF), a 48-nation platform mandated to attain 100% Renewable by 2050. Also, certain SDG goals are exclusively focused on energy transformation towards green and clean. Therefore, with global momentum shifting away from coal-fired power plants, Bangladesh's government cancelled 10 coal-fired power plants in 2021. Some of these cancelled projects were intended to be switched to LNG-based plants. Furthermore, to adjust to the shortage of gas supply, Bangladesh plans to rely on LNG imports more.

However, to attain an energy transformation towards green and clean, a milestone policy document was unveiled by the government titled “Mujib Climate Prosperity Plan (MCPP)” during COP-26. MCPP sets an ambitious renewable energy (RE) target as the most remarkable announcement was made by the Prime Minister during the same event that called for attaining the RE target of 30% by 2030 and 40% by 2041 in power generation. Afterwards, the 40% renewable energy target has been replaced by a 40% clean energy target including nuclear power plants and other clean resources like hydrogen and ammonia with renewable sources.

Against this backdrop, this study aims at exploring a sustainable pathway towards green and clean energy for Bangladesh. In particular, given the country’s heavy reliance on LNG and particularly on imported LNG, it is important that the available alternatives are duly explored and evaluated for understanding and choose the best energy mix available for the country. Through a critical analysis of alternative energy sources, this study, in particular aims at (i) estimating the economic and financial costs of reliance on LNG imports and their implication for the economy and (ii) exploring alternative pathways to LNG imports, especially renewable energy, to have a better understanding of Bangladesh’s comparative advantage in this regard.

We know that the Government of Bangladesh (GOB) is currently finalizing the new Integrated Energy and Power Master Plan (IEPMP) and in this connection, this research is expected to help the review process and thereby will promote green and clean energy strategies. To steer public perception and policymaking toward the adoption of renewable energy, robust empirical investigation based on evidence is essential. Moreover, advocacy with regional and international partners with regard to external financing of green and clean energy will require sound rationale with country-level economic analysis, to which this research work can make an important contribution.

2. Methodology

The study consists of three integral parts. First, a comprehensive desk review provides an overview of Bangladesh's power and energy sector. Second, a total of 11 KIIs were conducted to understand the challenges and potentials of the country's gas, LNG, and renewable energy sector. Third, an FGD was conducted to understand the feasibility and prospects of a sustainable pathway for Bangladesh's energy transformation towards green and clean energy.

2.1 Desk review

We conducted a comprehensive desk review to present an analysis of the LNG, domestic gas, and renewable energy sectors. The government documents regarding respective sectors have been reviewed thoroughly to understand the policies and analyse the data. The annual reports of the government bodies such as Rupantarita Prakritik Gas Company Limited (RPGCL), Petrobangla, Bangladesh Power Development Board (BPDB) Academic paper, Bangladesh Energy Regulatory Commission (BERC), Gas Transmission Company Ltd (GTCL), Power Division, Integrated Energy and Power Master Plan, Draft (IEPMP) and Sustainable and Renewable Energy Development Authority (SREDA) were reviewed. Also, academic research papers, journals for the energy sector, and newspaper articles were investigated to explore different alternative views of the sector. As our core purpose was to estimate the cost of LNG in Bangladesh, we went through some cost analyses available, too. A review of all these studies helped us shape the sector analysis and cost estimation.

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2.2 Key informant interviews (KIIs) & focus group discussions (FGDs)

We have consulted relevant stakeholders and gathered their opinion through Key Informant Interviews (KIIs) and Focused Group Discussion (FGD). We targeted to make eleven KIIs from the relevant sector (Table 1) and one FGD with a group of relevant experts. The timeline for conducting these research tools was from September 2022 to July 2023. Resource persons and industry insiders have been considered for the stakeholder consultation.

Table 1: Tentative list of the KIIs

Name of key informants	Number of KIIs
RPGCL	1
Power Division	1
SREDA	1
BERC	1
Gas Transmission Company Limited (GTCL)	1
Energy Experts	6
Total	**11**

Source: Authors' compilation

Resource persons and industry insiders were considered for the stakeholder consultation. The FGD is the extension of the in-depth interview of the KIIs. It helps to reach a consensus, verify consistency, and validate generalizations. The goal of stakeholder consultation is to inform policymakers about the outcomes of evidence-based research. Step-by-step plans were followed for the implementation of both the KIIs (Figure 1) and FGDs (Figure 2).

Figure 1: KII implementation plan

- Gathering and reviewing existing data
- Determining what are the gaps in the existing information
- Choosing key informants based on information need
- Identifying the type of interview (in-person/video)
- Developing the interview checklist
- Conducting the KII
- Compile, organise and analyse the KII data

Source: Adapted from Data, advocacy and technical assistance, UCLA Centre for Health Policy Research

Figure 2: FGD implementation plan

- Identify goals or objectives
- Identify questions
- Identify people (participants and moderators)
- Select time, place/environment
- Conduct research
- Evaluate findingds or data
- Report

Source: Adapted from Omar (2018)

3. An Overview of the Power Sector of Bangladesh

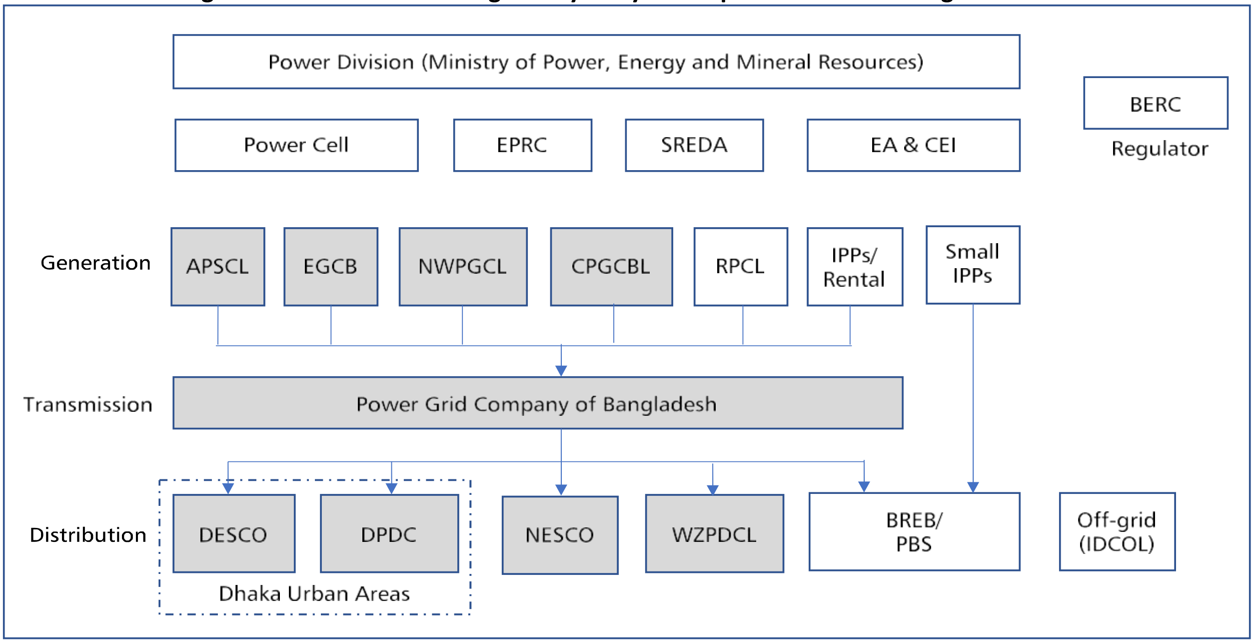
3.1 Structure of the power sectors

Bangladesh, on its path to the development process, has witnessed an exponential surge in the need for electricity across various industrial and agricultural domains. Over the past decade, electricity generation capacity has increased significantly. However, load-shedding due to transmission bottlenecks and distribution network overloads is still a common occurrence and a significant impediment to economic activity, despite the elimination of generation shortages as a cause of blackouts. The country has not remained unaffected by the recent global energy crisis, either. Furthermore, the energy crisis has been intensified by the prevailing dollar crisis in the economy.

Nevertheless, the government of Bangladesh has been aiming to achieve ambitious targets in the power sector to attain the development it promised. To prepare for a population of 200 million or more by 2050 and to achieve the national goal of developed country status by 2041, the government has aimed to construct 60 gigawatts (GW) of new generation by 2041, which is three times its current nominal installed capacity and five times its current average available capacity (ADB, 2020). The PSMP 2016 has undergone a comprehensive review and update in 2016, aiming to achieve a net generation capacity of 79,500 MW by the year 2041 to meet the peak demand. To achieve this goal, an investment of $193 billion is imperative for the development of generation, transmission, and distribution infrastructure by 2041, as per this revised version (Power Division, 2018).

The Ministry of Power, Energy, and Natural Resources (MPENR) and several state-owned corporations tend to manage the energy and electricity sector in Bangladesh in a highly centralized manner (Figure 3). The MPENR consists of two divisions: the power division and the energy and mineral resource division. The Energy and Mineral Resources Division of the MPENR is responsible for oil and gas, while PetroBangla is the primary state oil and gas operator under this division. On the other hand, the power division is responsible for only the generation, transmission and distribution of power. Under power division, there are four cells: power cell, EPRC, SREDA and EA & CEI. BPDP is the "single buyer" in Bangladesh's electricity infrastructure. It purchases electricity from generators and sells it to urban distribution companies and Bangladesh Rural Electrification Board (BREB) cooperatives, although BPDB has not been able to pass on the complete cost of electricity to distribution entities. The establishment of the Power Grid Company (PGC) of Bangladesh in 1996 occurred to run the high-voltage transmission system followed by the partial unbundling of the system in 1995. Bangladesh has established two energy regulatory agencies: the Bangladesh Energy Regulatory Commission (BERC), which was founded in 2003 to oversee tariffs and operations in electricity, gas, and oil; and the Sustainable and Renewable Energy Development Authority (SREDA), which was founded in 2014 to promote renewable energy and energy efficiency (ADB, 2020).

Figure 3: Structure of the regulatory body of the power sector in Bangladesh



Source: Power Cell and (ADB, 2020)

In the fiscal year 2020-21, the total grid-based installed capacity was 22,031 MW, including 10,146 MW in the public sector, 1,244 MW in Joint Venture (JV), 9,483 MW in the private sector, and 1,160 MW from India's cross-border power-trade. In FY 2021-22 (up to January 2022), the total grid-based installed capacity was 22,066 MW, including 9,996 MW from the Public Sector, 1,244 MW from joint ventures, 9,482 MW from the Private Sector, and 1,160 MW from India which is around 5.26% of the total installed capacity. Up until January 2023, the collective capacity of grid-connected installations stands at 23,482 MW, comprising 10,246 MW within the Public Sector, 1,861 MW as Joint Ventures, 10,215 MW from the Private Sector, and an additional 1,160 MW imported power from India. In the area of natural gas, the installed capacity is near to half of the total, around 49.07%. Furnace oil has the second-largest installed capacity of 26.95%. Bangladesh has still the lowest installed capacity from renewable energy (Figure 4) (Bangladesh Economic Review, 2023).

Total net generation from public and private sector power plants was 42,395 MkWh in FY 2021-22 (up to December 2021) where 40.02% of total net generation was produced by public sector power plants, 47.39% by private sector power plants, 4.10% by JV power plants, and 8.50% by power import. Gas accounted for 60.44% of fuel-based electricity generation, liquid fuel for 24.33%, imports for 8.50%, coal for 5.31%, hydropower for 1.14%, and renewable energy for 0.29%. During the fiscal year 2022-23 (up to December 2022), the net power generation composition stood as follows: 39.89 % originated from public sector power plants, 7.83% from JV power plants, 42.26% from private power plants, and an additional 10.02% from imported power sources. Among the comprehensive grid-based generation, the breakdown was: 50.32% gas-based, 9.87% coal-based, and 28.11% liquid fuel-based, 10.02% imported electricity, and 1.69% harnessed from renewable sources (Figure 5) (Bangladesh Economic Review, 2023).

Figure 4: Installed capacity by fuel type (2022-23)

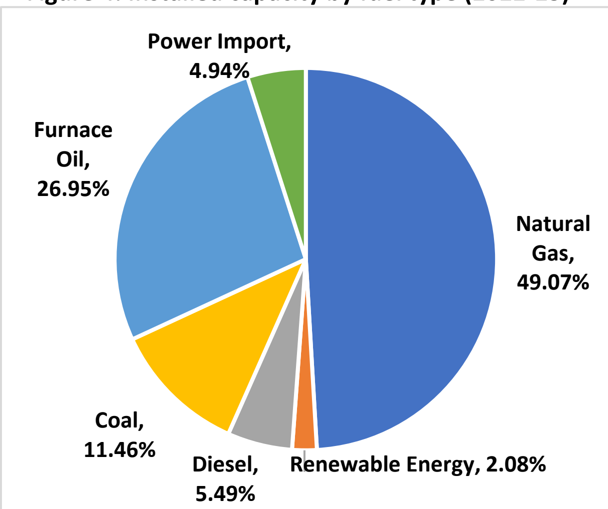
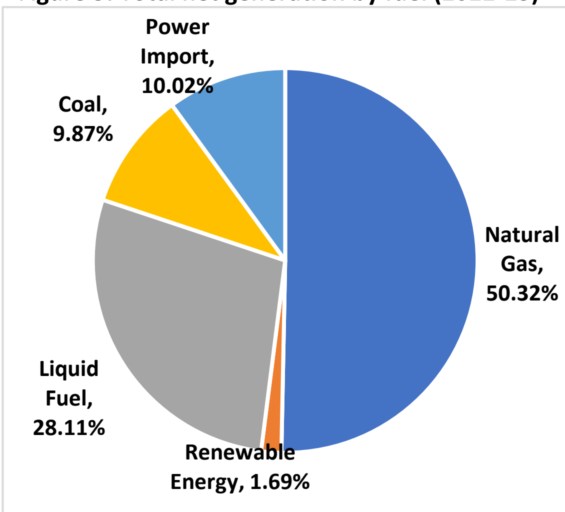


Figure 5: Total net generation by fuel (2022-23)



Source: Power Division (Up to December 2022)

The electricity generation in Bangladesh is highly dependent on fossil fuels. Since the start of the twenties, to generate electricity above 90% of fossil fuels have been required and the rate of usage of fossil fuels in this process is constantly increasing till now (up to 2022). Both domestic and imported fossil fuels play a significant role in Bangladesh's energy production. In 2022, more than 98% of all energy production originated from natural gas, oil, diesel, and coal (Figure 4 & Figure 5). Less than 2% of the energy mix is low-carbon. Among the fossil fuels, natural gas and coal are mostly used in the generation of electricity. Bangladesh relies largely on heavily subsidized domestic sources of natural gas (61% of total generation), which are diminishing. The government of Bangladesh intends to decrease reliance on domestic natural gas due to depleting gas reserves while increasing LNG imports. Also, the country continues to rely heavily on gas (59%) to meet its expanding demand, but coal's share in the power mix also grew in recent years (3% in 2015 to 15% in 2022) (Ember, 2023).

From Table 2, it can be seen that there is almost a 70% increase in the usage of gas in electricity from 2000 to 2020. The usage of gas since 2000 has an upward trend in generating electricity though the rate has decreased in 2022 than 2021 in response with gas shortage. But, the decreased use of gas has put pressure on the usage of coal and other fossils like petroleum. In 2022, the percentage of coal and other fossil-generating electricity has been higher than the previous year.

As of FY2022-23, the renewable energy sector in Bangladesh remains relatively underdeveloped. Figure 5 illustrates that the net generation from renewable sources accounts for only 1.69% of the total. Notably, the majority of this share primarily derives from hydro-power sources. Despite Bangladesh's ample river resources, the potential for hydropower generation falls short due to the absence of high head and high flow rates. Over time, the proportion of hydroelectricity in the overall electricity generation mix has dwindled, mainly due to limitations in capacity. Although there has been a notable increase in total electricity generation, the capacity of hydropower plants has remained stagnant. Consequently, the contribution of hydropower to the country's electricity generation has decreased as overall power generation has risen. Bangladesh is still in its emerging stages concerning the utilization of solar and wind energy, with less than 1% of the nation's electricity being sourced from these renewable options as of 2022. The country embarked on its journey to harness solar and wind energy for electricity generation as early as 2006. However, over the period from 2015 to 2022, the country's contribution to non-fossil energy generation declined from 3% to 2%. In stark contrast, the average across Asia during the same period increased significantly, rising from 24% to 32%. Bangladesh now maintains the smallest share of renewable energy among South Asian nations, in comparison with its neighbors such as Pakistan (43%), Sri Lanka (38%), and India (22%) (Ember, 2023).

Table 2: Bangladesh electricity generation by source (%)

Year	Fossil	Gas	Hydro	Clean	Bioenergy	Coal	Other Fossil	Solar	Wind	Wind and solar	Nuclear	Other Renewables
2000	93.68	40.28	6.32	6.32	0	0	53.4	0	0	0	0	0
2001	94.02	46.43	5.98	5.98	0	0	47.59	0	0	0	0	0
2002	94.04	51.14	5.97	5.97	0	0	42.9	0	0		0	0
2003	93.97	51.1	6.02	6.02	0	0	42.87	0	0	0	0	0
2004	94.8	51.55	5.2	5.2	0	0	43.25	0	0	0	0	0
2005	94.8	51.55	5.2	5.2	0	0	43.25	0	0	0	0	0
2006	95.25	50.09	4.72	4.75	0	4.85	40.31	0.03	0	0.03	0	0
2007	97.4	53.1	2.53	2.6	0	4.76	39.54	0.07	0	0.07	0	0
2008	97.03	52.91	2.91	2.97	0	4.73	39.39	0.06	0	0.06	0	0
2009	98.66	53.81	1.25	1.34	0	4.82	40.03	0.09	0	0.09	0	0
2010	97.82	55.44	1.97	2.18	0.03	4.55	37.83	0.18	0	0.18	0	0
2011	97.63	55.33	2.21	2.37	0.02	4.25	38.05	0.14	0	0.14	0	0
2012	97.97	53.97	1.79	2.03	0.04	3.95	40.05	0.2	0	0.2	0	0
2013	97.8	56.61	1.88	2.2	0.06	3.7	37.49	0.26	0	0.26	0	0
2014	98.46	58.36	1.18	1.54	0.06	3.59	36.51	0.3	0	0.3	0	0
2015	98.51	65.61	1.06	1.49	0.05	2.95	29.95	0.36	0.02	0.38	0	0
2016	98.04	68.65	1.56	1.97	0.05	2.62	26.77	0.34	0.02	0.36	0	0
2017	98.09	72.14	1.49	1.9	0.04	2.31	23.64	0.36	0.01	0.37	0	0
2018	98.1	72.27	1.46	1.89	0.04	4.39	21.44	0.38	0.01	0.39	0	0
2019	98.56	74.92	0.97	1.44	0.04	4.02	19.62	0.42	0.01	0.43	0	0
2020	98.28	68.23	1.16	1.73	0.04	12.59	17.46	0.52	0.01	0.53	0	0
2021	98.28	69.94	1.09	1.72	0.04	11.87	16.47	0.58	0.01	0.59	0	0
2022	98.05	60.54	1.14	1.95	0.04	14.31	23.2	0.76	0.01	0.77	0	0

Source: Ember's analysis of Bangladesh's annual generation and electricity demand data[1]

3.2 Major challenges

Bangladesh has made substantial progress toward achieving the development objectives specified in Vision 2021 and Vision 2041. According to experts, energy is integral to this development voyage. In addition to the standard reform policies, such as institutional restructuring and pricing reform, the government has announced a number of noteworthy policies during this time, such as welcoming privately owned quick rental power plants in 2010, developing the Mineral Resource Development Act in 2012, implementing the Power System Master Plans of 2010 and 2016, establishing a nodal agency for renewable energy development, and introducing the Gas Sector Master Plan in 2017 (Amin, 2023). But there is a debate that all the policies are not aligned to the same level.

Accordingly, the issue of balancing the supply and demand for electricity has remained mainly unresolved for many years. Failure to adequately manage the load when generating and distributing electricity results in extensive load shedding, which disrupts industrial production and other economic activities significantly. Approximately 669 MW of power have been added to the grid in FY2021-22 (Power Division), but the demand and supply imbalance has

[1] https://ember-climate.org/data/data-tools/data-explorer/

remained unchanged due to the increased demand for power resulting from rapid urbanization and industrialization.

The following challenges are prevalent in the power sector which have become subjects of widespread debate and discussion currently:

- Since 2022, Bangladesh has been struggling with an enduring energy crisis, which emerged shortly after the ambitious announcement of achieving 100% electricity coverage for its population. The volatility of global liquefied natural gas (LNG) prices, triggered by Russia's invasion of Ukraine in 2022, has profoundly impacted the nation. Faced with this tumultuous market, Bangladesh was compelled to slash its fossil fuel imports and implement precautionary load shedding measures due to the surging international fossil fuel prices. Interestingly, the months of May and June 2022 enjoyed respite from load shedding, but the situation took a drastic turn in July when evening load shedding during peak demand surged to an astonishing 2,385 megawatts (MW) (Alam, 2023). Bangladesh had to deal with 113 days of power cuts in 2022 and an additional 114 days within the first five months of 2023 (Reuters, 2023). Furthermore, in 2023, the global fuel crisis and a dollar shortage made it arduous to open letters of credit (LCs) for fuel and coal imports, leading to a 20-day shutdown of the critical Payra power plant. This advanced facility, equipped with ultra-supercritical technology, had played a pivotal role in managing the power crisis, supplying over 1,000 MW of electricity daily during the preceding months (The Financial express, 2023). Bangladesh continues to navigate these complex challenges in its pursuit of a stable and sustainable energy future.

- The BPDB's weak financial condition is underscored by a substantial net loss of 32,327 million taka. This precarious financial situation can be attributed in part to extensive investments in power generation, both in the public and private sectors. The fragility of BPDB's financial performance is exacerbated by the high per unit cost of electricity, coupled with overcapacity charges. Notably, the per unit purchase price of electricity has seen an uptick in both the public and private sectors. In the public sector, the purchase price has risen from Tk 4.29 kWh in 2021 to Tk 4.75 kWh in 2023, while in the private sector, it surged from Tk 8.02 kWh in 2021 to a staggering Tk 11.55 kWh in 2022. Furthermore, for purchases from rental sources, the price escalated to Tk 9.80 kWh from Tk 7.47 kWh (BPDB, 2022). These changes have placed additional financial strain on the BPDB.

- One of the primary factors contributing to the escalating losses experienced by the BPDB stems from the growing financial burden associated with capacity payments linked to surplus electricity generation capacity, technically referred to as the "reserve margin." Acting as the sole purchaser, the PDB has established an agreement with power plants wherein they receive a fixed compensation known as the capacity charge, even when they are not actively generating electricity. Remarkably, the PDB had to disburse capacity charges for its 22,482 MW of installed capacity, despite the maximum peak generation reaching only 14,782 MW (BPDB, 2022). This significant excess in capacity places a substantial financial strain on the BPDB, leading to substantial annual expenditure on capacity payments. Even with increasing sectoral subsidies, there remains a shortfall in meeting the required amount to cover these capacity charges. Consequently, the BPDB has been compelled to carry forward a portion of its annual capacity payment from one fiscal year to the next.

- Until 2021, there were deliberations within the Ministry of Power, Energy, and Mineral Resources regarding the adjustment of Bangladesh's energy mix to include more coal. However, in alignment with the global trend moving away from coal-based power generation, the government decided to halt the progress of 12 coal-fired power plant construction projects in recent years. Instead, the country set its sights on achieving 40 percent of its electricity from what it terms "clean energy" by 2041, as outlined in the ongoing draft of the Integrated Energy and Power Master Plan (IEPMP). Bangladesh's approach to coal utilization has been intertwined with its diplomatic strategies. Notably, the "Maitree" project as a collaborative effort with India's state-owned National Thermal Power Corporation, the transmission of electricity from an Indian coal plant operated by the conglomerate Adani into Bangladesh, the development of two coal plants by Chaina in Barisal and in Payra, the under construction coal plant in Matarbari. Unfortunately, the actual cost of electricity generated from coal has exceeded initial expectations, and its reliability has proven to be less than optimal. Almost immediately after Maitree resumed operations in mid-May after a halt, following successful efforts to secure foreign currency for coal procurement, the Payra plant which is operated by another state-owned entity, faced temporary shutdown due to a coal shortage (The New York Times, 2023).

- The most significant drawback of the plan of the latest master plan (PSMP 2016) was its dependence on imported primary energy supply and lack of renewable alternatives. In 2016, it was estimated that 90% of primary energy would have to be imported by 2030 at an annual cost of $20 billion. The PSMP 2016 and subsequent adjustments were predicated on the notion that Bangladesh's economic growth would be sufficient to support such an import bill (Tamim, 2023).

- A brief review of national budgets over the past decade reveals that the power sector typically receives the lion's share of the allocation for the energy and power sectors combined. In the fiscal year 2022-23 (FY2022-23), for example, the government allocated Tk 33,825 crore for the power division and Tk 994 crore for the energy and mineral resource division (Finance Division, 2023). This inadequate investment in energy sector development is frequently pointed out as the cause of the nation's excessive reliance on imported fossil fuels.

- The power sector of Bangladesh is also burdened by huge subsidies. During the fiscal year (FY) 2021-22, for instance, high prices of fossil fuels and increased power generation costs led to a subsidy burden of Bangladeshi Taka (Tk) 297 billion (US$2.82 billion), an increase of 152% from FY2020-21 and a staggering increase of 301% from FY2019-20 (Alam, 2023). Eventually, the government is compelled to pass on the rising cost of fossil fuel imports to consumers due to the growing import burden. This raises the possibility of sudden rises in prices for electricity and various fuels. Despite these price increases, the power sector's subsidy burden in FY2022-23 could exceed the million Tk 32327, the net loss documented in FY2021-22 (BPDB, 2022).

- The government of Bangladesh amended the Bangladesh Energy Regulatory Commission (BERC) Act of 2003 in December 2022. This amendment grants the power and energy ministry the authority to set fuel and electricity prices under special circumstances, changing BERC's role as the exclusive authority for fixing energy prices. Previously, BERC operated independently, setting energy prices after public hearings, with a focus on consumer protection. The amendment allows the government to expedite price increases, potentially avoiding utility losses caused by delays in the price adjustment process. While BERC has struggled to control wasteful investments by BPDB due to its limited power and independence, it has played a vital role in the last decade in protecting consumers' rights. BERC's scrutiny of utility companies' performances through public hearings has led to cost control measures and often rejected requested price increases. Without BERC or with its bypass, the situation would worsen, with the ministry accepting utility proposals. Overall, the amendment jeopardizes independent oversight in the energy sector and undermines BERC's crucial role in keeping energy tariffs affordable. The recent amendment granting the government unchecked authority to raise energy tariffs without public hearings or accountability poses a significant threat to consumer rights and diminishes BERC's role. It allows the government to generate revenue from energy commodities beyond existing taxes and duties (Hossain, 2023).

4. Overview of the Global LNG Sector

The global LNG market has been spurred by increased demand from both emerging and developed markets. Emerging markets are investing in infrastructure to accommodate their growing demand for natural gas and a significant portion of this investment is directed toward LNG. To meet this demand, companies have been investing in new LNG processing and transport capabilities like the development of pipelines, port facilities, and new technologies like Floating LNG (FLNG). Global investments in LNG will reach a peak of $42 billion in 2024, a 50% increase from current levels, as the global energy crisis worsens (Rysted Energy, 2022). Total LNG supply is expected to nearly double in the coming years, from approximately 380 million tons per annum (MTPA) in 2021 to approximately 636 MTPA in 2030 (Pekic, 2022). In the developed markets, LNG demand has also been driven by a desire to diversify energy supplies. This has been particularly true in Europe, where the share of LNG imports is expected to double over the next four years. However, as a result of Russia's invasion of Ukraine in February 2022 and its weaponization of energy supplies, the EU's share of pipeline imports from Russia has dropped substantially, and now Norway is the EU's most important pipeline gas import source (European Commission, 2022).

Liquefied Natural Gas (LNG) is natural gas that is converted to liquid form from gasified form through a cooling process. This process enables it to be transported and stored in specialized cryogenic tanks (EIA, 2023). LNG is generally 85 to 95% methane and contains less carbon than other fossil fuels. It is also odourless and colourless. Additionally, LNG includes trace quantities of ethane, propane, butane, and nitrogen. However, the exact proportions may vary depending on their source and method of production (National Grid, 2022). Therefore, this liquid form results in a significant decrease in volume and an increase in energy density that makes it easier to transport than traditional gas (Cryospain, 2021). Due to these benefits, the global LNG market has seen exceptional growth in the past few years. In 2020, LNG demand saw a modest growth of 1% despite a decline in global gas demand. Looking ahead, the proportion of LNG in the global gas supply is expected to rise from the current 13% to 23% by 2050 (Mckinsey, 2021). This increase will be driven by meeting the growing demand and replacing diminishing pipeline and domestic gas sources. The market is expected to grow by 11% between 2021 and 2025 (IEA, 2022). The growth of LNG demand is projected to face limitations due to supply constraints from 2021 to 2026 (Appendix). The supply growth has been predicted by 19% from the 2021 level of supply. An estimated 18% growth is anticipated from 2021 to 2026, but it is noteworthy that Europe is likely to experience a significant increase in imports during this period (Bloomberg, 2022).

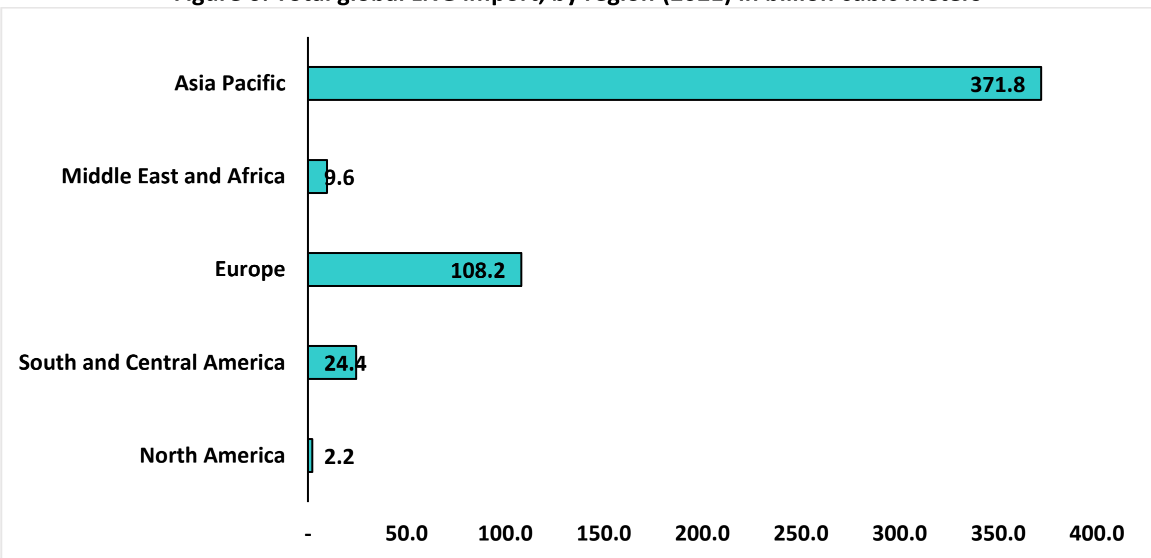
4.1 Global LNG trade and major players in the market

Globally, LNG supply increased by 2% in Q1 2023, driven mainly by the Asia Pacific region and the Middle East, with countries like Qatar, Indonesia, Australia, and Malaysia contributing significantly (International Energy Agency (IEA), 2023). In the first quarter of 2023, the Asia Pacific region saw a slight rise in LNG imports, with notable increases in South Korea, Thailand, Singapore, and Chinese Taipei, but declines in Japan, India, and China (IEA, 2023). In both the export and import markets for LNG, the Asia-Pacific region emerged as a dominant player - in 2021, the region exported 176.3 billion cubic meters of LNG (Figure 6) and imported 371.8 billion cubic meters (Figure 6). The import Figures signify the region's high demand for LNG in countries such as China, Japan, South Korea, and India. These countries are the top five importers of LNG in the Asia Pacific region, with China being the largest importer of LNG globally (Bp Statistical Review of World Energy, 2022). However, Japan, the second largest importer in Asia, is currently witnessing a decline in LNG imports as the country increasingly relies on solar and nuclear-generated electricity (Monthly Gas Market Report, 2023). China's LNG imports showed signs of recovery in February and March, marking the first year-on-year increase since December 2021 (IEA, 2023). However, despite remaining above historical averages, Asian LNG spot prices significantly decreased in Q1 2023 compared to the record levels seen during the summer of 2022 (IEA,2023).

Europe emerged as another primary generator of LNG demand. The region's imports increased by a significant margin of 55% in 2022 (Gas Market Report, 2022). The total import volume of Europe accounted for 108.2 billion cubic meters in 2021 (Figure 6). This substantial volume of imports highlights the region's dependence on LNG imports to meet energy needs. Spain, France, and the UK are the top three importers of LNG in Europe. These countries experienced growth in LNG imports in 2021 (Bp Statistical Review of World Energy, 2022). Europe's net LNG imports rose by 8% year-on-year in Q1 2023, mainly to compensate for declining Russian pipeline gas supplies. However, LNG inflows into France dropped significantly due to strikes at French LNG terminals, leading to diversions of LNG shipments to other European ports (IEA, 2023).

In terms of imports, South and Central America demonstrate significant LNG imports, contributing a total of 24.4 billion cubic meters (Bp Statistical Review of World Energy, 2022). In South and Central America, Brazil and Argentina are the two largest importers of LNG, respectively. North America exhibits a comparatively lower import volume of 2.2 billion cubic meters (Figure 6). In Central and South America, there was a notable decline in LNG demand, down by 28% year-on-year, primarily due to improved hydropower generation in Brazil and the increasing use of renewables in the Dominican Republic (IEA, 2023).

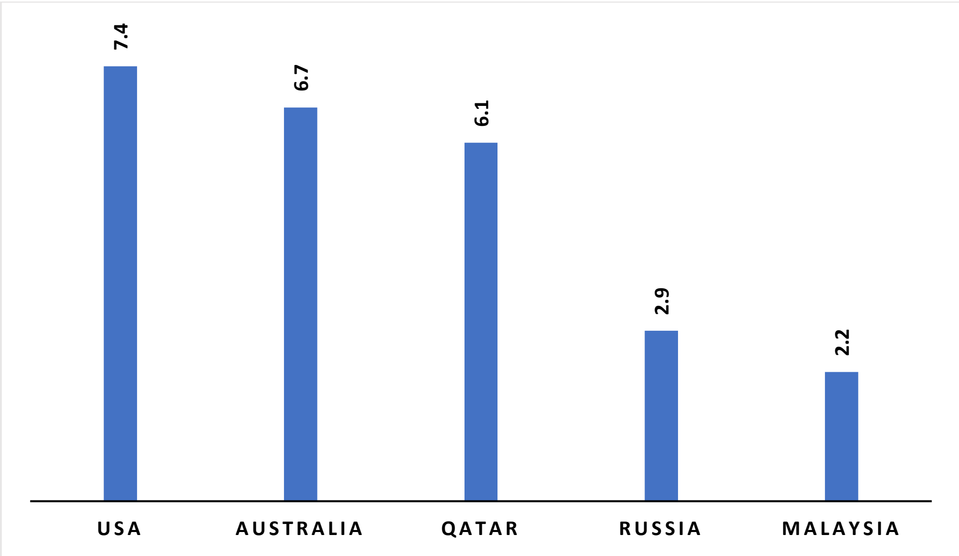
Figure 6: Total global LNG import, by region (2021) in billion cubic meters



Source: BP Statistical Review of World Energy (2022)

In terms of exports, Australia is the largest exporter in the Asia-Pacific region and the third largest exporter globally. In the first half of 2023, Australia became the second-largest exporter of LNG, surpassing Qatar (Figure 7). In 2021, Australia alone exported 108.1 billion cubic meters of LNG, almost 62% of the region's exports (Bp Statistical Review of World Energy, 2022). Other major exports of the region are Brunei, Indonesia, Malaysia, and Papua New Guinea. France, which had become the largest importer of LNG in Europe in 2022, faced significant drops in LNG imports due to strikes at French LNG terminals, leading to diversions of LNG shipments to other European ports.

Figure 7: Top five exporters of LNG (May 2023)



Source: Adapted from GECF monthly gas report of June 2023

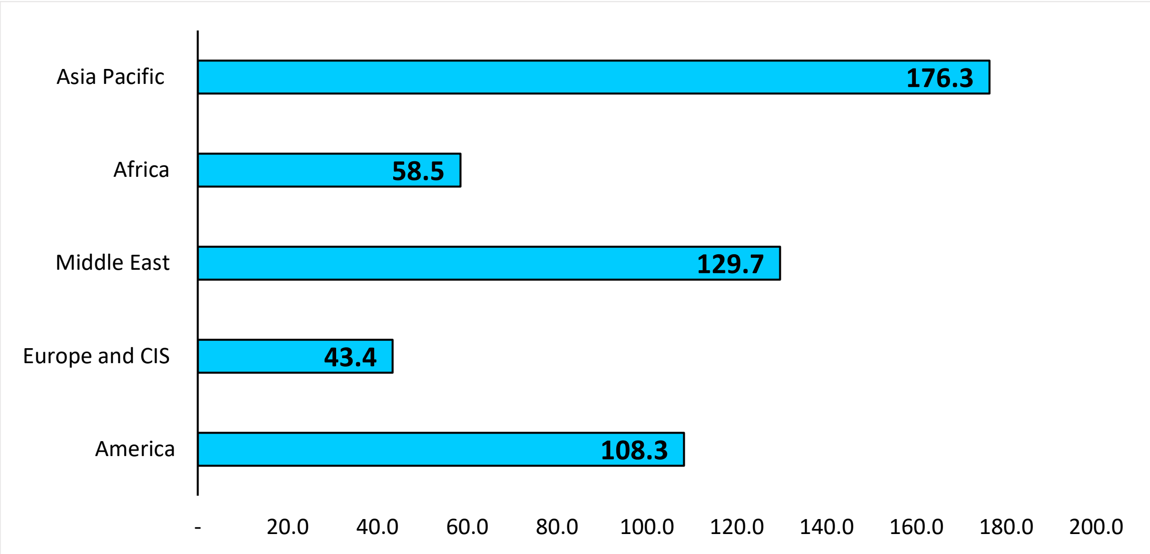
On the supply side, in 2021, Europe and the CIS[2] region together will exhibit a total export volume of 43.4 billion cubic meters (Figure 8). The exports from this region are relatively lower than those from other regions. In Europe, Russia and Norway are the biggest exporters of LNG, with Russia also being the fourth largest exporter worldwide (Bp Statistical Review of World Energy, 2022). In Europe, net LNG imports rose by 8% year-on-year in Q1 2023, mainly to compensate for declining Russian pipeline gas supplies (IEA, 2023).

In the export market, the Middle Eastern region demonstrated significant LNG exports, contributing 129.7 billion cubic meters to global trade (Figure 8). This highlights the substantial role played by Middle Eastern countries, particularly Qatar, Oman, and the UAE, which possess abundant natural gas reserves and have successfully established themselves as key exporters in the LNG market. Before the Ukraine-Russia conflict, Russia was the largest supplier of LNG to Europe. Qatar has taken advantage of the on-going situation in Russia. Consequently, Qatar has become an important country for the EU to buy more LNG from as they try to find new suppliers and increase LNG imports because of the sanctions on Russia. Moreover, Qatar has also signed a long-term deal with China to supply LNG. The deal is considered the second-biggest LNG supply deal (Al Jazeera, 2023). The LNG imports in the region are scanty, with Kuwait being the largest importer in the region.

[2] Commonwealth of Independent States

The America region (USA, Peru, Trinidad and Tobago, and other Americas) presents a noteworthy export volume of 108.3 billion cubic meters (Figure 8). Out of the total export from this region, the USA's export is around 95 billion cubic meters, which makes the country the largest exporter of LNG worldwide (Bp Statistical Review of World Energy, 2022). U.S. saw a substantial 16% rise in LNG exports during 2022, reaching 10.2 Bcf/d, a 1.4 Bcf/d increase from 2021. This growth surpassed that of all other LNG-exporting nations. The United States claimed the title of the world's leading LNG exporter in the first half of 2022, following the inauguration of a new LNG export facility. However, due to the closure of the Freeport LNG export terminal, U.S. LNG exports dipped in the latter half of the year. Throughout 2022, Qatar and Australia maintained their positions as the top two global LNG exporters, with Qatar averaging 10.5 Bcf/d in exports and Australia averaging 10.4 Bcf/d (Zaretskaya & Ober, 2023).

Figure 8: Total global LNG export, by region (2021) in billion cubic meters



Source: BP Statistical Review of World Energy (2022)

Looking ahead, the global LNG trade volume is expected to increase by 4% in 2023, driven by factors such as the return of the Freeport LNG terminal in the United States, improved feed gas availability in Trinidad & Tobago, and increased production at Mozambique's Coral South FLNG (IEA, 2023). Demand growth is anticipated to be primarily driven by Asia, particularly with China's LNG imports expected to rise, while Europe's LNG imports are predicted to decline later in the year due to lower injection needs and reduced gas consumption (IEA, 2023).

4.2 The global LNG projection

With new technological advancements, companies are increasingly investing in transportation, storage, and processing capabilities. This growth is further supported by increasing environmental concerns and the need for reliable sources of energy. Geopolitics has also played an important role in shaping the global LNG market, with countries seeking reliable and cost-effective sources of energy to meet their respective energy needs. The value of the worldwide LNG market was USD 30.34 billion in 2020 and is anticipated to reach USD 66.13 billion by 2027. During the projected period, the worldwide LNG market is anticipated to be driven by factors such as increased demand for gas power production and an increase in the number of LNG-fuelled fleets (2022–2027). In the following years, a large number of

LNG projects and development plans are anticipated to be submitted as a result of the increasing demand for LNG; this will create numerous possibilities for market participants in the African area, hence creating an emerging LNG industry. During the projected period (2022–2027), Asia-Pacific is anticipated to be the largest market, with the bulk of demand coming from China, Japan, etc (Mordor Intelligence, 2023).

4.3 Price volatility of LNG

Despite having a high concern about the energy crisis onwards after the on-going Russian invasion of Ukraine, lower demand due to warm weather, improved energy efficiency, behavioural changes in gas consumption and strong LNG inflows resulted in high inventories of natural gas in Europe. As a result, global natural gas prices collapsed in the second half of 2022, with a more than 70% fall in European prices and an 18-month-low price drop in the USA. Europe has been affected by a reduction in Russian natural gas production and exports. In contrast, production in the United States in the first ten months of 2022 reached record levels and was 12% higher than the 2017-2021 average However, continued unavailability of the Freeport LNG export terminal has constrained U.S. exports, exerting a downward impact on prices (Agnolucci, 2023).

LNG trade underwent a marked redirection in 2022 as EU demand for LNG surged to replace Russian pipeline imports (Russell, 2022). Amid high European prices, global LNG cargoes were redirected to Europe. Meanwhile, China's LNG imports were 85% lower as demand for natural gas shrank due to COVID-19 restrictions, helping to ease the shortage of LNG (Agnolucci, 2023). Nonetheless, the surge in demand for LNG from Europe reduced the amount available for other countries like Bangladesh and Pakistan, leading to electricity outages. The cost of LNG in Asia already surpassed all previous records late last year, even before Russia invaded Ukraine. Japan had its greatest power crisis since the Fukushima accident in 2021 resulting from soaring LNG prices.

In 2021, average prices per Metric Million British Thermal Units (MMBtu) LNG were 29.43%, 120.2%, 361.99%, and 92.96% higher in Japan, Germany, the UK and the USA respectively compared to 2020. Bangladesh was highly vulnerable to this price volatility as 59% of its LNG is purchased on spot markets. Spot market LNG imports might cost Bangladesh nearly $11 billion between 2022 and 2024 as approximately 12.42 mcm of LNG would have to be purchased, assuming Bangladesh's yearly spot market LNG imports do not rise and stay consistent within this period.

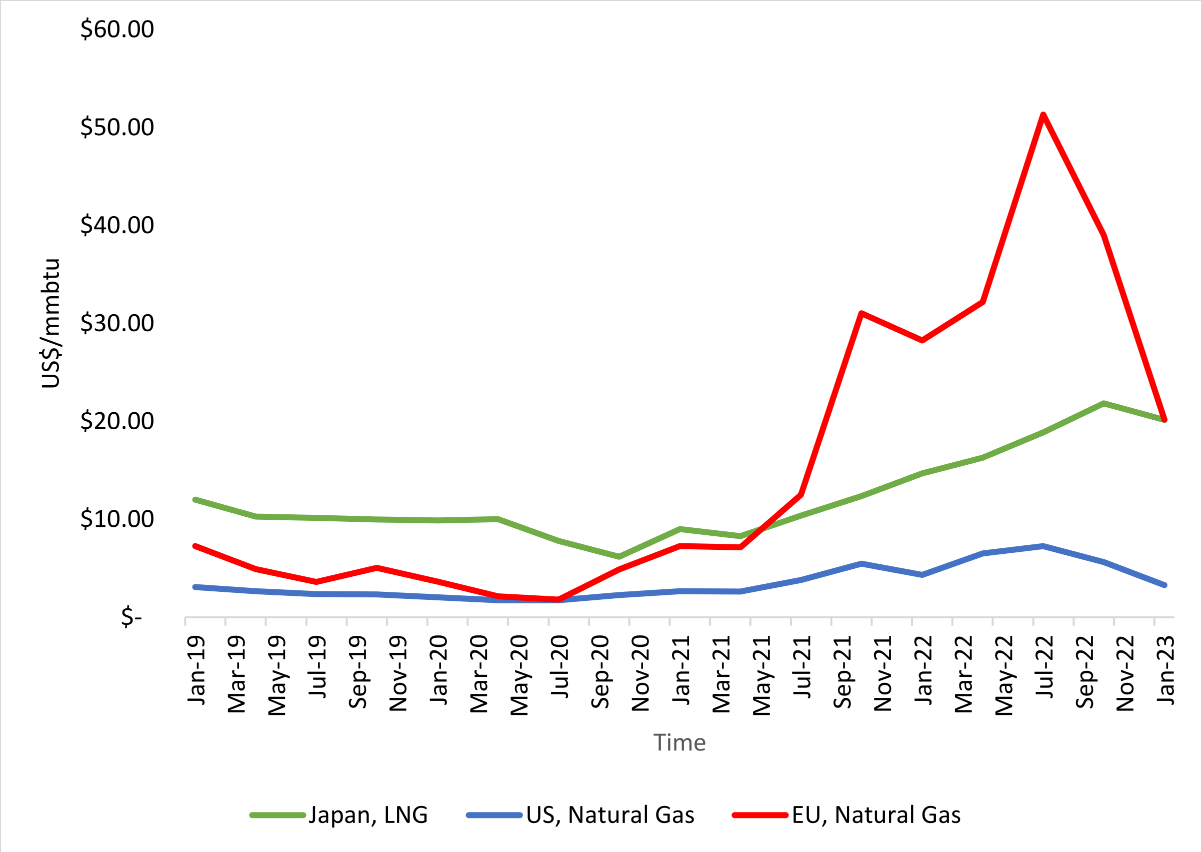
In the longer term, the drop in demand for Russian gas and shifts in LNG trade are expected to continue due to an increased focus on energy security in Europe. This is driving the diversification of energy sources, for example, Europe will boost LNG import capacity by 40 bcm by 2023 and increase investment in renewable energy.

Future markets predict lower natural gas prices in 2023, but higher than the 2017-21 average until end-2026. This may change with the on-going conflict in Ukraine, potential reductions in Russian pipeline exports to Europe (still 10% of Europe's supply), and increased global competition for LNG as China lifts its lockdown policies. The S&P Global outlook presumes China's total energy demand will increase by 3.3 million barrels of oil equivalent per day in

2023 from virtually no growth in 2022, representing 47% of the global energy demand growth next year (Corey Paul, 2022).

The price dynamics of natural gas in three vital regions have been presented in the following figure (Figure 9):

Figure 9: LNG price dynamics over different regions



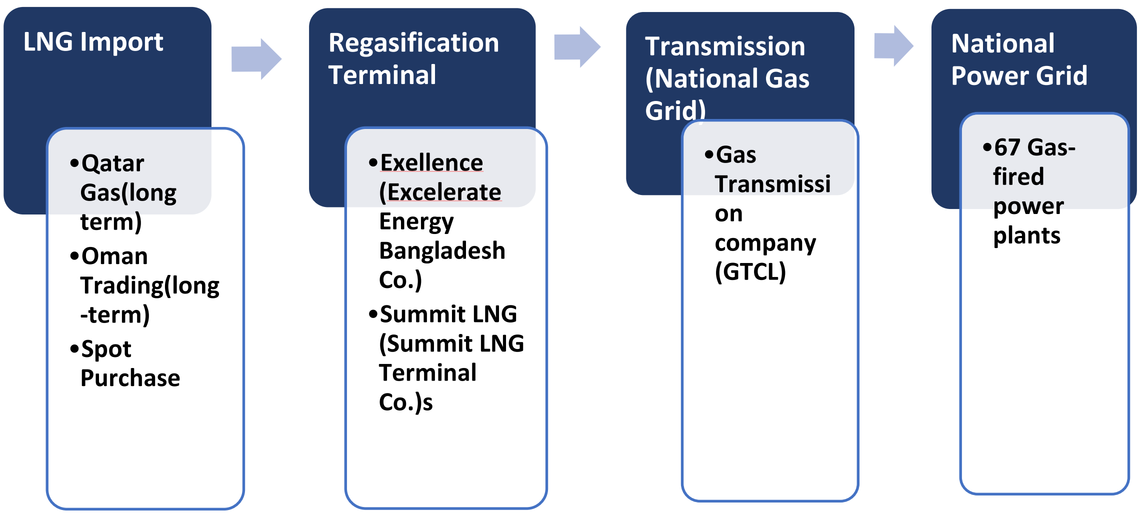
Source: World Bank Blogs

5. An Overview of the LNG Sector in Bangladesh

The LNG supply chain for Bangladesh can be broken down into four distinct phases, starting from the stage of importing and finishing while connecting to the end consumers like power plants (Figure 10). Once LNG is imported, it must undergo regasification before it can be implanted into the national gas infrastructure. Distribution corporations in the next stage transport natural gas from national systems to power plants.

The LNG import strategy of Bangladesh comprises both long-term contracts and spot market purchases. In this connection, two long-term contracts have been negotiated with Qatar and Oman, while 16 companies have signed to import LNG on the spot market. Two Floating Storage Regasification Units (FSRUs) are now used as LNG terminals in the country. Two FSRUs with a combined daily capacity of 500 MMscfd, located in Cox's Bazar are also in operation (RPGCL, 2022). Due to the construction of a pipeline linking the FSRUs to the national gas grid, re-gasified LNG is now being delivered into the national gas grid.

Figure 10: LNG supply chain in Bangladesh



Source: Authors' illustration

In Bangladesh, gas is transmitted exclusively by the Gas Transmission Company Limited (GTCL), a government-owned subsidiary of the Bangladesh Oil, Gas & Mineral Corporation (commonly known as Petrobangla). Petrobangla owns and operates all six of the country's gas distribution companies. These gas distribution firms in Bangladesh mostly serve power plants as their customers. One of Petrobangla's subsidiaries, Rupantarita Prakritik Gas Company Limited (RPGCL), is in sole charge of LNG activities in Bangladesh.

5.1 Bangladesh's LNG infrastructure and construction

RPGCL, under Petrobangla's supervision, has been carrying out all activities related to LNG in the country including the establishment of both floating and land-based LNG terminals, import of LNG, installation of Floating Storage Regasification Unit (FSRU), construction of LNG infrastructure, supply of Regasified Liquefied Natural Gas (RLNG) to the National Grid etc. The aim is to achieve the targets set forth in the SDGs 2030, vision 2021, and Vision 2041 as directed by the government. According to the Gas Sector Master Plan-2017 (Scenario-C), 5,257 and 6,228 MMSCFD of natural gas are expected to be consumed in the fiscal years 2025–26 and 2030–31, respectively. Therefore, it had been claimed by the government that the purchase of LNG is crucial given the unpredictability surrounding the supply of gas and the need to meet local gas demand (RPGCL, 2022).

Floating Storage Regasification Unit (FSRU)

Efforts have been made to swiftly address the gap between natural gas demand and supply by establishing Floating Storage Regasification Units (FSRU) for importing LNG in a short period of time. Currently, two FSRUs have been set up in deep-sea locations at Moheskhali in Cox's Bazar to facilitate this process.

FSRU by Excelerate Energy Bangladesh Limited (EEBL): Excelerate Energy Bangladesh Limited (EEBL) installed a 500 MMSCFD Floating Storage Regasification Unit (FSRU) on a Build-Own-Operate-and-Transfer (BOOT) basis at Maheshkhali in Cox's Bazar in July 2016, after an agreement with the Energy and Mineral Resources Division (EMRD), Petrobangla. After completing all necessary work, pre-commissioning, and commissioning, the FSRU became operational in August 2018. On August 19th of the same year, RLNG supply to the national gas grid began from this terminal.

FSRU by Summit: The EMRD, Petrobangla, and Summit LNG Terminal Co. (Pvt.) Ltd. reached another deal for the installation of FSRU on BOOT basis at Maheshkhali in Cox's Bazar. Following the conclusion of the required tasks, the FSRU's commissioning was finished in April 2019 and RLNG supply from this FSRU began (RPGCL, 2022).

5.2 LNG import scenario

5.2.1 Import of LNG from Qatargas

A 15-year "Sale and Purchase Agreement" (SPA) was struck with Ras Laffan Liquefied Natural Gas Co. Ltd. on September 25, 2017, with the intention of importing 1.8 to 2.5 MTPA of LNG from Qatar. Later, Qatargas was given to Ras Laffan Liquefied Natural Gas Co. Ltd. (3). As part of the Base Annual Contract Quantity, 1.8 million tons of LNG must be imported from Qatargas. (BACQ). 44 shipments from Qatargas totaled 2.71 million tons (6.15 million cubic meters) of imports during the fiscal year 2020–21. Between April 24, 2018, and June 30, 2022, a sum of 9.46 million tons (21.49 million cubic meters) of LNG was imported from Qatargas via 110 cargoes.

5.2.2 Import of LNG from OQ Trading Ltd. (OQT)

On May 6, 2018, a 10-year deal (SPA) was reached with Oman Trading International (current name: OQT) with the aim of importing 1.0-1.5 MTPA LNG from Oman on a long-term basis. As part of the Base Annual Contract Quantity, 1.0 million tons of LNG must be imported from

OQT. (BACQ). 20 shipments from OQT totalled 1.22 million tons (2.80 million cubic meters) of imports during the fiscal year 2020–21. From 31 January 2019 to 30 June 2022, 4.92 million tons (11.20 million cubic meters) of LNG were received from OQT via a total of 78 shipments.

5.2.3 Import of LNG from the Spot Market

The Government made the choice to import LNG from the Spot Market in order to open up possibilities for competitively priced imports of LNG from the foreign market. The Master Sales and Purchase Agreement (MSPA) between Petrobangla and 16 businesses were inked to achieve the goal. On September 25, 2020, imports of the first shipment from Spot Market began. Through 18 shipments from the spot market, 1.127 million tons (2.57 million cubic meters) of goods were purchased during the budgetary year 2020–21. As of June 30, 2021, 29 shipments totalling 1.826 million tons (4.16 million cubic meters) of LNG were purchased from the spot market (RPGCL, 2022). LNG import from two long-term contracts and the spot market till now from the beginning year of import FY2018-19 has been presented in Table 3:

Table 3: LNG import from Qatargas, OQT, and Spot Market (2018-2022)

Fiscal Year	LNG Import											
	Qatar Gas (24 April 2018 to 30 June 2022)			**OQ trading lid (OQT) (31 January 2019 to 30 June 2022)**			**Spot (25 September 2020 to 30 June 2022)**			Total		
	Cargo	**Million Cubic Meter**	**Million Metric Ton**	**Cargo**	**Million Cubic Meter**	**Million Metric Ton**	**Cargo**	**Million Cubic Meter**	**Million Metric Ton**	**Cargo**	**Million Cubic Meter**	Million Metric Ton
2018-19	33	4.58	2.02	08	1.15	0.51	0	0	0	41	5.73	**2.53**
2019-20	37	5.17	2.27	29	4.28	1.89	0	0	0	66	9.45	**4.16**
2020-21	40	5.59	2.46	21	2.97	1.298	11	1.59	0.699	72	10.15	**4.46**
2021-22	44	6.15	2.71	20	2.80	1.22	18	2.57	1.127	82	11.52	**5.06**
Total	**154**	**21.49**	**9.46**	**78**	**11.20**	**4.92**	**29**	**4.16**	**1.826**	**261**	**36.85**	**16.21**

Source: RPGCL

5.3 Supply of re-gasified Liquefied Natural Gas (RLNG) to the national grid

Starting from 2018 the RLNG supply from the existing two companies has been increasing except for the fiscal year 2021-2022, which is still a significant amount. RLNG Supply from the Maheshkhali LNG (MLNG) terminal and Summit LNG Terminals over the Last Four Fiscal years are mentioned in Table 4.

Table 4: RLNG supply from MLNG and Summit LNG terminals (2018-22)

Financial Year	RLNG Send-out to National Gas Grid					
	MLNG Terminal		**Summit LNG Terminal**		**Total**	
	Million Cubic Meter	MMSCF	Million Cubic Meter	MMSCF	Million Cubic Meter	**MMSCF**
2018-19	3,002.54	1,06,033.63	278.98	9,852.34	3,281.52	**115,885.97**
2019-20	2,912.69	02,860.67	2,832.19	100,016.96	5,744.88	**202,877.63**
2020-21	2,611.13	92,211.11	3,508.11	123,887.79	6,119.24	**216,098.90**
2021-22	3,871.82	136,811.06	2,938.15	103,759.90	6809.97	**240,570.97**
Total	**123,98,18**	**437,916.47**	**9,557.43**	**337,516.99**	**21,955.61**	**775,433.47**

Source: RPGCL 2022

5.4 On-going LNG-related activities

5.4.1 Installation of land-based LNG terminal having capacity 1000 MMSCFD at Matarbari

The government has issued a Request for Proposal (RFP) to eight shortlisted bidders on 15-03-2022 for the installation of a 1000 MMSCFD land-based terminal, named the 'Bangabandhu Sheikh Mujib Land-based LNG Terminal.' The purpose of this RFP is to select a suitable terminal developer, and the bid submission deadline is 12-02-2023. The terminal is expected to be fully operational by 2028. The Cox's Bazar District Land Allocation Committee has already given approval for the acquisition of 42.7860 hectares/15.7260 acres of land required for the installation of this terminal, and further land acquisition activities are currently in progress (RPGCL, 2022).

5.4.2 Installation of 3rd FSRU by Summit Oil & Shipping Co. Ltd. (SOSCL)

In accordance with the 2010 "Quick Enhancement of Electricity and Energy Supply (Special Provisions) (Last Reviewed in 2021) Act," the government has granted Summit Oil and Shipping Company Limited the task of establishing the third floating LNG terminal near Moheshkhali in Cox's Bazar (RPGCL, 2022). The proposed floating LNG terminal is designed to have a regasification capacity to handle 600 million cubic feet (mmcf) of LNG daily. It is anticipated to become operational by the year 2026. The Floating Storage and Regasification Unit (FSRU) is intended to provide a minimum of 600 million cubic feet per day (mmcfd) of gas, with the potential to increase this to 800 mmcfd. Situated approximately five kilometers from Moheshkhali island, this facility will be strategically positioned in the expansive waters of the Bay of Bengal (TBS, 2023).

5.4.3 Installation of 4th FSRU on BOOT Basis by Excelerate Energy (EE)

In accordance with the 2010 "Quick Enhancement of Electricity and Energy Supply (Special Provisions) (Last Reviewed in 2021) Act," The installation of the 4th mobile LNG facility, which would have a capacity of 500–1000 MMSCFD, in the Payra Deep Sea Area, Patuakhali, has received preliminary approval from the government. Negotiations with EE to implement the fourth FSRU are ongoing as part of the agreement's completion. Following the signing of the deal, the terminal is anticipated to be placed within three years (TBS, 2023).

5.4.4 Expansion of MLNG terminal installed by Excelerate Energy Bangladesh Limited (EEBL)

In order to expand the capability of the MLNG terminal that EEBL placed, a plan has been made. The plan will be processed in accordance with the "Quick Enhancement of Electricity and Energy Supply (Special Provisions) (Last revised in 2021) Act, 201O," which the government has given its preliminary approval. The MLNG facility run by EEBL is being expanded to have a capacity of 630 MMSCFD, and this is the subject of ongoing negotiations. After the contract is signed, the planned MLNG port extension work is anticipated to be completed by the end of the year 2023, during the MLNG port's dry-docking time (RPGCL, 2022).

5.4.5 LNG import from Summit Oil and Shipping Co. Ltd (SOSCL)

The proposal submitted by SOSCL for long-term LNG supply have been processed under the "Quick Enhancement of Electricity and Energy Supply (Special Provisions) (Last revised in 2021) Act, 2010 and approved. According to their recently finalized long-term agreement, Summit Oil & Shipping Co Ltd is slated to deliver 1.5 million metric tons per annum (MTPA) of Liquefied Natural Gas (LNG) starting from the year 2026. This contractual commitment spans over a 15-year duration (TBS, 2023).

5.4.6 LNG import from Emirates National Oil Company Limited (ENOC)

The government is currently processing a proposal from Emirates National Oil Company Limited (ENOC) to supply LNG on a long-term basis on a government-to-government (G-to-G) basis. Negotiations with ENOC are ongoing. Discussions are underway with ENOC regarding the potential provision of 1 million mt/year of LNG for a minimum duration of 10 years (Rahman & Ghosh, 2022).

5.4.7 LNG import from Qatargas

In a recent development, Bangladesh and Qatar have officially entered into a 15-year agreement. This agreement entails the import of a maximum of 1.8 million metric tonnes of liquefied natural gas (LNG) every year. Under the terms of this fresh arrangement, Bangladesh is positioned to receive an extra 1.8 MTPA of LNG, with the inauguration of this additional supply slated for the year 2026 (The Daily Star, 2023).

5.4.8 LNG import from Excelerate Energy (EE)

The "Quick Enhancement of Electricity and Energy Supply (Special Provisions) Act, 201O" has been used to handle EE's proposal to sell LNG on a long-term basis which has been approved. According to the proposition, Excelerate Energy Bangladesh Ltd, the company responsible for setting up a floating terminal and re-gasification unit (FSRU) in the Moheshkhali area of Cox's Bazar, is preparing to provide a quantity ranging from 1 to 1.5 million tonnes per year (MTPA) of Liquefied Natural Gas (LNG) starting in 2026. This commitment for supplying LNG is part of a lengthy contractual agreement that covers a duration of 15 years (TBS, 2023).

5.4.9 Import of RLNG to Bangladesh through the cross-border pipeline

To transport RLNG to Bangladesh from India via cross-border pipelines, Petrobangla and IOCL, and H-Energy each inked a non-binding memorandum of understanding. The Quick Enhancement of Electricity and Energy Distribution (Special Provisions) (Last amended in 2021) Act, 2010, will be used to handle the government's in-principal approval of H-energy's proposal to distribute RLNG through cross-border pipes. Draft RLNG SA was successfully completed to receive RLNG from H-Energy via international networks. The negotiations with H-Energy will start very shortly (RPGCL, 2022).

5.5 Future scenario of the LNG sector in Bangladesh

Bangladesh, being a gas-importing country, is exceptionally natural gas dependent since it had very cheap and easily accessible gas reserves. However, at present its gas reserve is depleting to a significantly low level which drives the growing import of LNG. According to the projection of the Gas Sector Master Plan (2017), 21.6 million tonnes (3000 mmcfd gas) is required by 2030, and 32 million tonnes of LNG in 2041. Petrobangla has a plan to build three new LNG terminals having regasification capacity between 2000-3000 mcf/d combined among which two terminals will be floating storage and regasification units (FSRUs) and one will be a land-based terminal. They will be established in Payra (south-western Bangladesh, 5.2-10.3 bcm/year), Moheshkhali (5.2-10.3 bcm/year), and Matarbari (south-eastern Bangladesh (The Financial Express, 2023).

Table 5: Projects to be commissioned in 2022-2027

Sl No.	Name of the Powerplant	Capacity(MW)	Ownership	Type of Fuel	Expected Commissioning dare
Public Sector					
1.	Rupsa 800 MW CCPP; Unit- 1	440	NWPGCL	LNG	October 2023
2.	Rupsa 800 MW CCPP; Unit- 2	440	NWPGCL	LNG	April 2024
3.	Haripur 250 MW CCPP	243	BPDB	LNG	December 2025
4.	Raojan 400± 10% MW CCPP	400	BPDB	LNG	December 2025
5.	Ghorashal 225 MW CCPP	225	BPDB	LNG	June 2026
6.	Payra 1200 MW LNG based CCPP (1st Phase)	1200	NWPGCL	LNG	June 2026
7.	Shiddhirgonj 400± 10% MW CCPP	550	BPDB	LNG	June 2027
8.	Gazaria 600MW LNG Based Power Plant	660	RPCL	LNG	June 2027
Sub Total		**4158**			
Joined Venture					
1.	LNG based 1200 MW CCPP at Moheshkhali Phase- 1	1164	BPDB	LNG	June 2027
Sub Total		**1164**			
Private Sector					
1.	Meghnaghat 583 MW CCPP (Summit Unit- 2)	583	IPP	LNG/HSD	March 2023
2.	Meghnaghat 600 MW CCPP (Unique)	584	IPP	LNG	March 2023
3.	Meghnaghat 750 MW CCPP (Reliance)	718	IPP	LNG	March 2023
4.	Anowara 590 MW CCPPC (United)	590	IPP	LNG	January 2026
5.	Meghnaghat 500 MW CCPP (Unlima	450	IPP	LNG	January 2026
6.	Gozaria 600 MW CCPP (IDRA)	660	IPP	LNG	December 2026
7.	Mirsorai 660 MW CCPP (Confidence)	660	IPP	LNG	June 2027
Sub Total		**4245**			
TOTAL		**9567**			

Source: RPGCL

According to the integrated power sector master plan (draft), the LNG import growth rate was inevitable to rise but not as much as expected due to the start-ups of new power generation units as well as the revised demand outlook. The increase in LNG import will reach 9 million tonnes (Mt) in 2030, 21 Mt in 2040, and 46 Mt in 2050 for the PP2041 GDP case and 5 Mt in 2030, 12 Mt in 2040, and 19 Mt in 2050 for the In-Between case. But the situation will change in case of unsuccessful exploration of the high-risk potential resources. An additional 7.1 Mt in 2040 and 9.4 Mt in 2050 might be required then according to the projection. A business structure for LNG import has been proposed in the IEPMP where the regasification and power generation will be performed by the same company at the onshore LNG terminals and adjacent GTCC thermal power plants, respectively. The justification of this proposal has been articulated that customers could receive different services from operation companies whereas private companies will face competition controlling the LNG procurement costs. Also, it will enable the government to gain the LNG import know-how from these private companies which will be helpful to procure LNG according to supply stability, economy, and elasticity. The following table (Table 5) has enlisted the LNG-based future generation projects till 2027 which portrays the significance of LNG import in the energy sector of Bangladesh.

5.6 Contemporary energy crisis and LNG scenario in Bangladesh

Bangladesh has been experiencing a worsening energy crisis caused by the covid-19 and the Russia-Ukraine war. Widespread power shortages are affecting households and businesses, with electricity and gas shortages significantly impacting factory production. Local gas resources had been depleted for years, forcing power plants to convert to the imported LNG despite its skyrocketing spot market price. The crisis is less intense now, still, the energy sector is suffering due to its over-reliance on highly volatile and costly imported LNG, coal, and oil. Increasing dependence on imported fossil fuels for power generation is intensifying the volatility of the energy sector along with the country's fiscal burden. Additionally, the foreign currency reserve and the subsidy burden have been affected significantly.

In 2022, the crisis reached its peak until now. The government had to initiate precautionary load-shedding, stopped Liquefied Natural Gas (LNG) imports from the spot market, and kept diesel-based power generation on hold. Costly fossil fuel was unaffordable as the foreign reserve was depleting at an alarming rate though the industrial output was falling. The government's response to the fiscal burden was raising prices two times by 5% in a 20 days gap in January 2023 (TBS, 2023). Gas prices were also hiked gas for power, industries, and commercial (hotel and restaurant) sectors up to 179% (TBS, 2023). Though the government reasons out these price hikes with fiscal reasons the power generation cost will continue to rise until any change occurs in the imported fossil-fuel-dependent energy system.

The problem of overcapacity of the power sector will magnify the fiscal burden further. Bangladesh Development Board (BPDB) in its revised annual report published that by 2027, 25,840 MW of new power capacity will be added which was 22608 MW in December 2022, 13,103 MW of new power capacity will come from under-construction power plants whereas power plants supplying 3127 MW power capacity are at contract signing and tendering stage. There are more than 9610 MW of power plants that are in the planning phase. If the under-construction would be activated by 2027 and, the depreciation of existing/old power plants is 3000 MW in the meantime, total installed capacity will be 32711 MW in 2027. Currently, the maximum peak demand for electricity is 14792 MW (BPDB, 2022). With the expected GDP growth rate of 7.5% in the current year and a similar kind of growth expected over the next few years, the electricity demand growth rate will be approximately 7%. It could generate a peak demand of 20747 MW in 2027 creating a surplus power generation capacity of 7815 MW giving a 23.89% reserve margin. It can be argued that 97 economic zones will have vast amounts of investment resulting higher power demand growth rate in the future. But even 8% peak annual demand from 2023 to 2027 would have a surplus capacity of 6,630MW (20.27%).

The 80% of the above-mentioned newly to-be-added power capacity (25840 MW) by 2027 will be run by fossil fuels whereas only 10% will come from renewable sources and the rest from nuclear sources (Alam, 2023). As there is no guarantee of stable price in the international fossil fuel market soon, the imported coal and LNG-based power plants will sell expensive power to BPDB. Overcapacity will not help due to contractual obligations. Moreover, there is the political economy implication of the current crisis in the energy sector. The political economy of increasing imports is a quick moneymaking opportunity. Since anything long-term will not serve the political interest, the government is focusing on short-term solutions more. Hence, the subsidy burden will be heavier as the government would need to allocate more funds to the power and energy sector. Along with the high-cost problem, the overcapacity will exclude large-scale investment in the renewable energy sector in the near future.

Due to the declining foreign reserves, the government's new projects are also of concern. In the Payra Sea port case, there have been delayed payments to import coal. Coal import payments had to be made in US dollars, which slowed down power production at the Rampal power station. In light of these developments, companies' confidence in the government's ability to pay for spot market LNG imports is eroding.

With the LNG price dropped to the $16-20 range in February 2023, the government has considered making spot market imports again. Also, the Matarbari Port & Terminal would help to lessen the importing cost of LNG. There are projections of better prices and supply of LNG in the future, still overdependence on LNG import will affect energy security as projections are not guaranteed. Natural gas on which the industries rely mainly will not be cheap anymore, as it is been replaced by imported LNG. To be fully equipped for any other crisis ahead, industries should come to the national power grid and consider other fuel opportunities. Bangladesh may experience a complicated situation while importing LNG and other fuels with the long-run vulnerability of the power sector until it restructures the power system.

Historically, Bangladesh's energy sector has relied heavily on cooperation with China and Russia. The majority of Bangladesh's current energy initiatives are supported by Chinese funding. The energy sector in Bangladesh has seen a surge in Chinese investment and loans to the tune of US$ 8.31 billion since 2016. China has expressed interest in helping Bangladesh switch to renewable energy sources in recent years, and the two countries have communicated that coal mining and coal-fired power plants are off the table for Bangladesh.

However, Russia has assisted Bangladesh in its gas drilling and exploration efforts with assistance from Moscow. By constructing Bangladesh's first nuclear power plant, it has also expanded nuclear cooperation. Recently, Russia proposed to export LNG to Bangladesh directly for the first time during the fourth session of the Russia-Bangladesh Intergovernmental Commission on Trade, Economic, Scientific, and Technical Cooperation. But no formal proposal or decision could find after this proposal. For Bangladesh, it is in fact a delicate situation of expanding its energy dependence on Russia. Because, due to its energy dependence, Bangladesh initially abstained from voting on the first United Nations resolution condemning Russia's invasion of Ukraine. However, the war's financial repercussions, sanctions against Russia, and intensified US diplomatic efforts have all had an impact as of late.

5.7 Cost and feasibility analysis of intermediate LNG for power generation

5.7.1 Economic cost of LNG import

Calculating the economic cost of importing liquefied natural gas (LNG) in different energy mixes involves several factors that must be considered. The estimation of economic cost requires calculating both the accounting cost and the opportunity cost as it is consisting of these two cost components. The explicit cost incurred by a company on business activities is known as accounting cost. As Bangladesh is an LNG importer country the accounting cost of LNG comprises all the costs ranging from import to final consumption. On the other hand, the opportunity cost of LNG is the cost of the best alternative forgone for choosing LNG as a fuel option.

Accounting cost of LNG

To estimate the accounting cost of LNG we must consider the import cost of LNG, the regasification cost of the LNG terminal, value-added tax (VAT), advance income tax (AIT), port service charge, and at-cost charge. However, data availability is a big factor when we want to calculate the economic cost. Hence, the study attempted to estimate the economic cost with available data (Table 6). All the data for this cost estimation has been collected from the Rupantarita Prakritik Gas Company Limited (RPGCL), the sole LNG operator government agency in Bangladesh. We have performed the estimation according to the following steps:

- The cost components before the regasification process, that is, only import of LNG include cost of LNG import, VAT (Value added tax) charge, AIT (Advanced income tax) charge, and port service charge.

- Post-regasification cost components include regasification costs for each company, the at-cost charge and the cost of operation. By summing up pre and post-regasification cost components we estimated the total accounting cost.

- To estimate per unit LNG cost we have used the approach of calculating the cost of LNG to generate 1 Kwh (Kilo-watt hour) power. LNG is imported in cryogenic form which expands after regasification. The total quantity of regasified LNG has been used as the LNG quantity to estimate per unit power generation from it (kwh). First, the total quantity has been converted to RLNG form and afterwards, it has been converted to a different unit MMCF for further calculation.

- After we have estimated the per unit (MMCF) LNG accounting cost, we calculated power generation from RLNG in the year 2022. The total power generation from gas fuel has been used to estimate per unit (MMCF) power generation. We calculated the total power generation from RLNG supply by multiplying the per unit (MMCF) power generation and the total yearly RLNG supply to the national gas grid. Afterwards, the power generation from per unit of RLNG (1 MMCF) has been estimated.

- The final step analyses two pieces of information obtained: The cost of producing 1 MMCF of RLNG and power generation (Kwh) from 1 MMCF of RLNG. Using these two pieces of information we have estimated the cost of RLNG to generate 1 Kwh of power.

Table 6: Cost components of LNG import to final use

Cost Component	Cost (in Taka) in the year 2022		
Import sources	**Qatar gas (Million BDT)**	**Oman Trading (Million BDT)**	**Spot Market (Million BDT)**
Cost of LNG Import	17,1000	6,5000	12,0000
VAT (15%)	2,5650	9750	1,8000
AIT (2%)	3420	1300	2400
Port service charge	145	70	45
Total cost per company before regasification	20,0215	7,6120	14,0445
Total cost before regasification	416780		
Regasification cost of LNG Terminal for the year 2022			
Regasification companies	Excelerate Energy (million BDT)	Summit Group (million BDT)	
Cost of regasification	9000	9000	
At Cost Charge	350		
Total cost (accounting)	**435130**		
Total accounting cost of LNG (USD)	**3992.0183 Million USD**[3]		
Total accounting cost (% GDP)	**1.43%**[4]		

Source: Authors' calculation using data from RPGCL

The process of importing liquefied natural gas (LNG) involves converting it back into its gaseous state through a process called regasification. The quantity of LNG expands while regasified. In the year 2022, Bangladesh imported a total of 11.52 million cubic meters of LNG, which was subsequently regasified to produce 6809.97 million cubic meters of natural gas. So, the conversion ratio from LNG to RLNG is 590.9696, that is, 1 unit of LNG expands to 590.9696 units of RLNG[5]. This conversion ratio has been used and the total quantity of RLNG as well as per unit (MMCF) accounting cost has been estimated (Table 7).

Table 7: Unit cost of LNG per MMCF

Name of the Import Sources	Qatar Gas	Oman Trading	Spot market
Quantity (2022) in Cubic meters	**5,730,407**	**2,254,601**	**1,697,648**
Total LNG Quantity (Cubic meter)	9682656		
Total Regasified LNG quantity (Cubic meter)	5722155343.257		
Total Quantity (MMCF)	202076.01		
Unit Cost of LNG (Total cost/Total quantity)	2.153 million BDT per MMCF		
Unit Cost of LNG (USD)	0.0198 Million USD per MMCF		

Source: Authors' calculation

Natural gas plays a significant role in the energy landscape of Bangladesh, contributing to approximately 55.06% of the total power generation in the country in the fiscal year 2021-22. This indicates that natural gas constitutes a substantial portion of the energy mix in Bangladesh. According to BPDB annual report, the amount of power generation from natural gas in the mentioned year is 47136 Mkwh. The cost of LNG regarding all of its operations in the country to produce 1 Kwh power has been estimated in the following table (Table 8).

[3] According to the exchange rate of Bangladesh Bank on 31.0723; 1 USD=109 BDT
[4] 30,351,496 Million BDT(BBS, 2022)
[5] https://www.chevron.com/operations/liquefied-natural-gas-lng

Table 8: Unit cost of LNG per Kwh

Name of the supply components	Quantity
A. Total Power Generation from Natural Gas(2021-22)	47136 Mkwh[6]
B. Percentage of RLNG supply of total natural gas supply	22.24%[7]
C .Power generation from RLNG(A×B)	10483.0464 Mkwh
E .Power Generation from 1 MMCF RLNG(Power generation from RLNG/ Quantity of RLNG)	51876.7487541 kwh
F. Cost per Kwh (Unit cost of LNG per MMCF/Power generation per MMCF)	41.50 BDT/Kwh
G. Cost per Kwh (USD)	0.3807 USD

Source: Authors' calculation

Economic cost estimation:

Estimating the economic cost of LNG requires the calculation of opportunity cost. In this study, to estimate the opportunity cost, we will use different scenarios. Our approach will be estimating additional cost of LNG import while the alternative option will be these scenarios, respectively. That is, the extra cost which could have been saved if the alternative option is used. The scenario refers to the different energy mixes. The mix can include fossil fuels (such as coal, oil, and natural gas), renewable energy sources (such as wind, solar, hydro, and geothermal), and nuclear energy. The following scenarios (energy mix) have been used to estimate opportunity costs in three situations.

1. One is the current energy mix (table 9), which is the mix of energy sources that has been used in the year 2022. We have estimated how much additional cost could have been saved by using current energy mix to generate the same amount of power that had been produced by LNG import in 2022.

2. The next one is using domestic gas instead of LNG import. We have calculated the potential cost savings that could have been realized by utilizing domestic natural gas to produce an equivalent amount of power as was generated through LNG imports in the year 2022.

3. The last one is the predicted energy mix (ATS-in-between) of 2030 by the draft IEPMP. We have approximated the potential supplementary cost reduction that might have been achieved in 2030 if the envisioned energy mix for that year could be used to generate the projected power volume from LNG import.

Table 9: Fuel-wise power generation for FY-2021-22

Fuel Type	Quantity	% of Total power generation
Hydro	744	0.87
Gas	47136	55.06
Furnace Oil	22867	26.71
Diesel	1483	1.73
Coal	5342	6.24
Renewable Energy	323	0.38
Power Import	7712	9.01

Source: BPDB

[6] BPDB annual report (2021-22)
[7] BERC annual report (2021-22)

The cost estimation of fuels per Kwh (IEPMP) has been tabulated (Table 10) as follows. We have used this unit cost estimation for the opportunity cost estimation of scenario one and three.

Table 10: Per unit cost of power generation (Tk/kWh)

Fuel types in generation	Unit cost (Tk/kWh)
Furnace Oil (FO)	17
HSD	26
LNG	13
Imported Coal	8.1
Domestic Coal	6
Domestic Gas	2.57
Hydro	1
Solar Power Plant	12
Nuclear[8]	14
Imported Power	6.48

Source: Power Division

Opportunity cost of LNG import

Opportunity cost of importing LNG in comparison with current energy mix:

To estimate opportunity cost of LNG import, we have to estimate that how much additional cost will be incurred to increase 1 unit of power generation if the fuel is imported LNG while the alternative option is the current energy mix of the country. We have not considered the associated environmental cost here as it has been estimated separately. If we want to estimate the opportunity cost of imported LNG in 2022 the following steps should be performed:

1. At first, we will estimate the opportunity cost of total power generation if the fuel is imported LNG keeping the alternative option as the current energy mix. That is, the additional cost of total power generation if imported LNG is used overall instead of current energy mix.

   Opportunity cost of imported LNG to produce total power generation quantity in 2022= Total cost of imported LNG to produce total power generation quantity in 2022 - Total cost of current energy mix to produce total power generation quantity in 2022.

2. **Opportunity cost of LNG import for 1 unit of power generation=** Opportunity cost of imported LNG to produce total power generation quantity in 2022/ total power generation quantity

3. **Opportunity cost of imported LNG quantity used in power generation in 2022**= Opportunity cost of LNG import for 1 unit of power generation × the quantity of LNG import in 2022

[8] https://www.tbsnews.net/bangladesh/energy/pdb-gets-1400mw-coal-power-dec-double-cost-538570

Table 11: Opportunity cost and economic cost estimation based on the current energy mix

Year	2022
Net Power Generation	85607000000 kwh
Cost of using only LNG (BDT)	3552690.5 Million BDT
Cost of current energy mix (BDT)	Furnace Oil(p×q) +Hydro(p×q)+Diesel(p×q)+ Coal(p×q)+RE(p×q)+ power import(p×q)+LNG(p×q)+ Domestic gas(p×q)
Furnace Oil (17×22865629700)+Hydro(1×744780900)+Diesel (26×1481001100)+ Coal (7.05× 5341876800)+ RE(12×325306600)+ Import(6.48×7713190700)+ LNG(41.50×10461750000)+ Domestic gas(2.57× 36674250000)	1032052.455476 Million BDT
Opportunity Cost of LNG for total power generation amount in 2022(Cost of using only LNG- Cost of current energy mix)	2520638.044524 Million BDT
Per KWH opportunity cost for LNG import	29.4443 BDT Per Kwh
Opportunity cost for the imported LNG amount in 2022	308665.963 Million BDT
Economic Cost of LNG in 2022(Accounting Cost of LNG+ Opportunity cost of LNG)	743795.963 Million BDT
Economic Cost of LNG (% GDP at constant price[9])	2.45%
Economic Cost of LNG (USD)	6823.357459 Million USD

Source: Authors' calculation

Opportunity cost of importing LNG in comparison with domestic gas:

The opportunity cost of imported LNG while the alternative is the domestic gas has been estimated through performing the following steps:

1. **Total cost incurred in 2022 for LNG import**=
   Total power generation from re-gasified LNG× Cost of imported LNG per Kwh
2. **Total cost of producing the same quantity of power with domestic gas** =
   Total power generation from re-gasified LNG× Cost of domestic gas per Kwh
3. **Opportunity Cost of imported LNG in 2022**=
   Total cost incurred for LNG import - Total cost of producing the same quantity of power with domestic gas

Table 12: Opportunity cost and economic cost estimation based on domestic gas

Year	2022
Power generation from re-gasified LNG	10483.0464 Mkwh or 10483.0464 ×10^6 kwh
Cost of LNG per Kwh power generation	41.50 BDT (Estimated)
Cost of domestic natural gas	2.57 BDT (Power Division)
Total cost of imported LNG in 2022= Cost of LNG per Kwh power generation × Power generation from re-gasified LNG	41.50 BDT ×(10483.0464 ×10^6) = 435046.4256 Million BDT
Total cost of generating the same quantity of power from domestic gas which had been generated from re-gasified LNG	2.57 BDT×(10483.0464 ×10^6 kwh)= 26941.429248 Million BDT

[9] 30,351,496 Million BDT (BBS)

Opportunity cost of imported LNG in 2022 = Total cost of imported LNG in 2022- Total cost of generating the same quantity of power from domestic gas	435046.4256 Million BDT - 26941.429248 Million BDT
Opportunity cost of imported LNG in 2022	408104.996352 Million BDT
Economic Cost of LNG in 2022(Accounting Cost of LNG + Opportunity cost of LNG)	843234.996352 Million BDT
Economic cost (USD)	Million USD
Economic cost as a percentage of GDP	2.778%

Source: Authors' calculation

Opportunity cost of importing LNG in comparison with the predicted energy mix in the IEPMP (ATS-In between):

Another energy mix is according to ATS (Advanced Technology Scenario)-In between for the year 2030. In-between refers to the scenario between the Perspective Plan 2041 and the IMF projection. Basically, the economic growth assumption in both the PP2041 and IMF economic outlook have been used to determine future power demand and supply in the draft IEPMP (Integrated Energy and Power Master Plan). An in-between scenario has been calculated in the plan to portray an average growth of the PP2041 and IMF outlook so that a national ambitious goal and an international assumption about the future could be combined.

Table 13: Opportunity cost and economic cost estimation based on ATS-in-between scenarios energy-mix

Year	2030
Power Generation (ATS-In-Between)	1.879× 10^11 Kwh
Cost of using only LNG (BDT)	7797850 Million BDT
Cost of ATS-In-Between energy mix of 2030[10](BDT)	
Oil (30×9395) +Solar (12×9395) +Import (6.48×16911) + Nuclear (14×15032) + Gas (41.50×77039) + Coal (7.05×56370) + Hydrogen (14.84×3758)	4364917 Million BDT
Opportunity Cost of LNG for total power generation in 2030 (Cost of using only LNG- Cost of proposed energy mix)	3432933 Million BDT
Opportunity cost of LNG import to produce 1 Kwh power	18.27 BDT
Opportunity cost of predicted LNG amount to be imported in 2030	1309663 Million BDT
Economic Cost (Accounting Cost of LNG+ Opportunity cost of LNG)	5122323 Million BDT
Economic Cost (USD)	46993.788991 Million USD
Economic Cost of LNG import (% GDP[11])	10.88%

Source: Authors' calculation

The power generation is 1.879 × 10^11 Kwh according to the outlook of power supply in the draft IEPMP (Table 4.3-1). The power generation mix according to ATS- In-Between scenario is 41% natural gas, 5% oil, 30% coal ,8% nuclear, 9% import, 2% hydrogen and 5% solar (Draft IEPMP; Figure 4.3-2). Since only a percentage of oil has been mentioned, the price has been assumed to be the average of furnace oil and diesel. The cost of Hydrogen is assumed

[10] Figure 4.3-2, IEPMP Draft

[11] Projected GDP for in-between case in 2030 is 432 Billion USD

according to the IEPMP. Also, the cost of coal has been assumed as the average cost of domestic and imported coal.

The price of gas has been assumed to be the price of LNG because, till 2030, domestic gas has been assumed to be depleted completely. Hence, **the prediction of the LNG accounting cost** = Price of LNG× predicted Quantity of LNG= 41.50 × (1.879 × 10^11 × 41%) = 3.81266 × 10^6 Million BDT. The prediction of the opportunity cost of imported LNG in 2030 has been estimated following the similar steps of section A with the predicted cost, GDP and energy mix.

Table 14: Summary of the cost estimation

		Scenario 1	Scenario 2	Scenario 3
Accounting Cost				
	BDT	435130 Million BDT	435130[12] Million BDT	3.81266 × 10^6 Million BDT
	USD	3992.0183 Million USD	3992.0183 Million USD	34987.53211 Million USD
	% of GDP	1.43%	1.43%	8.097%
Opportunity Cost				
	BDT	308665.963 Million BDT	408104.996352 Million BDT	1309663 Million BDT
	USD	2831.7978257 Million USD	3744.08254 Million BDT	12015.25688 Million BDT
	% of GDP	1.02%	1.345%	2.78%
Economic Cost				
	BDT	743795.963 Million BDT	843234.996352 Million BDT	5122323 Million BDT
	USD	2.45%	Million USD	46993.788991 Million USD
	% of GDP	6823.357459 Million USD	2.778%	10.88%

Source: Authors' calculation

5.7.2 Environmental cost of LNG import

The estimation of environmental costs is more complex than the estimation of economic costs. To estimate the environmental cost in this analysis, we have chosen the three alternative methodologies: the life cycle assessment strategy, the global warming potential method, and the Monte Carlo Simulation approach.

Life cycle assessment: Though there are quite a few estimation methods to assess the environmental cost of LNG, the Life cycle assessment is the most commonly used method for estimating environmental costs such as impact on human health and air emission (Al-Yafei et al., 2021). In this method, to understand the environmental impact of a certain fuel, the focus should be on the emission it produces over its life cycle. However, environmental emission within the boundary is not sufficient as that boundary only covers a tiny part of the total life cycle of imported LNG. Greenhouse gases emission from LNG as fuel to produce electrical energy is considered to comment on the environmental cost of LNG. While natural gas has

[12] Since Scenario 1 and 2 are considering the same period 2022, accounting costs are same for both.

comparatively lower GHG emissions than coal, LNG has GHG emissions close to coal. This is because of the extra processes LNG goes through e.g., liquefaction, shipping, and LNG life cycle emissions can be high (Balcombe et al. 2021, Moazzem et al.,2022, Swanson et al., 2020). (Al-Yafei,2021) used the Hybrid Life Cycle Air Emission Assessment Model to assess the impact on human health and air emission. MRIO-LCA, process-based (P-LCA), and LNG Transport-LCA are the three primary approaches for conducting LCA in the LNG sector and supply chain. The MRIO-LCA technique can account for environmental consequences and emissions along the whole supply chain while preventing cutoff errors. In addition, the MRIO-LCA approach can only provide standard processes, and NG extraction and exploration are effectively combined. Still, the MRIO-LCA method also adds uncertainty because it groups together sectors that are typical of the manufactured goods or activities being looked at.

Global warming potentials (GWPs): The impact of LNG import on the environment can also be assessed by observing climate change metrics like that of Global warming potentials (GWPs) (Balcombe et al. 2021). By converting emissions into 'CO2 equivalents', GWPs compare the relative impact of different GHGs on climate forcing. GWP is the average time-integrated radiative forcing of a pulse emission over a defined time horizon, compared to CO2. For example, the GWP100 gives the average climate-forcing impact over 100 years compared to that of CO2 - the 100-year time horizon is the most commonly used one, giving a CO2 equivalent value of 28e36 for methane (depending on whether various indirect climate effects and eventual oxidation to CO2 are included).

Monte Carlo Simulation (Risk assessment): A combination of LCA and Monte Carlo simulation is also used in the literature to assess the environmental impact of LNG (Sun and Ertz, 2020). Monte Carlo simulation is a statistical method that can be used to estimate the environmental costs of LNG production and use. It is typically a statistical method that involves generating a large number of random samples from a probability distribution and In the context of assessing the environmental cots of LNG it models the uncertainty and variability of the environmental costs. The Monte Carlo simulation can be applied to various aspects of LNG production and use, such as the emissions of greenhouse gases, the impacts on air and water quality, and the effects on biodiversity (Sun and Ertz, 2020). It can also be used to estimate the costs of mitigation measures and the benefits of using LNG as a cleaner alternative to other fossil fuels. One of the advantages of using Monte Carlo simulation is that it can provide a range of possible outcomes and probabilities, rather than a single-point estimate. Thus it can help decision-makers to assess the risks and uncertainties associated with the environmental costs of LNG and to design more robust and resilient strategies. However, it is worth noting that the reliability of the Monte Carlo simulation results depends on the quality and accuracy of the input data and the assumptions made in the model. Therefore, it's essential to use high-quality data, to validate the model against real-world observations, and to conduct sensitivity analyses to test the robustness of the results (KENTON,2022).

While comparing all three methods on the basis of feasibility in the context of Bangladesh, the global potential factor seems to be the most suitable option. As for the life cycle assessment approach, the data requirement is quite high and it requires a pool of data that are not readily available for Bangladesh. On the other hand, as for the Monte Carlo Simulation, the simulation results do not always demonstrate an accurate representation of reality.

Estimation of environmental cost

To estimate the environmental cost of importing LNG for Bangladesh, we would need to gather information on the GHG emissions associated with the production, transportation, and consumption of LNG. The estimation of the global warming factor requires data on the source of the LNG and the CO2 emissions associated with its production, data on the transportation route for the LNG, including the distance and mode of transportation, data on the efficiency of the power plants using the LNG in Bangladesh and the CO2 emissions associated with the combustion of natural gas. However, since Bangladesh is an LNG-importing country and we are only interested in the environmental cost of LNG occurring in Bangladesh, we will just use the data on the CO2 emissions associated with the consumption of LNG. Then we will convert the emissions into CO2 equivalents using the GWP factor. Lastly, we will use an appropriate social cost of carbon (SCC) value to determine the environmental cost of the emissions in terms of their impact on climate change.

Estimation:
To calculate the GWP of this consumption, we would need to estimate the total CO2 and methane emissions associated with the combustion of that LNG.

Estimation of CO2 emissions:
0.0053 metric tons CO_2/therm of Carbon dioxide is emitted when LNG is burned (EPA, 2023).

Table 15: CO2 emission from LNG in FY 2021-22

RLNG Amount	Co_2 Emission
1 Therm	0.0053 metric tons
0.1 MMBtu	0.0053 metric tons
0.0001 MMCF	0.0053 metric tons
202076.01 MMCF	10710028.53 metric ton
	10710.02853 Kt

Source: Authors' calculation

Estimation of methane emissions:

The primary origins of methane emissions at LNG export/import terminals encompass several aspects:

- Unintentional escapes of methane from equipment and loading arms.
- Purposeful release of methane (blowdown) from LNG storage tanks and equipment for managing pressure or in emergencies, facilitated through pressure relief valves and vent stacks.
- Methane release during the cooling process of equipment at the terminal.
- Suboptimal burning of fuel (e.g., natural gas) in power generation equipment.
- Inadequate combustion of boil-off-gas during operational phases and blowdown gas during maintenance or emergency shutdowns, often managed through flare systems.

Methane is a much more potent greenhouse gas than CO_2, with a GWP factor that is 28 times higher than CO_2 over a 100-year time horizon. According to a study in 2019 performed by the National Energy Technology Laboratory in the United States, during regasification, methane emissions were measured at a rate of 90 grams per ton of LNG processed (Clean air task force, 2021).

The average calculated emission factor (EF) is 5.4 (+10/–5.4) g CH4/million British thermal units (MMBTU) natural gas for natural gas-fired power plant (Hajny et al., 2019).

Table 16: Methane emission from LNG in FY 2021-22

LNG	Methane
1 metric ton	90 gram (during regasification)
3419397.6962 metric ton[13]	307745793.658 gram
	307.74579366 metric ton
RLNG	**Methane**
1 MMBtu	5.4 gram
207,734,137 MMBtu(202076.01 MMCF)	1.121764339×10^9 gram
	1121.764339 Metric ton
Total Methane emission for LNG operation in FY2021-22	1429.510133 Metric Ton

Source: Authors' calculation

Estimation of GWP of the emissions:

To calculate the GWP of the emissions, we need to convert the CO2 and methane emissions into Co_2 equivalents using the appropriate GWP factors.

Table 17: Global warming potential (GWP) estimation

Gas Name	Gwp factor/Carbon equivalent amount
Co_2 (GWP Factor)	1(Since Co_2 is used as the reference gas)
Methane (GWP Factor)	28 over a 100-year time horizon
Total Co_2 equivalent emissions	(10710028.53 metric tons of $Co_2\times1$) + (1429.510133 metric tons of methane× 28)
=	10750054.813724 metric tons of CO2 equivalents

Source: Authors' calculation

Estimation of the overall environmental cost:

After determining the net carbon di-oxide equivalent emissions, we then use the costs of carbon to determine the environmental cost through the social cost of carbon emission (Wright & Doelle, 2019). In the assessment of the benefits associated with mitigating one metric ton of carbon emissions, two primary approaches are employed. One approach involves utilizing the price of carbon, while the other relies on the concept of the social cost of carbon. The social cost of carbon approach is preferred due to the inherent price volatility of carbon and the reliance on carbon caps as regulatory mechanisms. The social cost of carbon, as documented in the scientific literature, exhibits a significant range, spanning three orders of magnitude, with estimates varying from as low as USD 1 to as high as USD 1,500 per ton, (Yohe et al., 2007). Further investigation into peer-reviewed research on the social cost of carbon reveals a consensus mean estimate of USD 43 per ton, accompanied by a standard deviation of USD 83 per ton (Wadud &Khan, 2011). It's worth noting that for their calculations pertaining to the cost of carbon emissions, Wadud and Khan (2011) utilized a specific social cost of carbon figure, namely USD 43 per ton. With this social cost as the base social cost of

[13]According to the RPGCL data, 3419397.6962 metric ton (9682656 Cubic meter) LNG has been imported in cryogenic form in FY2021-22.

$45 in 2009, and an average inflation rate of 5.5 percent, adjusted Price has been estimated as $95.22 in 2023 (appendix).

This adjusted price takes into account the effects of inflation over time. In this case, it represents the estimated price of the product in 2023 when adjusted for inflation based on the specified inflation rate and base year.

Table 18: Social (environmental) cost estimation of LNG in FY 2021-22

Gas Name	Emission Quantity
Co_2 equivalents emission in 2021-22	12791480.4824 metric tons
Social Cost	10750054.813724 MT * $95.22/MT
=	$1.0198489 Billion USD (approximately)
Social cost (% GDP)	0.366%

Source: Authors' calculation

6. A Review of the Demand and Supply of Gas Fuel under the Current Scenario Context

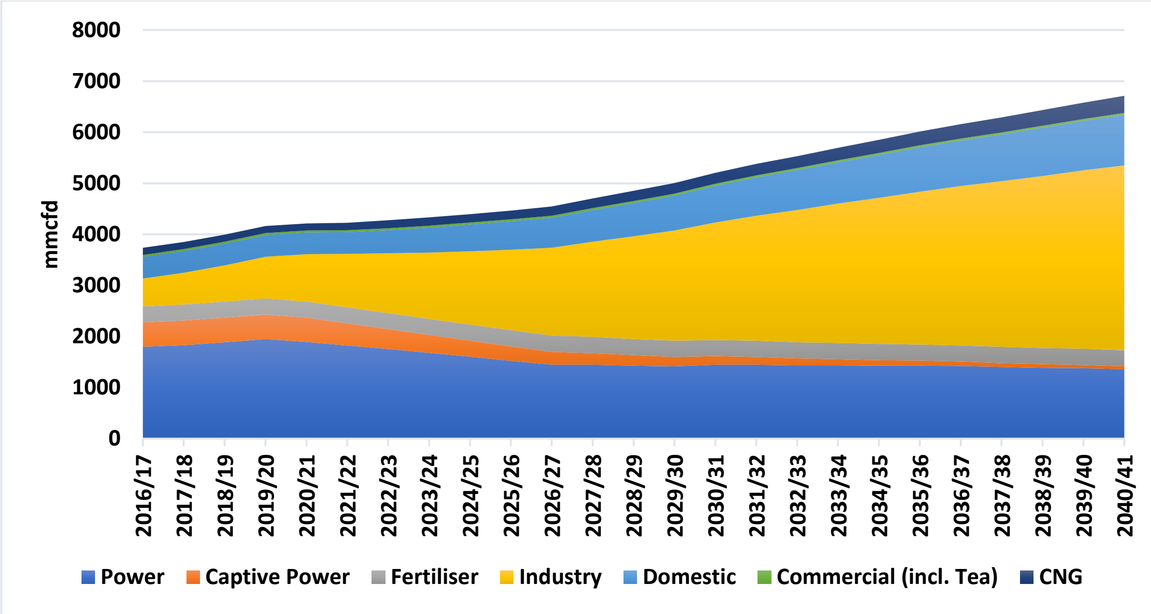
Gas, the naturally occurring combination of combustion products, is found deep inside the Earth's crust (often in conjunction with petroleum) and is one of the three most important fossil fuels used today, with coal and oil. Natural gas has been contributing to the national economy of Bangladesh as a primary fuel since its first discovery in Bangladesh in the 60s. Currently, 59% of the commercial energy in the country comes from natural gas (Bangladesh Economic Review, 2023). The gas sector in Bangladesh has been a significant contributor to the country's remarkable rapid economic growth and steady development. The strong economic expansion of the country during the last two decades was powered by natural gas as it is a relatively cheap source of primary energy. Still, a higher and more secure rate of energy supply is needed as we have the vision to become a developed nation by 2041.

According to the Gas Sector Master Plan 2017, within the next 6-8 years there is no such possibility of any significant increase in the domestic production of natural gas. At the same time, the current demand for gas is growing and it has been forecasted that the sharp increase in demand will be continued for the next some years. So, the current gas shortage is expected to expand in the coming years, which has compelled the government to curb gas supply to fertilizer production, businesses, households, and industrial units prioritizing the state-owned and privately-owned power plants. Also, the use of primary energy is being diversified toward coal, and the import of liquefied natural gas (LNG) from abroad continues to enhance the energy supply. Though the natural gas shortage has been a headache for a long time, the exploration activities are not up to the mark yet keeping vast areas of the country unexplored and underexplored.

6.1 Demand for natural gas in Bangladesh

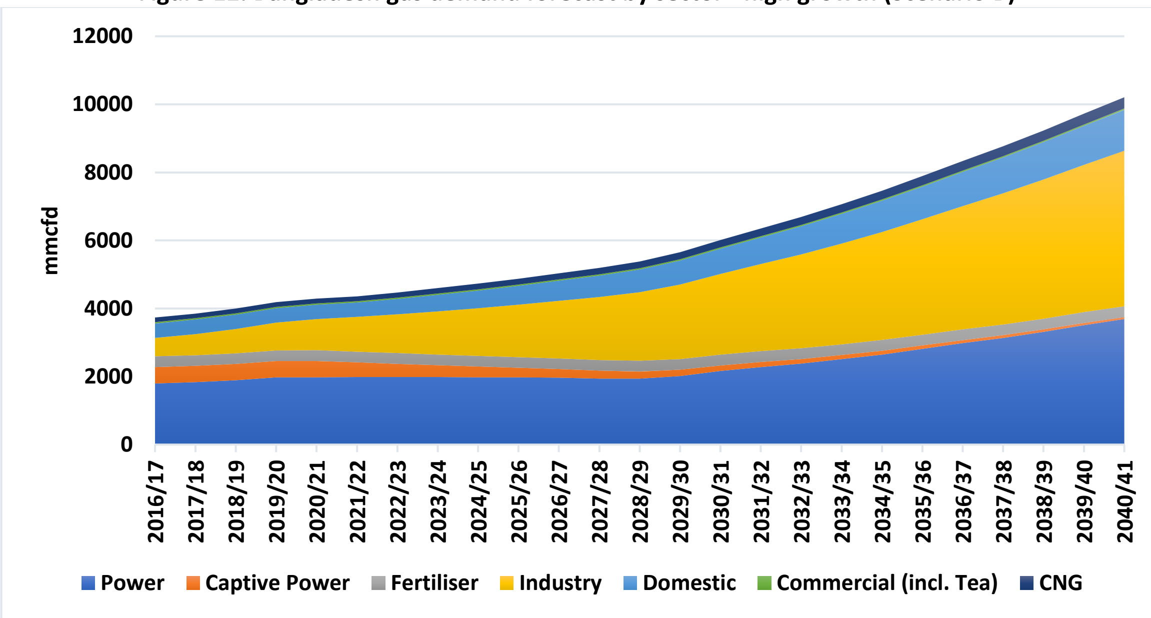
The production and consumption of gas have doubled over the past decade, that is, in 2006-2016 period, reaching 2,750 MMCFD. Due to gas reserve depletion, the amount decreases to 2310 MMCFD (BERC,2022).Due to high levels of unmet demand and the consequent necessity of reducing supply, demand is even higher than before. According to the Gas Sector Master Plan (GSMP) 2017, three scenarios are considered: A) base scenario (similar to PSMP2016) with a focus on self-sufficiency and hereby introduction of coal on a large scale, B) a high growth, an international-oriented scenario with focus on gas, and C) climate scenario, where climate change renewable energy supplement use of gas on large scale. Scenario C is considered the basis for further analysis. From the following figures, it is clear that the gas demand is likely to grow more, and the extent is dependent on whether we are focusing on gas or renewable energies.

Figure 11: Bangladesh gas demand forecast by sector - modified PSMP2016 (Scenario A)



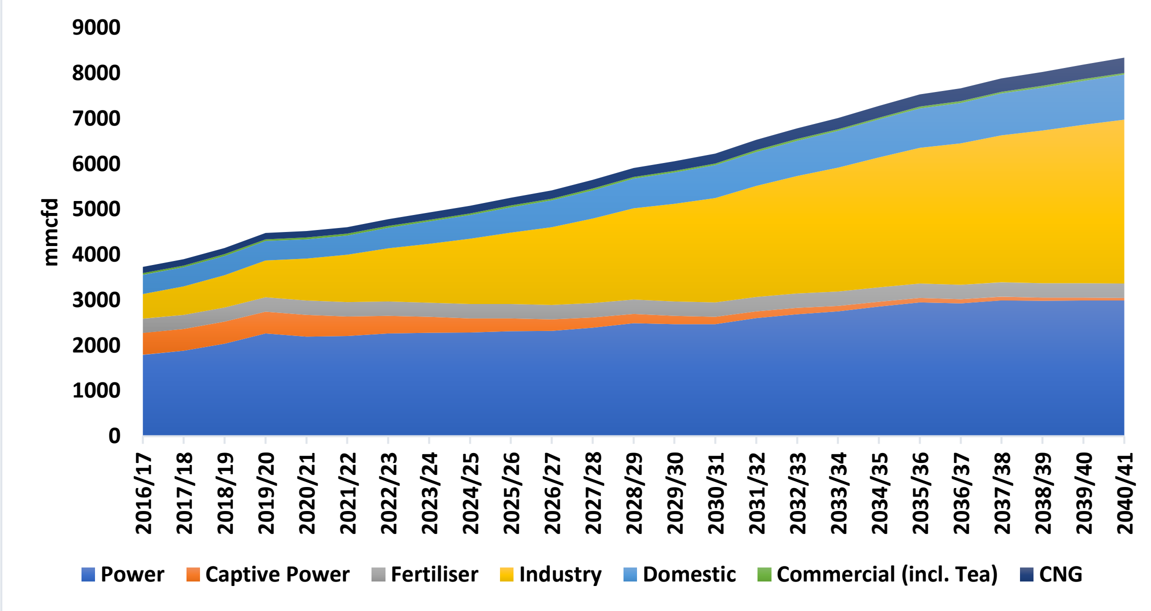
Source: Ramboll, GSMPB 2017

Figure 12: Bangladesh gas demand forecast by sector - high growth (Scenario B)



Source: Ramboll, GSMPB 2017

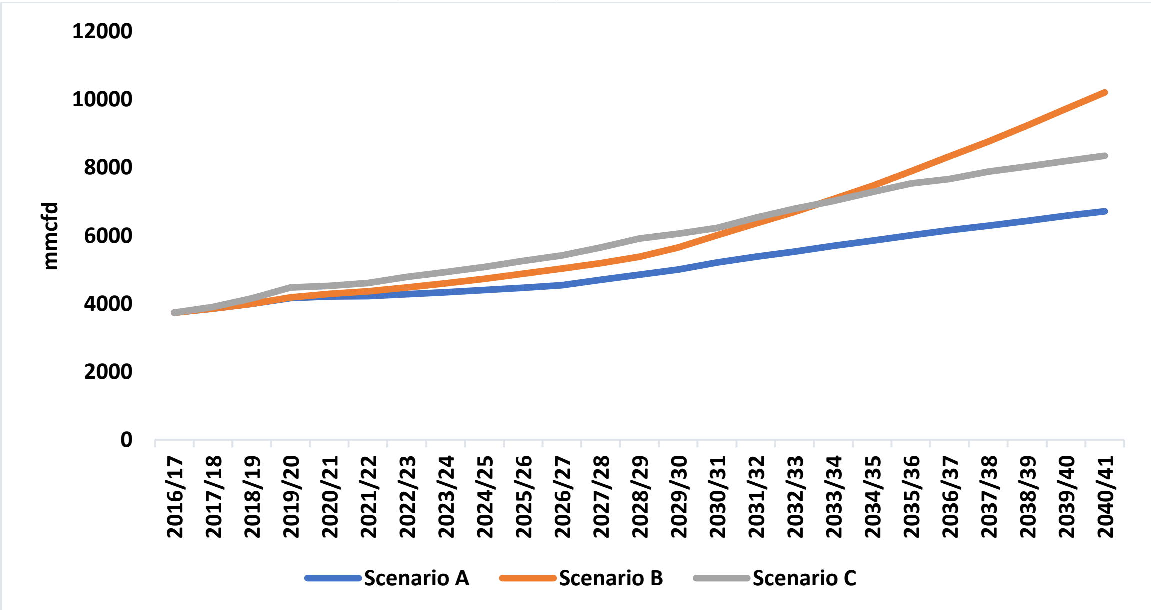
Figure 13: Bangladesh gas demand forecast by sector - climate change (Scenario C)



Source: Ramboll, GSMPB 2017

In the gas sector master plan 2017, while using Petrobangla's estimate as per base year demand, In Scenario A (Figure 11), the total gas demand was predicted to reach 6,713 MMCFD (equivalent to 2.5tcf/year), while in Scenario B (Figure 12), it was predicted to reach 10,208MMCFD (equivalent to 3.7tcf/year), and in Scenario C (Figure 13), it was predicted to reach 8,346MMCFD (equivalent to 3.0tcf/year) by 2041. Figure 14 shows the overall gas demand forecast by scenario.

Figure 14: Total gas demand forecast



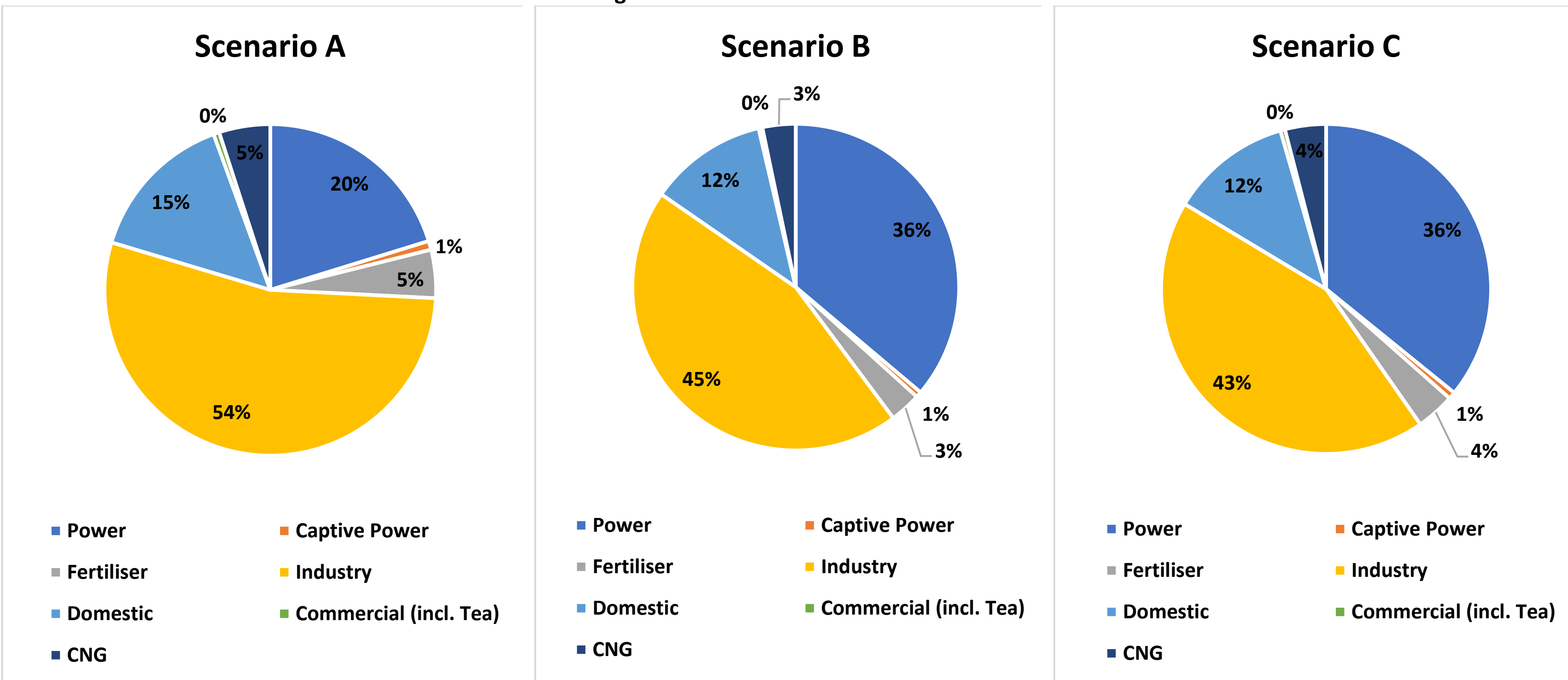
Source: Ramboll, GSMPB 2017

Gas consumption from the power sector is expected to decrease in Scenario A if the gas share in power generation is lowered from its current level of roughly more than 50% to only 20% by 2041, which is less than the IEA World Energy Outlook 2016 global average of more than 20%. Captive power is predicted to stop altogether by 2041, while its percentage of overall gas demand falls from 48% in 2016/17 to only 20% in 2041. In contrast, residential and industrial demand is expected to expand rapidly, making up about 69% of total gas consumption in 2041.

Scenario B calls for a far more gradual decline in gas's participation in power generation than Scenario A does, from its current level of roughly more than 50% to 40% by 2041. Although power's percentage of total gas demand decreases from 48% in 2016–17 to 36% in 2041, absolute power's need for gas doubles from current levels by that time. Likewise, to Scenario A, it is expected that captive power will drop while demand from both the industrial and residential sectors will increase significantly throughout the period. In Scenario C, all sectors except power have the same projected gas consumption as Scenario A until 2041, when power's sectoral gas demand hits roughly 3,000 MMCFD, accounting for 36% of total gas demand in Bangladesh.

Gas demand forecast by sector have been presented in Figure 15 below. Scenario B and C forecast higher use of natural gas for power generation than scenario A. Industrial sector is the prime sector for gas consumption irrespective of scenarios.

Figure 15: Gas sectoral demand 2041



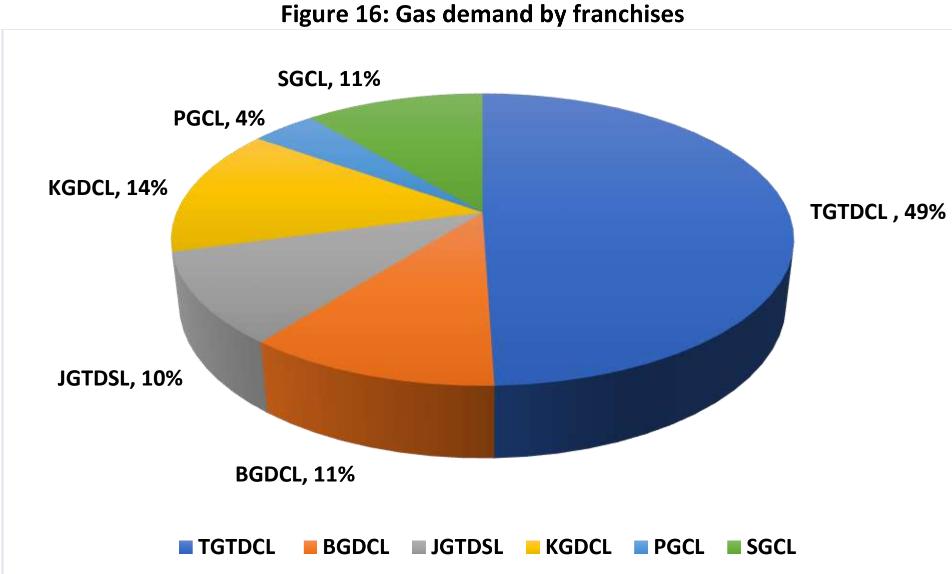
Source: Ramboll, GSMPB 2017

6.2 Regional gas demand

There are 6 corporations for the regional distribution of natural gas in Bangladesh: Titas Gas Transmission and Distribution Company Limited (TGTDCL), Bakhrabad Gas Distribution Company Limited (BGDCL), Jalalabad Gas Transmission and Distribution System Limited (JGTDSL), Pashchimanchal Gas Company Limited (PGCL), Karnaphuli Gas Distribution Company Limited (KGDCL) and Sundarban Gas Company Limited (SGCL).

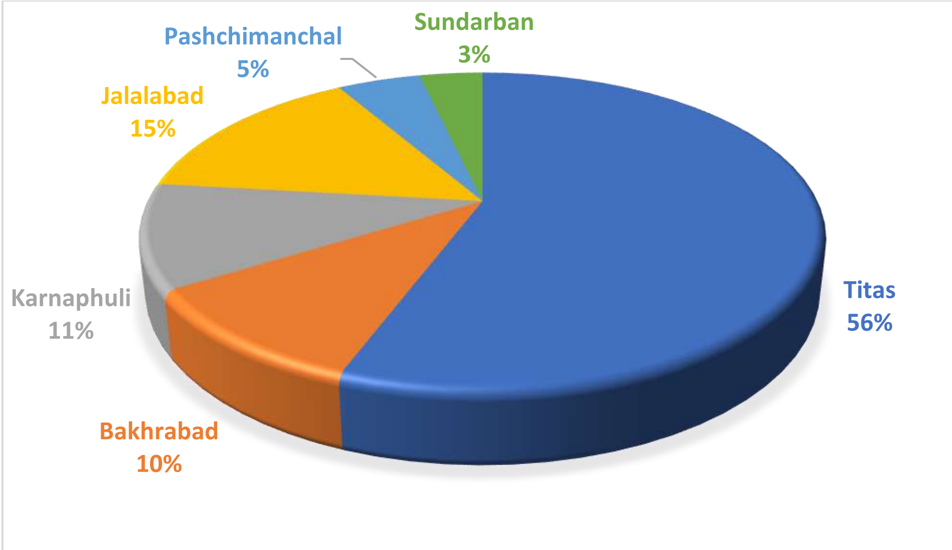
Figure 16 illustrates the estimated gas demand for each franchise region in 2016–17 as per the gas sector master plan. The demand for gas in the Titas franchise area is the highest in Bangladesh, at nearly half of the total; the demand in the Karnaphuli franchise area is the second highest, at 14% of the total; the demand in the Bakharbad, Jalalabad, and Sundarban franchise areas is very similar, at 10%-11% of the total; and the demand in the Pashchimanchal franchise area is the lowest, at 4% of the total. The gas purchase by fracnchises in 2021-22 shows that Titas and Jalalabad raised their purchase significantly whereas Sundarban and Karnuphulis' purchase fell (Figure 17)

Figure 16: Gas demand by franchises



Source: Ramboll, GSMPB 2017

Figure 17: Gas purchase by franchises (2021-22)



Source: Annual Report (2021-22), Hydrocarbon Unit

6.3 Natural gas supply projection in Bangladesh by the Gas sector master Plan 2017

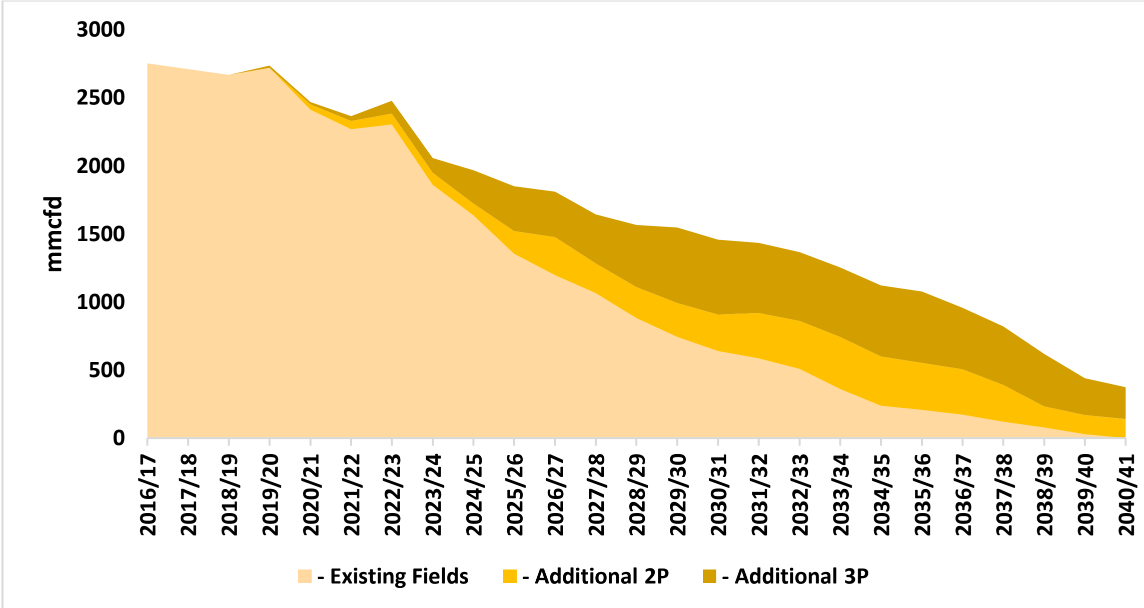
Petrobangla and its subsidiaries had proposed long-term gas production (2016-2041) scenarios where the forecast relies on a deterministic method based on a material balance, and the associated uncertainties should not be underestimated. There is some variation amongst the forecasts. The predictions vary slightly from one another, but they all predict steady to slightly declining production from current fields, and a steep fall in production after 2022. Strategic planning for the long term (+10 years) was the main focus in the gas sector master plan 2017. The following sections present and analyse three different gas supply scenarios according to that master plan.

Case A – Proven, Probable, and Possible (3P) reserves

With no more resources discovered, this scenario offers the optimal use of currently available fields (Figure 18). According to the Consultants' output prediction for 2016–2041, daily gas production is 2500 mmcf up to 2022, after which it rapidly declines. This output forecast incorporates authorized and planned field development plans. The Consultants do not have access to the field development plans.

The Consultants have made projections for the extra 2P reserve that was not taken into account in the production schemes that were submitted. No development strategy exists for this "extra 2P" production, hence it depends on future development. Because of this increased 2P reserve, an increase in production is not anticipated in the near future, but it is anticipated in the medium to long term, subject to the necessary development. The additional 2p reserve has a 1.6 tcf potential. Rashidpur and Semutang fields are now anticipated in the operator's production forecast as having the largest reserve within the extra 2p class.

Figure 18: Case A Proven, probable(2P) and possible (3P) reserves forecast



Source: Ramboll, GSMPB 2017

Case B – Proven, Probable and Possible (3P) reserves with Yet to Found (YTF) contribution

With a YTF contribution of 6.4 tcf, this scenario makes the best use of currently available fields. The Consultants have received the YTF contribution in the form of BAPEX new, Shallow Offshore, and Deep Offshore.

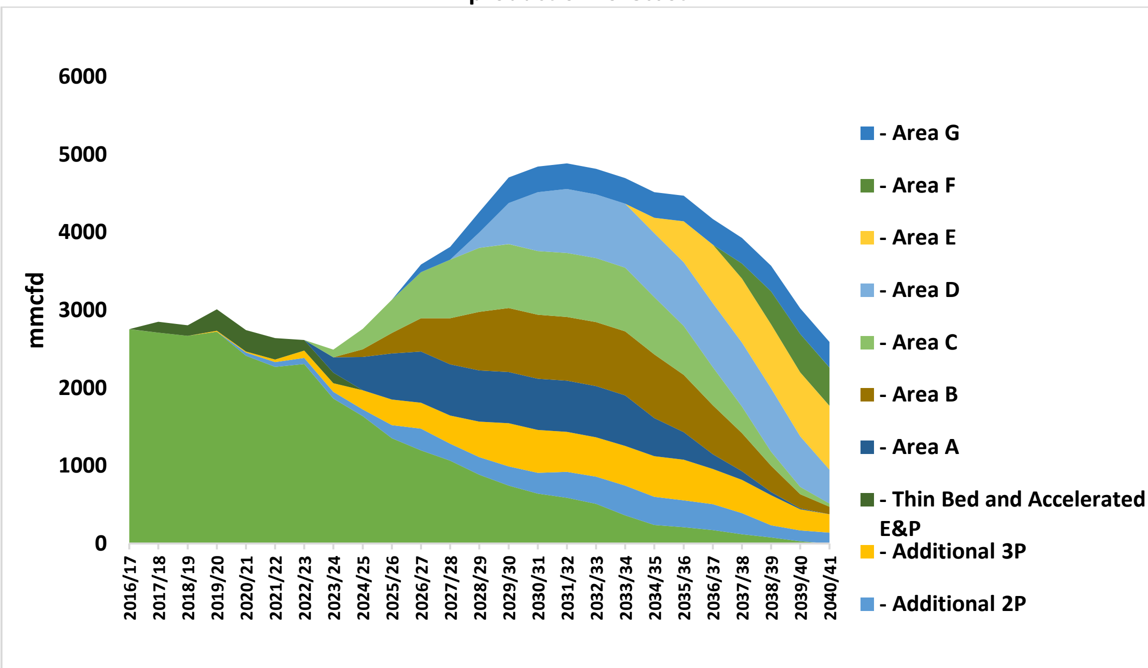
Production from "yet-to-be-discovered" reserves in onshore, shallow offshore, and deep offshore fields has been anticipated in the "Gas Production Augmentation Plan (2016-2041). The contribution of the YTF is anticipated to be 2.6 tcf from new onshore fields and 2.1 and 1.7 tcf from shallow offshore fields and deep offshore resources, respectively.

The inclusion of the YTF resource is anticipated to have an effect on output in the near, medium, and distant futures. The addition of new products is anticipated to begin in 2017 and to maintain production above 3000 MMCFD until 2025 when shallow offshore production is also anticipated. With the new YTF, production rates exceeding 2500 MMCFD are anticipated until 2031. The Consultants do not have access to the specifics of these anticipated YTF by BAPEX or the underlying assumptions that will affect the strategic reserve prediction.

Case C – Proven, Probable and Possible (3P) reserves with an additional YTF contribution

According to Gustavson's (2011) assessment, this scenario provides the optimal use of current fields with a YTF contribution, and the Consultants' investigation indicates that around 16–17 tcf can be produced till 2041. The Consultants have evaluated the YTF contribution using the available reports and their anticipation of the impending and accelerated future exploratory activities announced by Petrobangla and its subsidiaries (Figure 19). In this scenario, reserve growth is 1000 bcf per year, which is twice the typical historical rate for Bangladesh.

Figure 19: Case C- Proveb, probable and Possible(3P) Reserves with 34 TCF YTF(A-G) contribution to the production forecast



Source: Ramboll, GSMP 2017

According to the findings, the nation has access to a sizable YTF (Area A to G; Figure 19) resource. Existing fields have access to the resource in the form of both conventional gas and thin-bed resources. As discussed in previous cases, Petrobangla and its subsidiaries are currently carrying out an ambitious exploration program that has been sanctioned by the Government of Bangladesh. The experts conclude that a scenario with a bigger YTF contribution than that outlined in Scenario B is warranted based on these actions. Scenario C assumes that the average GIIP growth rate may be increased by well over 500 bcf per year through a systematic and well-planned exploration strategy. A summary of the risked gas resources according to each type has been tabulated in Table 19.

Table 19: Summary of risked Gas resources (Bcf)

Type of Resources	P90	P50	P10
Identified Prospects	12510	19295	**28259**
Identified Leads	21844	34057	**49719**
Unmapped	65	443	**2548**
Total Prospective Resources	**34419**	**53795**	80526
Shale Gas and Shale Oil	4007	9392	**18931**
Coalbed Methane	346	426	**522**
Total Contingent Resources	4353	9818	19453

Source: Gustavon (2011)

6.4 Gas sector summary for FY 2021-22

Gas Production Scenario

In the 2021-22 fiscal year total production of gas reached 841.99 Bcf in 20 producing gas fields, and daily average production was 2306.83 MMcfd. During the year well-wise maximum daily gas production was 1203.50 MMcfd, and well-wise minimum gas production was 0.78 MMcfd from the Semutang gas field. In comparison with the 2020-21 fiscal year, the decrease in annual and daily gas production in 2021-22 was 50.76 Bcf and 139.09 MMcfd respectively. Gas production in Bangladesh is largely dependent on the Bibiyana, Titas, Jalalabad, and Habiganj gas fields with the contribution of 84% of the total production. The biggest field-wise producer in 2021-22 is Bibiyana (52%) followed by Titas (17%), Jalalabad (8%), Habiganj (7%), etc. During this year National Companies produced an average of 844.31 MMcfd gas daily from 70, wells which amount to 308.17 of Bcf gas production yearly. On the other hand, the international companies, Chevron and Tullow Oil, harnessed an average of 1462.52 MMcfd gas daily from 42 wells, which is equivalent to 533.82 Bcf of gas production yearly. Of the total volume of annual gas production by national companies, BGFCL accounts for the lion's share (73%), followed by BAPEX (16%), and SGFL (11%). And, of the total volume of annual gas production by international companies, Chevron clearly dominates with 96% shares in production. Table 20 illustrates that the biggest company-wise producer in 2021-22 is Chevron (61%) followed by BGFCL (27%), BAPEX (6%), etc.

Table 20: Company-wise Gas Production in FY 2021-22

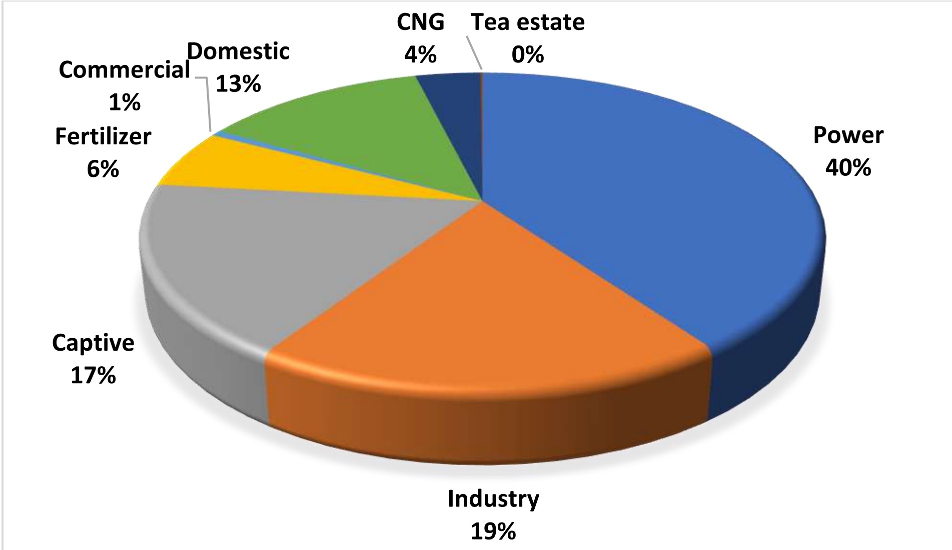
SI No.	Name of Company	Total well	Production well	Suspended well	Bcf	MMcfd
1.	BAPEX	35	15	20	49.95	**136.84**
2.	BGFCL	51	44	7	225.86	**618.80**
3.	SGFL	29	11	18	32.37	**88.67**
4.	Chevron	44	37	7	513.13	**1405.84**
5.	Tullow	7	5	2	20.69	**56.68**
6	Santos	9	0	9	Suspended	**Suspended**
Total		**175**	**112**	**63**	**841.99**	**2306.83**

Source: HCU Data Bank

Gas Consumption Scenario

Considering the gas consumption scenario for Bangladesh, Figure 20 illustrates that the total gas consumption was 1001.180 Bcf in 2021-22, and the biggest consuming sectors are Power (40%) with 401.927 Bcf, followed by Industry (19%) with 190.995 Bcf, and Captive (17%) with 175.685 Bcf. The Domestic, Fertilizer, and CNG sectors account for 13%, 6%, and 4% of the total consumption respectively. On the other hand, Commercial and Tea estates have the lowest shares, at 1% and 11% respectively.

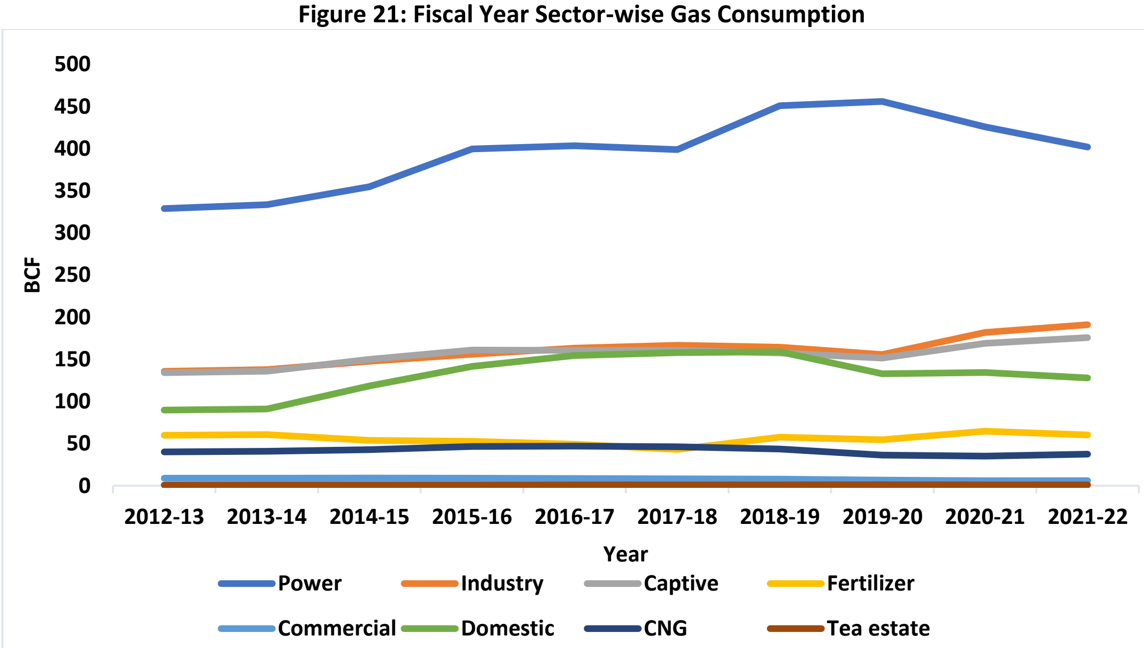
Figure 20: Gas Consumption Scenario FY2021-22



Source: Ministry of Power, Energy and Mineral Resources 2023

If we look at the historical trend in gas consumption in Figure 21, we can conclude that Power, Industry, and Captive have been roughly dominant since 2012-13, with Domestic steadily increasing its consumption volume. Other sectors somewhat follow an oscillating path over the years.

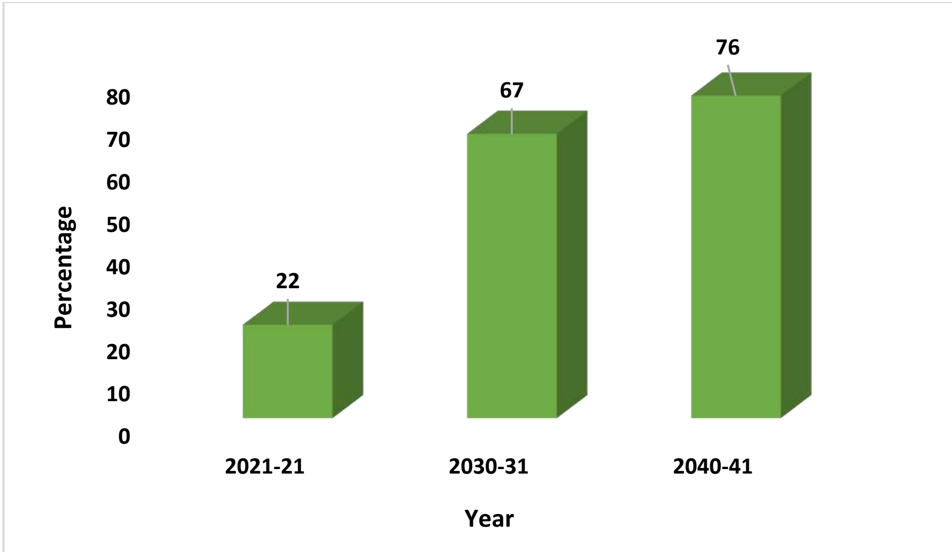
Figure 21: Fiscal Year Sector-wise Gas Consumption



Source: Ministry of Power, Energy and Mineral Resources 2023

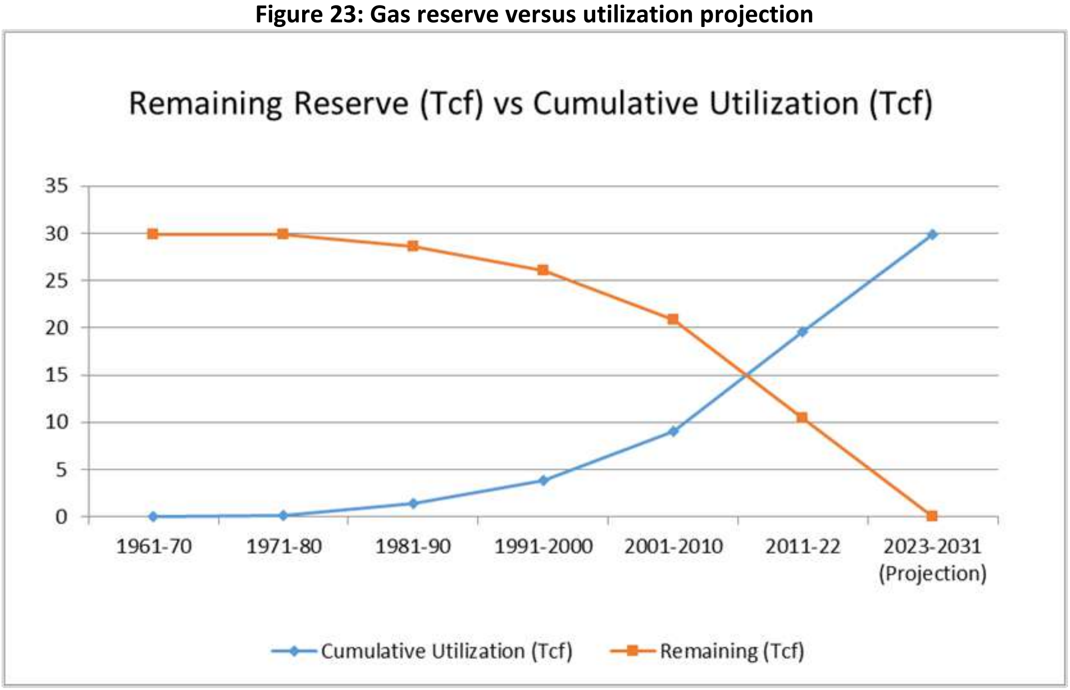
The import dependency has been projected to rise sharply in the coming decades according to the Hydrocarbon unit of EMRD (Figure 22). Without any further development the gas reserve will be fully exhaustive by 2030-31 according to their gas supply projection (Figure 23).

Figure 22: Import dependency according to gas supply projection



Source: Annual Report (2021-22), Hydrocarbon Unit, EMRD

Figure 23: Gas reserve versus utilization projection



Source: Annual Report On Gas Production, Distribution and Consumption 2021-22

6.4 Gas sector prospects according to key stakeholders

According to gas-sector specialists, there are three stages of gas exploration. The first stage is the easily identifiable gas fields. The other two stages involve studying complex areas. Traditionally around the world, complex areas are also explored. Bangladesh has been limited to this first stage and has stopped exploring more gas fields in the other two-thirds of the area. It is claimed by experts that there are not enough exploration activities. If enough exploration could be performed, then there would be fewer shortages. Two-thirds of the area has not been explored yet. Sylhet-Comilla regions have only been explored. Despite exploring one-third of the area, the number of discovered gas fields have been remarkable. In the case of offshore exploration, India and Myanmar have already started exploring gas fields after settling maritime disputes with Bangladesh. They are already seeing success. But Bangladesh is still years behind in this aspect as the low gas price offered by the government could not convince foreign companies. Also, it is claimed that exploration projects are riddled with various bureaucratic complexities. According to experts' opinion, with an exploration success rate of 33% in BD, it would be a good idea to explore more gas fields.

Currently, GTCL supplies natural gas to six distribution companies. There is always a gap of 500 to 700 million between production and demand. For example, about 2800 to 2900 million cubic meter of gas is distributed but the demand is about 3600 million cubic meters of gas. The pressure is lower due to insufficient supply, the end users don't get gas at the desired pressure and amount. Another challenge is the under-utilization of the central grid line in terms of cost-effectiveness. The cost of setting up the central grid line is considerably intensive—about 15 to 20 crores taka which is the highest among other types of costs. The capacity of this line is approximately 4000 million (our demand is nearly 3500 to 3600 million) but the supply is pretty much less than that. We are getting 1500 million less gas compared to our well-developed infrastructure. Hence, under-utilization is taking place. Another important challenge is the wheeling charge from the government for transmission is lower than what it should be. The current wheeling charge is 47 paisa per unit. It should be at least 2 taka per unit. Therefore, two things: to raise the wheeling charge, and, then, to increase the volume of gas are crucial for the proper utilization of gas.

A Korean company called Dayo surveyed to find out whether gas extraction is possible. If such gas mines are discovered then contracts can be entered into with various companies. Recently multi-client survey is also happening. They will survey our offshore to see the potential. The data will be sold to those who want to come to explore. If the data of the survey is feasible, they will come. But there are many possibilities here. Since Myanmar is getting gas from the same place, we are supposed to get it from the same basin.

7. An Overview of the Renewable Energy Sector: Challenges and Prospects

7.1 Renewable energy

Since renewable energies offer a secure source of energy, the world's most powerful nations are now stepping up their investment in renewables in light of the present geopolitical unrest. The conflict in Ukraine revealed the expense and unreliability of relying on gas. Controlling energy also implies that Bangladesh's inhabitants will have more dependable power. According to a USAID report, only 11% of homes in Bangladesh that are linked to the grid have access to energy for more than 16 hours a day (Nicholas, 2022). This issue may be resolved by supplying secure renewable energy at a set cost that is unaffected by fluctuations in the price of fossil fuels to households and businesses.

A new clean energy target of 25% of the total (including renewable and nuclear) by 2030 has recently been proposed to be included in the IEPMP by Bangladesh's Sustainable and Renewable Energy Development Authority (SREDA) (Nicholas, 2022). This objective would be 10,000MW of power, with 5,000MW coming from wind energy. However, till now, the draft IEPMP has proposed 40% of clean energy having nuclear, hydro, solar PV, wind, CCS, ammonia, and hydrogen in the clean energy mix. The Mujib Climate Prosperity Plan was introduced by Bangladesh in 2021 (MCPP) to enhance the nation's resiliency to climate change. The ambitious MCPP-M scenario relies on Bangladesh being able to reach 80% of its self-determined maximum RE contribution in the power mix by 2030 and suggests a solar capacity goal of 2.7 GW by 2025. If this trajectory had been followed, 9.4 TWh more solar energy would have been produced between 2022 and 2024 than it did on the existing trajectory. This would reduce the amount of LNG that would need to be imported on the spot market during this period by 25% (3.1 mcm), saving $2.7 billion on the price of imported gas (Lolla, 2022). The reliance on fossil fuels is being rapidly reduced in other nations. Planning is being done for 21st-century energy markets, not those from the past. That transition will be accelerated by the recent volatility in fossil fuel prices.

Table 21: Potential renewable and fossil fuel energy resources in Bangladesh

Renewable energy resources	Resource capacity/ potential/ reserve
Solar	40,000 MW
Hydro	2228 MW
Wind	30,000 MW
Other	1848 MW
Fossil fuel energy resources	
Natural gas	28.69 Tcf
Coal	3100 M tons

Source: Bhuiyan and Mamur, 2021

To fulfil the rising energy needs of the country, Bangladesh has a number of renewable resources including solar, wind, hydro, biomass, and biogas. Solar power has seen the most advancements of all renewable energy sources (Table 21). In rural areas, where more than 62% of the total population resides, solar electricity can offer immediate and substantial benefits. Solar energy's portability and accessibility are its main benefits. As opposed to erecting wind turbines, hydroelectric dams, or fossil fuel facilities, installing solar panels is a lot simpler. Therefore, renewable energy deployment in Bangladesh is mostly based on solar power (Table 22).

Table 22: Renewable energy deployment in Bangladesh

Technology	Off-grid (MW)	On-grid (MW)	Total (MW)
Solar	347.43	196.01	543.44
Wind	2	0.9	2.9
Hydro	0	230	230
Biogas to Electricity	0.69	0	0.69
Biomass to Electricity	0.4	0	0.4
Total	350.52	426.91	777.43

Source: SREDA

7.2 Solar energy

Recognizing the significance of sustainable energy, the Bangladesh government is presently prioritizing a transition from non-renewable to renewable energy sources across various industries. This focus reflects the nation's commitment to harnessing its natural solar abundance and mitigating environmental impacts, paving the way for a more sustainable and cleaner energy future.

Bangladesh holds remarkable potential for harnessing solar energy, making it one of the most promising renewable resources in the country. With an average daily solar radiation of about 4.5 kWh/m2, there lies a significant opportunity to capitalize on this abundant energy through both thermal and photovoltaic methods. These approaches offer practical ways to convert solar radiation into usable energy sources. The National Solar Energy Roadmap (SREDA) suggests a new solar goal to address the stagnant renewable energy development. According to the high case the goal of solar-based power generation is to reach 30 GW by 2041, with 40% covered by large-scale solar PV power projects and another 40% originating from rooftop solar installations. If the government prioritizes the expedited action plan, Bangladesh's solar energy potential could reach 50% of its installed capacity by 2041 (National Solar Energy Roadmap, 2020).

Despite the immense potential, solar photovoltaic (PV) systems have so far contributed only a fraction of Bangladesh's energy needs. As of December 2021, the renewable energy sector generates an approximate total of 777 MW of electricity. Notably, a substantial portion, nearly 70% of this capacity, is derived from solar power, amounting to approximately 543 MW. Among these solar installations, around 347 MW comes from off-grid solar systems, while the remaining 196 MW is contributed by grid-connected solar power sources (IEPMP (Draft), 2022).

Solar energy development initiatives in Bangladesh can be classified into distinct categories, encompassing both private and public enterprises as follows (SREDA,2023):

1. Solar home system(SHS)
2. Solar Park

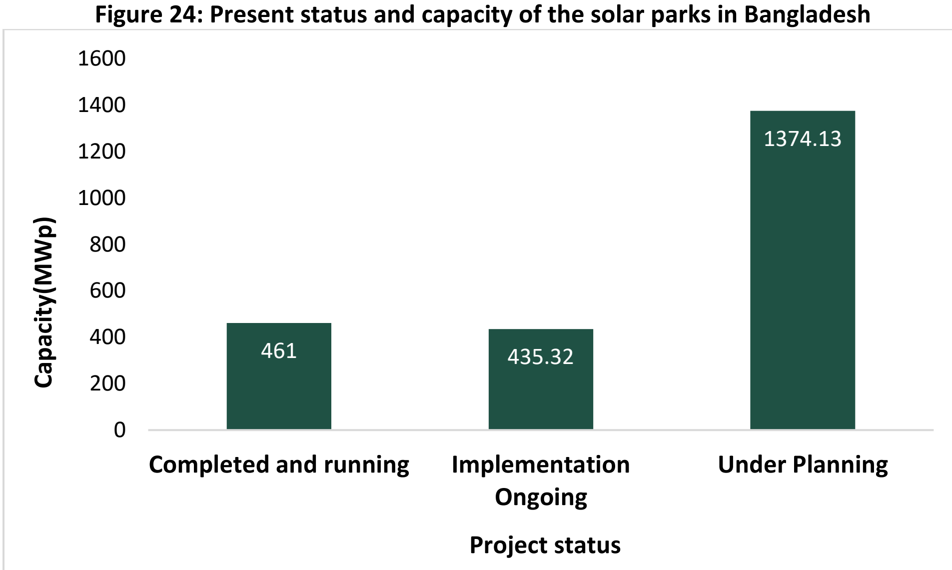
3. Rooftop solar except for NEM
4. Net Metering rooftop solar.
5. Solar Irrigation
6. Solar Minigrid
7. Solar Microgrid
8. Solar Nanogrid
9. Solar charging station
10. Solar Power Telecom BTS
11. Solar drinking water system
12. Solar street light
13. Solar water heater

Among all categories solar parks, rooftop solar power and solar irrigation system are considered the large-scale RE project by SREDA dominating the solar industry in Bangladesh. Regarding small renewable energy projects solar home system (SHS), and the mini-grid system are significant.

Solar parks:

Solar parks or large solar photovoltaic plants contribute the most to generating power in the solar industry of the country. As of now, there are ten completed and running solar parks along with eight implementations ongoing and twenty-four under-planning solar park projects. Solar parks have the largest capacity of 2470.66 MWp in comparison with other solar systems. The rush to expand solar power plants is evident in Figure 24, where the planned projects indicate a significantly larger future capacity compared to the projects those are completed, running and ongoing implementation.

Figure 24: Present status and capacity of the solar parks in Bangladesh



Source: National database of renewable energy, SREDA

Climate Analytics has reported that harnessing solar energy by installing solar panels across more than 1.5% of Bangladesh's total land area has the potential to generate an impressive 3080 TWh of power (Uddin, et al., 2019). To put this into perspective, this amount is equivalent to seven times the power consumption in the year 2016. The National Solar Energy Roadmap provides three estimates for solar energy production in Bangladesh by 2041: 6 GW under the Business as Usual (BAU) scenario, 20 GW in the mid-case scenario, and an ambitious 30 GW in the high-case scenario.

According to the Bangladesh Power Development Board (PDB), the first seven blocks of the proposed power hub in Maheshkhali, Cox's Bazaar will each feature a 50MW solar power plant, as planned by the government (Saif, 2023). The Bay of Bengal Power Company is conducting feasibility studies for the development of a grid-connected solar power plant in Maheshkhali (Saif, 2023). The Bangladesh Power Development Board (PDB) plans to construct a 135 MW solar power facility on 410 acres of land in Block 9 of the power centre. The initiative is expected to cost 1.185 billion Bangladeshi taka and will be completed by 2026. In addition, Amara Raja Infra Pvt. Ltd. of India will construct a 100 MW solar power facility in Bangladesh. The project will be financed by the Exim Bank of India with a budget of $13 million (Akter, 2023). It is anticipated that construction will commence this year and be completed within 18 months.

The opportunity cost of land is one of the biggest obstacles to developing renewable energy infrastructure globally. The opportunity cost is much larger for a country with a high population density like Bangladesh since land that could be used for housing or food cultivation is instead used for energy production.

Solar rooftop:

Rooftop solar system stands as one of the most significant applications of solar energy, presenting a unique opportunity for industrial consumers to utilize their idle roof spaces for power generation. The government of Bangladesh introduced net metering guidelines on July 28, 2018, to promote rooftop solar power. In this system, consumers can connect their rooftop solar systems to the distribution grid, enabling surplus electricity to be supplied back to the country's grid line. The government has set a target of adding 300 MW of rooftop solar power capacity by 2025 through rooftop power generation on all high-rise buildings with financial support from IDCOL. Presently, 84.6 MWp has been achieved through rooftop net-metering and an additional 69.934 MWp capacity through rooftop systems without net metering, as reported by SREDA.

Several crucial challenges are prevalent in the rooftop solar system market such as lack of domestically manufactured high-quality solar inverters, high import duties on inverters, inadequate testing facilities and the prevalence of sub-standard solar accessories in the market. Additionally, the green refinance scheme, initiated by the Bangladesh Bank back in 2009, has undergone numerous revisions over time which is hampering its widespread adoption due to unaware stakeholders.

Solar-irrigation:

The solar irrigation pump is a way of agricultural cultivation. The utilization of solar energy to power irrigation has significant potential in Bangladesh. A key factor contributing to the success of this irrigation process is the uninterrupted supply of electricity, which ensures continuous water availability.

Each SIP has the capacity to cover approximately 12 hectares of land and can provide up to 500,000 liters of water per day. In a collaborative effort, all farmers share the cost of acquiring and operating a SIP, which efficiently caters to the irrigation needs of their fields. By adopting this approach, farmers have witnessed a significant reduction in irrigation costs, nearly halving their expenses compared to traditional methods.

In Bangladesh, rural electrification is driving the adoption of solar-powered irrigation solutions through a collaborative public-private partnership model. Various government organizations, including the Bangladesh Agricultural Development Corporation (BADC), Bangladesh Rural Electrification Board (BREB), Barind Multipurpose Development Authority (BMDA), and IDCOL, have played vital roles as implementing agencies in bringing solar irrigation pump (SIP) projects to fruition. Among them, IDCOL serves as the channel for grant and credit funding to non-government organizations and private financiers responsible for setting up SIPs. The principal goal of the IDCOL program is to deploy solar PV-based irrigation systems in regions with the potential to cultivate three types of crops year-round, while also mitigating the risks of flooding, arsenic contamination, and saline water intrusion. To achieve this ambitious objective, IDCOL has set a target to install 10,000 solar irrigation pumps by 2030. As of now, there are 1,523 solar irrigation pumps already operational, collectively boasting a capacity of 42.08 MWp (IDCOL). Including IDCOL and other implementing agencies, the total number of solar irrigation installations is 2973 having a capacity of 55.085 MWp (SREDA).

Support for this system comes from esteemed international organizations, including the World Bank, KfW (Kreditanstalt für Wiederaufbau), GPOBA (Global Partnership on Output-Based Aid), JICA (Japan International Cooperation Agency), USAID (United States Agency for International Development), ADB (Asian Development Bank), and BCCRF (Bangladesh Climate Change Resilience Fund). The World Bank has been instrumental in supporting the government's efforts in this area, assisting in the installation of 11,500 SIPs by 2018. Subsequently, recognizing the potential and acceptance of SIPs among farmers, the target was revised upwards to an ambitious 50,000 SIPs to be installed by 2025 (Bhuyian et al., 2021).

Solar home system (SHS):

In a solar home system package, customers are provided with solar panels, batteries, inverters, and additional equipment, all accompanied by necessary cables. Upon subscribing to the system, customers are responsible for covering the cost of each component included in the package. Regrettably, many of these systems have encountered issues primarily attributed to the inferior quality of the batteries and inverters used.

In January 2003, IDCOL launched the solar home system programme, receiving credit and grant assistance from the World Bank and the Global Environment Facility. Over time, several other financing partners, including GIZ and KfW from Germany, the Asian Development Bank, the Islamic Development Bank, the Japan International Cooperation Agency, and the United States Agency for International Development, extended their financial support to expand the program. Collaborating with 56 partner organizations, IDCOL successfully installed approximately 41.3 million solar systems in remote regions as of January 2019. Concurrently, the government initiated the distribution of systems through the TR/KABITA project, which was under the Department of Relief as a part of its social safety net programs. Since FY2015-16, this project has successfully distributed 12.21 lakh solar systems (IDCOL).

Currently, approximately US$1,094.93 million has been invested in SHS program to provide electricity services to about 20 million people or about US$266 per household (World Bank, 2021). SHS installations were initially introduced in remote regions of the country lacking grid electricity supply. Between 2003 and 2014, the SHS Program enjoyed considerable success, owing to a robust implementation model with strong leadership from IDCOL (Infrastructure Development Company Limited). However, with the expansion of the grid, the utilization of solar systems has witnessed a decline. In 2015, a significant challenge emerged for the SHS Program, mainly due to the rapid and unexpected expansion of the national grid. This expansion led to a remarkable 280% increase in household connections to the grid over the following five years (World Bank, 2021). As an unintended outcome, the demand for SHS experienced a sharp decline, causing the market to contract rapidly. Moreover, some SHS households faced difficulties and defaulted on their debt repayments, further complicating the situation for the program.

Furthermore, the adverse impact on SHS Program sales was compounded by the TR/KABITA off-grid program's expansion, which provided free SHS systems to households. This created expectations among people of receiving a free SHS, further hampering the demand for the Program's offerings. There have been complaints that the TR/KABITA initiative distributed solar systems without conducting proper quality checks, monitoring, or offering any training to the partner organizations involved. After 2013, a significant problem arose as the majority of customers who received units through the distribution program did not receive satisfactory after-sales service from the partner organizations associated with IDCOL. Consequently, some of these organizations opted to close their local service offices, citing financial challenges arising from consumers defaulting on their instalment payments.

Based on IDCOL's Technical Specifications for Solar Home System, batteries are expected to have a minimum lifespan of five years. In situations where a battery fails or does not meet the specified standards during the warranty period, it is the responsibility of the partner organizations to provide a replacement. However, the financial unsustainability caused by consumers' inability to pay their due instalments led these partner organizations to discontinue the operation of their local offices.

A key issue that arose over time was the lack of better planning and coordination in electrification efforts. The Government of Bangladesh (GOB) was concurrently accelerating three major initiatives without proper coordination: the grid expansion, the promotion of SHS under the SHS Program, and the distribution of free systems to the poorest households and public institutions under the TR/KABITA Program.

IDCOL played a significant role in supporting partner organizations by providing grants, soft loans, and essential technical assistance. These organizations were responsible for selecting customers, extending loans, installing solar systems, and offering after-sale services. The total investment made by IDCOL for this program amounts to approximately $696 million, out of which $600 million was provided as a loan and $96 million as a grant. Among the partner organizations, Grameen Shakti captured the largest customer share, accounting for 38.8% of the total, followed by Rural Services Foundation with 14.5% (BIDS, 2018). The remaining partner organizations collectively served around 25% of the customers, as per IDCOL's records. However, despite these investments, IDCOL is still awaiting the recovery of approximately Tk850 crore from the partner organizations (IDCOL).

Solar Mini-grid:

In remote regions of Bangladesh, where the possibility of grid expansion in the near future is slim, solar PV-based mini-grid projects have been established. These initiatives aim to provide high-quality electricity to households and small commercial users, effectively fostering economic activities in these project areas.

In the year 2010, Bangladesh achieved a significant milestone with the successful implementation of the country's first-ever commercial off-grid solar-diesel hybrid mini-grid on Sandwip Island. Purobi Green Energy Limited (PGEL) took the lead in sponsoring this pioneering project, which featured a 100 kWp plant. Notably, the company set the tariff at Tk. 32/kWh, marking a crucial step in the adoption of sustainable energy practices.

As of July 2023, Bangladesh has made remarkable progress, claiming a total of 28 solar PV-powered off-grid mini-grids with a cumulative capacity of 5.805 MWp. These mini-grids are complemented by diesel generators, serving as reliable backup power sources. This advancement showcases the nation's commitment to diversifying its energy mix and expanding renewable energy solutions to various regions, providing access to clean and reliable electricity in off-grid areas (National Solar Energy Road Map, 2021-2041).

IDCOL has played a crucial role in financing the installation of 26 solar mini-grids, with a combined generation capacity of 5 MW. These mini-grid projects have proven successful in granting approximately 16,000 beneficiaries in rural Bangladesh access to clean and low-emission electricity. Over the lifetime of these projects, an estimated reduction of 29,300 tons of CO_2 emissions has been achieved. This sector has received financial support from esteemed organizations, including the World Bank, KfW (Kreditanstalt für Wiederaufbau), GPOBA (Global Partnership on Output-Based Aid), JICA (Japan International Cooperation Agency), USAID (United

States Agency for International Development), ADB (Asian Development Bank), and DFID (Department for International Development). Their contributions further fuel IDCOL's Solar Mini Grid Project, driving sustainable energy development in the country's remote areas (IDCOL).

Floating solar:

With 1,500 km2 of ponds, Bangladesh has a substantial floating solar potential. Even by utilizing just one-third of these ponds for solar panels, the country could generate a substantial 15 gigawatts of electricity. Moreover, Bangladesh also has vast shallow water areas spanning 2,500 km2 of land. By dedicating only 10% of these areas to floating solar panel installations, the nation has the capacity to produce an impressive 25 gigawatts of clean and renewable energy (Tachev, 2022).

7.3 Wind energy

Wind energy is a significant renewable energy source in Bangladesh but has not yet been thoroughly explored. Countries like Australia, the United Kingdom, the United States, Russia, Brazil, China, Japan, India, Indonesia and countries of the European Union, use wind energy extensively (IEA, 2023). In 2022, the wind power industry witnessed the addition of approximately 78 GW of capacity, marking the lowest increment over the past three years. Nevertheless, this achievement still ranks as the third-highest annual capacity added in history. This accomplishment is even more remarkable considering the challenging economic conditions and disruptions in the global supply chain caused by the concurrent global health and energy crises. Global wind energy council (GWEC) market intelligence predicts that the annual wind power installations will surpass 100 GW in 2023, with an estimated additional capacity of 680 GW expected to be introduced over the next five years under current policies. This translates to an average annual installation of more than 136 GW until the year 2027. The compound annual growth rate (CAGR) for this period is projected to be 15%. (Global Wind Report, 2023).

Bangladesh's geographic location would be ideal to harness wind energy. Bangladesh can enjoy a favourable wind profile according to its location between 20°30’ to 26°38’ North latitude and 88°04’ to 92°44’ East longitude (Khan et al., 2004). Furthermore, the Bay of Bengal has a 574 km long coastline that has a lot of potential for wind power generation. During the summer, Bangladesh has a sea breeze and trade winds from the southwest. A light north-easterly trade wind blows during the winter, which causes a land breeze. More than 20,000 MW of potential wind energy exists in Bangladesh, where the average wind speed is 7 m/s (Nandi et al., 2012).

The Power Division of the Ministry of Power, Energy, and Mineral Resources (MPEMR), in collaboration with the National Renewable Energy Laboratory (NREL) and with support from the USAID, conducted a study to address this gap (Chowdhury, 2020). According to the preliminary findings of this technical potential analysis, “for wind speeds of 5.75–7.75 ms-1, there are more than 20,000 km2 of land with a gross wind potential of over 30,000 MW” (Jackobson et al., 2018). According to the National Solar Energy Roadmap, 2021-41, the southern part of Bangladesh (coastal region) possesses a greater wind potential. Wind power potential increases with increasing hub height. Given the cyclone-prone nature of the coastal region, it is difficult for Bangladesh to achieve a higher center height in coastal regions.

Bangladesh has substantially more wind energy potential than was formerly believed, particularly at hub heights between 140 and 160 meters. The regions with the greatest potential are 724 kilometres long, including the littoral of the Bay of Bengal, Kuakata, Sandwip, and Saint Martin. Off-grid residents in these areas would gain access to energy through the installation of wind power. Already, the government has started moving in this direction. It approved a 55 MW wind power plant in Mongla in December 2020 (Tachev, 2022). The Bangladesh Power Development Board (BPDB) entered into an agreement with the consortium known as Mongla Green Power Ltd to construct a wind farm in Bagerhat's Mongla area on September 4, 2022. This wind farm is set to generate 55 megawatts (MW) of electricity. According to the contract, the consortium will complete the project within the next two years. Subsequently, BPDB will be procuring electricity from this wind farm for a duration of 20 years. The cost per unit of electricity (per kilowatt-hour) is estimated at $0.1320, which is approximately equivalent to Tk 12.5 (The Daily Star, 2022).

To harness wind energy for electricity generation, BPDB (Bangladesh Power Development Board) established a grid-connected Wind Plant with a total capacity of 900 KW (4x225 KW) in the Muhuri Dam region of Sonagazi, Feni. Additionally, a separate venture, the 1000 KW Wind Battery Hybrid Power Plant on Kutubdia Island, was successfully concluded in 2008. This project encompassed 50 Wind Turbines, each with a capacity of 20 kW. However, they are not in operation currently. Repairs and improvements are in progress for the existing 900 kW grid-connected Wind Power Project at Muhuri Dam in Sonagazi, Feni. Additionally, the ongoing focus includes repair, operation, and maintenance of the existing Kutubdia 1000 kW Wind Battery Hybrid Power Project. Plans are underway for the installation of a 15 MW Wind Power Plant in various coastal regions of Bangladesh. This initiative follows a year-long Wind Resources Assessment conducted in areas such as Muhuri Dam in Feni, Mognamaghat in Cox's Bazar, Parky Beach in Anwara (Chittagong), Kepupara in Borguna, and Kuakata in Patuakhali. Wind Mapping efforts are actively ongoing in the Muhuri Dam area of Feni and Mognamaghat in Cox’s Bazar, facilitated by Regen Powertech Ltd. from India. Furthermore, the installation of Wind Monitoring Stations is progressing at Inani Beach in Cox's Bazar, Parky Beach in Anwara, Sitakundu in Chittagong, and Chandpur, as part of the USAID TA project (BPDB, 2023).

US-DK Green Energy Bangladesh Limited undertook a 60 MW project for a wind power facility in Cox’sbazar Sadar Upazila with a total investment of $116.51 million USD. Seven out of ten turbines are operational and capable of supplying approximately 15-20MW to the national grid. The executive engineer of Cox's Bazar Power Development Board and project director of the wind power plant, stated that the facility produced more than 300,000-kilowatt hours of electricity in June. According to Mr. Taufiq-e-Ilahi Chowdhury, advisor to PM Sheikh Hasina, the plant is capable of meeting the total electricity requirement (45MW) of Cox's Bazar and the surrounding area. However, according to Mukit Alam Khan, project manager of the center, a potential obstacle for the project is that the average wind speed required for energy production is three times the standard speed (Shuvo, 2023).

A study by Uddin and Rahman (2019) showed the feasibility of wind conditions for power generation at different prospective places in Bangladesh (Table 23).

Table 23: Feasibility of wind condition for the generation of electricity at different places in Bangladesh

Site	Reference Height (m)	Annual-Average Wind Speed (m/s)
Cox's Bazar	10	2.42
Sandip Island	5	2.16
Teknaf	5	2.16
Patenga Airport	5	2.45
Comilla Airport	6	2.21
Khepupara	10	2.36
Kutubdia Island	6	2.09
Bhola	7	2.44
Hatia Island	6	2.08

Source: Uddin and Rahman, 2019

Bangladesh has the longest coastline stretch in the world, stretching 724 km along the Bay of Bengal, and further techno-economic analysis is required in Bangladesh before electrification from wind turbines can be considered there. 22 sites were identified for wind energy generation and onshore wind plants along the coastline by BPDB. In addition, BPDB has planned a 50-200 MW wind generation plant at Anawara in Chittagong, a 15 MW wind power plant at Muhuri Dam Area in Feni, Mognamaghat in Cox's Bazar, Parky Beach in Chittagong, Kepupara in Borguna, and Kuakata in Patuakhali.

7.4 Hydro-energy

Hydroelectricity is a naturally renewable source of energy. Water is used for the creation of electricity by the process of turning the water head into kinetic energy, which causes the turbine propeller to revolve utilizing the force of the water flow. The Kaptai power plant was the first hydroelectric plant in Bangladesh. It was estimated that the country's total hydropower potential at Kaptai (1000 MkWh/year), Matamuhury (300 MkWh/year), and Sangu (200 MkWh/year) was 1500 MkWh/year. Despite being a riverine country, Bangladesh's hydropower potential is constrained by geographical and geopolitical factors. Large lakes such as the Kaptai and the thousands of kilometres long river basins could produce an additional 20 GW in the country (Tachev, 2022). Power Cell, in collaboration with the US consulting firm M/s. Stream Tech Inc., conducted a study to evaluate the hydropower potential in the southeast of Bangladesh. The study uncovered minimal opportunities for mini- and micro-hydro projects on rivers such as Sangu, Matamuhuri, and Bakkhali, highlighting the need for comprehensive feasibility analyses (Chowdhury, 2020). Bangladesh produces less hydroelectricity than the rest of the globe on average, with a total of 879.0 MTOE (Million Tons of Oil Equivalent) produced at the end of 2014, a 2.0% increase over the previous two years and below the 3.3% average for the previous ten years. In contrast, Bangladesh's hydroelectricity production capacity in 2014 was 230 MW, and worldwide sharing is incredibly minimal (Uddin, et al., 2019). The proposed future hydro-power generation projects are presented below (Table 24).

Table 24: Proposed future hydro-electricity projects in Bangladesh

Name of the river	The potential of electrical energy in MW
Kaptai	100
Shangu river	100
Matamuhuri river	100
Mohamaya	23-65
Lohajari	4.5

Source: Uddin and Rahman, 2019

There are also some other potential sources of renewable energy like biofuel, geothermal energy, atomic energy, etc. Overall, Bangladesh's transition to renewable energy leaves a lot to be desired. Although there are some natural causes for the slow growth, such as a lack of available land and limited solar potential, there are also administrative barriers. Barriers include lengthy land acquisition procedures, hefty equipment costs, the possibility of cancellation, and the dearth of large-scale auctions.

The present situation makes it obvious that Bangladesh has to diversify its energy mix in a more sustainable manner. In contrast to conventional fossil energy sources, renewable energy—especially solar energy—represents a low-risk and diversified choice. Domestic renewable energy sources provide Bangladesh with control over the energy and protection against fluctuations in the international market. A solar power plant in India presently being built costs $560 million per GW on average. A total of 6.5 GW of solar could be installed using the same $11 billion that Bangladesh might have to spend in just three years on spot market LNG purchases, even if such projects are 50% more expensive in Bangladesh and we assume flexibility as well as grid augmentation costs are double the overall project cost (Lolla, 2022).

7.5 Prospects of renewable energy according to key stakeholders

7.5.1 Solar energy

Solar energy is one of the cheapest sources of generating electricity. The cost of generating electricity from solar energy and the cost of generating electricity from other sources is almost the same (more or less 10 taka). Using 4.5 hours of sunlight as solar energy can save up fossil fuel.

According to various academic opinions, there are contrasting perspectives within different groups regarding the energy transition. Green activists advocate for a complete shift to 100% renewable energy, while there are dissenting voices opposing this approach. However, the reality lies somewhere in between these two extremes, leaning towards the lower end. Bangladesh, with an average of 4.5 hours of daylight, possesses the potential to generate 2500MW of electricity rapidly using solar energy. Nevertheless, the current solar energy production stands at a mere 500MW, despite the capacity to reach up to 3500MW with proper measures. The country has room for significant improvement in optimizing the utilization of available sunlight and wind resources. An example of inefficiency can be observed through the occurrence of load shedding, leading to a loss of 2500MW throughout the day. Such a deficit could have been easily met by harnessing solar energy, but instead, an additional 2500MW coal-based power plant was utilized, which is deemed inexcusable and wasteful. Considering the increasing demand for electricity each year, adding an extra 300-500MW of solar energy annually would be immensely advantageous. By 2030, Bangladesh is projected to generate an additional 2000MW of solar electricity, potentially reaching a total of 4000MW of solar energy capacity. However, the government's progress needs acceleration, as the current renewable energy capacity falls short of even meeting the minimum requirements, let alone reaching the ambitious targets of 40% or 100% renewable energy.

Academicians raised a concern that reserving more than necessary solar energy (5000MW) interferes with baseload power plants and is unfavourable. Solar energy does not dispatch; if more solar energy is available than demanded, the Grid Operator must shut down other (coal, nuclear) power plants. However, shutting down other power plants seems unrealistic. Consequently, an essential aspect that requires attention is the estimation of the minimum base load demand. The significance of understanding and meeting the minimum energy demands while also acknowledging the upper limit of solar energy generation in the country can facilitate renewable energy sector expansion.

As per insights from key government stakeholders, following thorough feasibility studies, certain development partners have displayed a keen interest in investing in renewable energy projects. The current approach involves adopting the Independent Power Producer (IPP) plan, whereas renewable plants are being established by private entities that arrange their own funding. On the other hand, the government is actively seeking funds to support its planned initiatives. Typically, the IPPs manage both the land and technology required for these projects, while the government acts as the purchaser of the generated power. Consequently, some renewable projects have thrived under this arrangement, while others faced challenges. Some ventures experienced limited or no profitability, leading to their cessation due to issues related to land acquisition and funding constraints.

To explore the potential of renewable energy, Bangladesh has undertaken several pilot projects. For instance, in Sonagazi, a 50 MW pilot project is being executed by EGCB, funded by the World Bank. Additionally, the government is seeking funding from interested parties like ADB for other ongoing projects, which remain under government supervision.

According to input from stakeholders, conducting feasibility studies is a crucial requirement for the candidate sites identified in the Delta plan. Given the extensive 100-year duration of the plan, several components are still at the projection stage, and their feasibility will largely depend on future land availability. In an effort to promote renewable energy adoption, various entities, including economic zones, BIDA, and BEPZA, are encouraged to integrate renewable energy facilities. Depending on availability, they are advised to target generating 10-15% of their energy from renewable sources. Furthermore, efforts are being made to utilize available free lands for renewable energy purposes. Railway authorities and civil aviation authorities have been approached and requested to permit the use of their unused lands for renewable energy projects. Regarding solar mini-grids, significant progress has been made in completing the process of integrating the 28th solar mini-grid into the overall grid system. Tariffs have been formally established, and the finalization of the entire process has been accomplished, paving the way for smoother integration and operation.

The failure to achieve the target of reaching 10% renewable energy by 2021, as outlined in the Renewable Energy Policy (2008), can be attributed to several factors. Among these reasons are land scarcity, competition with other more cost-effective alternatives, challenges associated with the nighttime availability of solar power, concerns related to grid reliability, and the potential risk of grid instability that could lead to blackouts. As of now, renewable energy generation stands at 6% of the peak generation capacity, which is 14,782 MW. When compared to the overall installed capacity, renewable energy contributes only 4%.

Scarce land is one of the most fundamental problems of solar energy generation in Bangladesh. It has been said by experts that 1% of land given up will be enough for the required solar energy generation. But policy Relaxation is not possible to give up 1% of arable land for the purpose of renewable energy generation. Even 1% arable land is very important since it will not be possible to convince the farmers to give up their lands. There is no comparable incentive for them. Mainly, the private sector working on solar development projects faces adversaries when retrieving land for projects, as agricultural lands fragment available lands. As per the laws of Bangladesh, agricultural lands are strictly protected and cannot be utilized or altered under any circumstances. This stringent regulation imposes significant restrictions on any activities that may involve the use or development of agricultural lands. A suggestion by an academician is that the private sector should be allowed to take up a certain amount of land (for example, 250 acres from a 1000-acre land) as this minuscule amount of land will not hamper the food security of the country and provide land to produce the minimum amount of 2000MW electricity. He believes that food security and electricity security are equally crucial for us, as Bangladesh imports both. Economic calculation by dollar shows that land provides five times more electricity than food. Also, 20-25% of food is wasted annually; we can save from there. A realistic plan regarding these issues will open the path for renewable energy against land constraints.

Studies on using arable land for both cultivation and renewable energy have been conducted Indicating that 17-18 Gigawatt could be produced theoretically. However, cropping patterns and shading are crucial to consider here. Not all crops require the same amount of shading. Moreover, Lack of light may result in lower crop productivity. Since a substantial area is necessary for solar energy generation, it’s not feasible for small farmers. Only 3-4% of farmers, who have big lands, can be targeted in that case. Considering rooftop renewable energy installation to cope with land scarcity, it costs 3 lakh taka while only powering a water pump. The viability of renewable energy projects heavily relies on taking into account the profitability for customers. Without offering incentives, such ventures may not be economically feasible. Another concern is the grid system in the country. The grids must be converted to smart grids to adjust with power generation from renewable sources.

Storing renewable energy poses a significant challenge as it can be quite expensive. Batteries are considered the best storage option, but they require substantial land space to accommodate large units capable of storing high outputs of renewable energy. The cost of renewable energy itself is not a hindrance for Bangladesh but the cost and quality of storage system matter. Hence, the main obstacle lies in the lack of infrastructure readiness to facilitate a seamless transition towards renewable energy sources.

In the field of solar development projects in the private sector, acquiring land often poses challenges due to strict regulations that prevent the use of agricultural lands. Dr. Ijaz Hossain[14] proposes a potential solution, suggesting that a certain portion of land, say 250 acres out of a 1000-acre plot, could be allocated to the private sector for solar projects without significantly impacting the country's food security. By implementing this approach, it becomes feasible to generate a minimum of 2000MW electricity from solar power. One of the key stakeholders emphasizes the equal importance of food security and electricity security for Bangladesh, as both are reliant on imports. He points out that land, when utilized for electricity generation, yields five times more electricity than it does for food production. Additionally, considering the substantial annual wastage of food (around 20-25%), there is potential to save resources from that aspect. This realistic plan addresses the challenges posed by land constraints and opens up opportunities for the expansion of renewable energy sources while simultaneously reducing the country's dependence on energy imports.

BERC, as the energy regulatory entity of the country can facilitate renewable energy production through tariffs. According to the BERC, it encourages producers to co-generation or tri-generation. Also, it takes care of the tariff so that producers can market the energy after production. The producers get assistance in terms of licensing and tariffs from the institution, too. Still, there could be more facilitation space to encourage green and clean energy.

Academicians also mentioned that It would not be feasible if we tried to use 100% renewable energy for electricity production. In Bangladesh, 1KW of electricity costs 10 taka. If we wanted to use solar energy at night, we would need a battery (hydrogen), and the total cost would add up to 25 BDT. As the government doesn’t get more than 10 BDT for electricity, it is unrealistic for them to purchase electricity that costs 25 BDT. Hence, if the government chose to use 100% renewable energy, the electricity price would be three times more to make up for the cost. 100% renewable energy is feasible in Japan, the USA, UK as they sell electricity for 30-32 cents which make 100% renewable energy affordable for them. Therefore, in Bangladesh, for practical reasons, usage of renewable energy has to be limited to daylight hours, only producing 2000-3000MW. Further investments in the grid can increase the output to 3500-4000MW. It has been claimed by experts that, more than 4000MW RE in Bangladesh would be difficult.

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The presence of excess solar energy, exceeding the required capacity of 5000MW, can present challenges for base-load power plants. Unlike traditional power sources, solar energy generation lacks dispatchability, meaning it cannot be precisely controlled to match fluctuations in electricity demand. This situation poses a dilemma for Grid Operators, who must decide whether to waste the surplus solar energy or reduce generation from other sources like coal or nuclear plants to accommodate the solar influx. However, shutting down other power plants to accommodate solar energy becomes impractical, as it could lead to grid instability and disruptions in power supply. Thus, effectively integrating solar energy into the grid necessitates careful analysis of demand patterns and the overall energy mix to maintain a reliable and efficient power system. This requires finding a balance between solar energy utilization and the existing power generation infrastructure to ensure a consistent and uninterrupted electricity supply.

7.5.2 Wind energy

Based on a US study, nine potential land areas have been identified as suitable sites for constructing wind turbines. One of these locations is the Chittagong - Cox's Bazar area, where a 60 MW wind plant is currently under construction. For wind plants to be considered commercially viable, they must achieve a minimum yearly average of 20% of their maximum output. The success of the ongoing 60 MW wind plant in the Chittagong - Cox's Bazar area is critical to observe, as it could serve as a determining factor for future wind power projects. Projections indicate that by the year 2050, Bangladesh could potentially generate up to 17,000 MW of wind power. However, the Bangladesh Power Development Board (BPDB) has a more conservative estimate, predicting only 500-600 MW of wind power capacity. Without external funding, wind power generation in Bangladesh is likely to be limited to less than 500 MW, in accordance with the country's commitment to the Conference of Parties (COP). To reach the higher target of 500 MW, external funding support is necessary. The availability of funding will play a crucial role in the country's efforts to expand its wind power capacity beyond the baseline level.

8. Policy Recommendations

Despite having an adequate power system capacity, Bangladesh continues to face frequent power outages due to energy shortages. Therefore, the primary focus should now shift towards ensuring the country's energy security. The imported fossil-fuel-based energy system has been confirmed as a vulnerable one considering the energy crisis and Dollar-crisis for the last two years. The continuous change in the geo-political equations would influence the energy sector and thus affect the energy security of the country. Also, imported fossil fuels are expensive while considering both the economic and environmental costs. Previously power generation from fossil fuels was cheaper which has now become costly due to the rise in the world energy price. The average cost of power generation per unit could be stable and cheaper if long-term solar-power projects are considered. To be self-sufficient we need to concentrate on our own resources. The following policy suggestions have been prepared in light of the LNG, Domestic Gas, and Renewable sector analysis and cost comparison:

Domestic gas exploration should be revisited according to the experts' suggestions and direction. The gas potential of Bangladesh has received commendable recognition from both national and international geoscientists, affirming its status as a highly promising gas province. But Bangladesh is allocating more budget in paying the import bills in the energy sector which is making its energy sector more vulnerable. Increasing the allocation for local onshore gas exploration offers will reduce the reliance on costly LNG imports and eliminate the need for extensive investment in LNG infrastructure. Also, it will provide Bangladesh with an opportunity to safeguard itself against potential future price fluctuations and uncertainties associated with LNG. Among the world's potentially lucrative gas basins, Bangladesh stands as one of the least explored countries. Surprisingly, in the past two decades, Bangladesh has drilled a mere 28 exploratory wells, translating to an average drilling rate slightly exceeding one well annually. By any measure, this level of exploration falls significantly short. Notably, despite consuming approximately 13 trillion cubic feet (Tcf) of gas during this period, the country has managed to make new gas discoveries amounting to less than 2 Tcf (Imam, 2021). This outcome clearly signifies the inadequacies and apparent absence of eagerness to foster the progress of domestic exploration efforts.

Furthermore, it is important to highlight that exploration in the deep ocean remains entirely uncharted in Bangladesh, with no drilling conducted in the deep offshore areas. Remarkably, neighbouring countries such as Myanmar and India, situated across the maritime boundaries in the Bay of Bengal, have made significant gas discoveries in their respective offshore regions. Despite these notable findings, Bangladesh is yet to embark on deep offshore exploration, representing an untapped potential for the country's gas reserves. Offshore exploration should be one of the priorities. Since gas is mobile, it will move from one place to another. In that case, offshore exploration should be considered with no more delay.

LNG versus solar plant: According to experts' opinion, an initial investment in LNG and renewable energy is equivalent. LNG-based plants are the cheapest. 300 MW gas plant and 500 MW solar plant costs are close enough. When assessing the cost-effectiveness and advantages of LNG-based power plants in comparison to solar power plants, a common concern revolves around the limited hours of power generation by solar facilities, contrasting with the continuous service offered by LNG-based plants. Nevertheless, it is crucial to undertake a comprehensive evaluation of the long-term economic and environmental implications when comparing these two energy sources.

According to government estimates, the cost of LNG and solar power stands at 13 BDT/kWh and 12 BDT/kWh, respectively. However, our in-depth research indicates a significant cost disparity, with LNG costing approximately 41.50 BDT/kWh. This calculation takes into account the entire LNG operational process within the country, encompassing import, regasification, and distribution to the national gas grid. Such a substantial difference in cost underscores the potential for Bangladesh to achieve cost stability in power generation by embracing solar power expansion. This move not only supports economic stability but also serves to significantly diminish the nation's carbon footprint, fostering a greener and more sustainable future.

Alternative uses of outdated power plants: The sluggish progress in implementing utility-scale renewable energy projects in Bangladesh can be attributed to the difficulties encountered in identifying sizeable and suitable land areas. However, it is worth noting that certain public sector power plants reliant on fossil fuels exhibit notable inefficiencies and are outdated, presenting an opportunity for repurposing them into solar energy installations.

Considering that public sector employees are already engaged in operating the existing fossil fuel-based power plants, Bangladesh could explore the possibility of developing an energy transition fund to facilitate the repurposing of the inefficient plants where the employees would be involved. Although this transition process might require a longer timeframe, the government can initiate the necessary steps towards this transformation. Such an endeavour holds the potential to reintegrate the current workforce into the clean energy sector while concurrently mitigating the financial burden associated with inefficient systems (Alam, 2023).

Incentivize solar power sector: The widespread adoption of economically viable rooftop solar systems has not gained significant momentum in the country. Despite the issuance of net metering guidelines in 2018, followed by revisions in 2019, the current data indicate that rooftop solar capacity operating under these guidelines stands at approximately 70MW. The current import duty on inverters, which stands at 37%, significantly increases project costs and acts as a deterrent for potential investors. Given the cost-effectiveness of rooftop solar installations, especially considering the escalating electricity prices, granting import duty exemptions on solar accessories would serve as a compelling incentive for both the industry and commercial building owners. This, in turn, would facilitate substantial reductions in Bangladesh's dependence on imported fossil fuels (Alam, 2023)**.** Also, taxes on solar energy materials should be reduced and other incentive opportunities for solar energy should be explored. In order to bolster the renewable energy capacity of the country, it is advisable for the government to remove the existing limitation on rooftop solar installation capacity, which currently stands at 70% of the sanctioned load for industrial and commercial buildings. Additionally, the government should consider exempting duties on essential components for rooftop solar projects such as fibrereinforced polymer (FRP) walkways, imported inverters, mounting structures, and direct current (DC) cables. These duties, which currently range from 15.25% to 58.6%, should be waived to send a strong market signal regarding the government's commitment to the transition of the electricity sector (Alam,2023).

Financing for renewable energy market development: According to Alam (2023), Bangladesh must establish a comprehensive funding roadmap that encompasses both domestic resources and international channels, including multilateral agencies, climate funds, global pension funds, private equity, and infrastructure funds. By drawing insights from successful models like Indonesia and Vietnam's Just Energy Transition Partnership, Bangladesh can explore potential collaborations with developed nations to secure financing for the transformation of its electricity sector. Additionally, the rapid implementation of renewable energy projects necessitates the development of supportive financial instruments.

Learning from India's experience, the implementation of risk mitigation measures such as risk guarantee funds can offer protection to project developers. Furthermore, adopting competitive procurement processes, such as renewable energy auctions, will contribute to reducing renewable energy tariffs and enable Bangladesh to effectively manage the escalating costs of electricity generation. Furthermore, analysing Vietnam's renewable energy revolution reveals that the existing tariff structure for industries in Bangladesh, even after three successive upward adjustments, remains more favourable compared to what the Southeast Asian nation offers for solar energy. Hence, from a financial perspective, Bangladesh's industries should consider the prevailing circumstances highly conducive for adopting rooftop solar solutions.

Facilitating rooftop solar power: Addressing certain issues is of utmost importance to fully capitalize on the substantial potential of rooftop solar facilities in Bangladesh. One key challenge lies in the absence of locally manufactured high-quality inverters, leading to reliance on imported alternatives. Another significant concern relates to the quality of solar equipment. While Bangladesh needs to import solar panels and inverters, there is a lack of sufficient testing facilities to ensure and verify their quality. This highlights the need to establish accredited testing laboratories equipped with the capacity to conduct thorough quality checks on solar panels and related accessories. Additionally, to safeguard against the market penetration of sub-standard solar accessories, consistent monitoring by the Bangladesh Standards and Testing Institute (BSTI) is essential. By addressing these challenges and ensuring the availability of high-quality inverters, establishing adequate testing facilities, and implementing effective market monitoring mechanisms, Bangladesh can foster a conducive environment for the widespread adoption of rooftop solar systems (Alam, 2023).

Using daylight for day-time power generation: According to experts' opinions, in Bangladesh, the average duration of daylight hour's amounts to approximately 4.5 hours, during which solar energy has the potential to swiftly generate 2500MW of electricity. However, there is considerable room for enhancing the efficient utilization of valuable daylight hours and tapping into the available wind resources in the country. A striking example of inefficiency is observed through the occurrence of load shedding, where a deficit of 2500 MW persists throughout the day. This situation is especially disheartening since this energy requirement could have been met with solar power, given the ample sunlight available. Instead, resorting to the usage of another 2500 MW coal-based power plant seems inexcusable and wasteful, neglecting the considerable clean energy opportunities that could be harnessed from renewable sources like solar and wind.

Estimating minimum base load and introducing smart grid: It has been stated by key-stakeholder that two key factors need consideration in order to integrate renewable energy sources effectively. Firstly, accurately estimating the minimum base load demand is essential to ensure a stable energy supply during periods of low renewable generation. Secondly, the availability and implementation of smart grids and advanced technologies play a vital role in optimizing renewable energy utilization. Smart grids allow for real-time monitoring and control of energy flows, enabling the efficient storage and distribution of surplus renewable energy. By combining these elements, we can achieve a sustainable energy ecosystem that maximizes renewable energy utilization while ensuring a reliable and stable power supply.

Bringing alignment in the policy plans and prioritize short-term targets: Several national policy plans have been formulated and published since 2008. The policy plans are not aligned with a central focus, which actually puzzles the stakeholders. A comprehensive single-focused plan should be formulated. Also, it is advisable for the government by the energy analysts to prioritize short-term strategies/targets over long-term plans that often fail to produce desirable outcomes.

Creating a supportive business environment for renewable energies: There is a need to create a level playing field for technologies utilizing renewable energy. Domestic policy frameworks need to be quickly changed to streamline and accelerate renewable energy projects and spur private sector investments. Policies and procedures must be put in place to lower market risk, enable investments, and provide incentives – including by streamlining the planning, perming, and regulatory processes and avoiding bottlenecks and red tape. The adoption of solar and wind energy technologies can be accelerated by the availability of modern energy transmission infrastructure, clear and strong policies, transparent processes, and public support (Raihan, 2023). Furthermore, it is critically important to make considerable investments in renewable energy. There is a need for commitment and accountability, especially from the financial systems, including banks and other public and private financial institutions, which must direct their lending portfolios toward hastening the transition to renewable energy (Raihan, 2023).

Shifting subsidies from fossil fuel to renewable energies: The country needs to switch energy subsidies from fossil fuels to renewable energy. One of the largest financial obstacles preventing the country's transition to renewable energy is fossil fuel subsidies. The cost of subsidizing the fossil fuel industry alone is enormous and includes direct subsidies, tax benefits, and costs for health and the environment that weren't factored into the pricing of fossil fuels. Subsidies for fossil fuels are unfair and inefficient. Subsidizing renewable energy instead of fossil fuels reduces emissions and has the potential of fostering sustainable economic growth, job creation, improved public health, and greater equality, especially for the poorest and most vulnerable people (Raihan, 2023).

Crafting successful strategies and enabling the transition to sustainable energy systems: Resources must be shifted between competing industrial sectors and political constituencies as part of a sustainable energy transition. As stakeholders in this process have varying degrees of political and economic power, understanding how political and economic factors influence the transition to renewable energy is crucial for formulating effective policies and facilitating the shift to sustainable energy systems (Raihan, 2023).

Feed-in-tariff scheme: Under the framework of feed-in tariff schemes, households and businesses are financially incentivized by the government to produce electricity primarily from renewable sources through their individual endeavors. If connected effectively, this approach could significantly augment the national grid's renewable energy capacity through the implementation of numerous small-scale distributed projects according to Professor M. Tamim[15].

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9. Conclusion

Countries worldwide are putting effort both into lessening carbon emissions and fossil-fuel dependence. Spending on clean energy is being prioritized over fossil fuel which was the opposite a few years ago. The volatility of the fossil-fuel market has created concern about energy security which has resulted in this changed ratio of spending. Though this increased spending is mostly done by developed countries, the developing world needs to join with them to cope with the uneven market of fossil fuel.

Bangladesh's energy mix heavily relies on imported fossil fuels, creating a significant dependence on external sources for meeting its energy needs. This reliance on imports is expected to persist in the near future, as the country continues to expand its import capabilities. On-going LNG infrastructure building and the long list of planned future infrastructure prove the government policy in favour of LNG import further. This over-dependency may cancel out the scope of investment in renewable energy production as the over-capacity problem also prevails. Sooner or later the eco-system of renewable energy storage will be the prime source of energy due to growing carbon-emission from fossil fuel sources. Hence, plans and preparations are required to start now. It is expected that with the growing advanced technology the cost of battery storage will fall down significantly. So, the policy advocacy should move in a way that further reduces renewable energy costs through storage in the local setting.

Embracing renewable energy offers multifaceted benefits. Firstly, it enhances energy security by reducing reliance on external sources and fosters energy independence. By harnessing the country's abundant renewable resources such as solar, wind, and hydro, Bangladesh can create a diversified and resilient energy mix. Secondly, transitioning to renewables aligns with global climate goals, allowing Bangladesh to play its part in mitigating climate change and reducing greenhouse gas emissions. This, in turn, Bangladesh will be contributing to the global effort to combat the adverse effects of climate change, ensuring a sustainable environment for future generations. Furthermore, investing in renewable energy infrastructure can drive economic growth and create employment opportunities. The shift to renewables can stimulate innovation and attract investments in green technologies, fostering a thriving renewable energy industry in the country.

Adopting a strategy of setting short-term and attainable objectives for renewable energy will be wise, as it facilitates easier implementation and ensures adaptability to evolving energy markets worldwide. By breaking down our goals into manageable milestones, we can make steady progress and build momentum in transitioning towards renewable energy sources. This approach enables us to remain responsive to changing dynamics in the global energy landscape, making necessary adjustments as needed to stay on course. Ultimately, this pragmatic approach positions us for success in our pursuit of a cleaner and more sustainable energy future.

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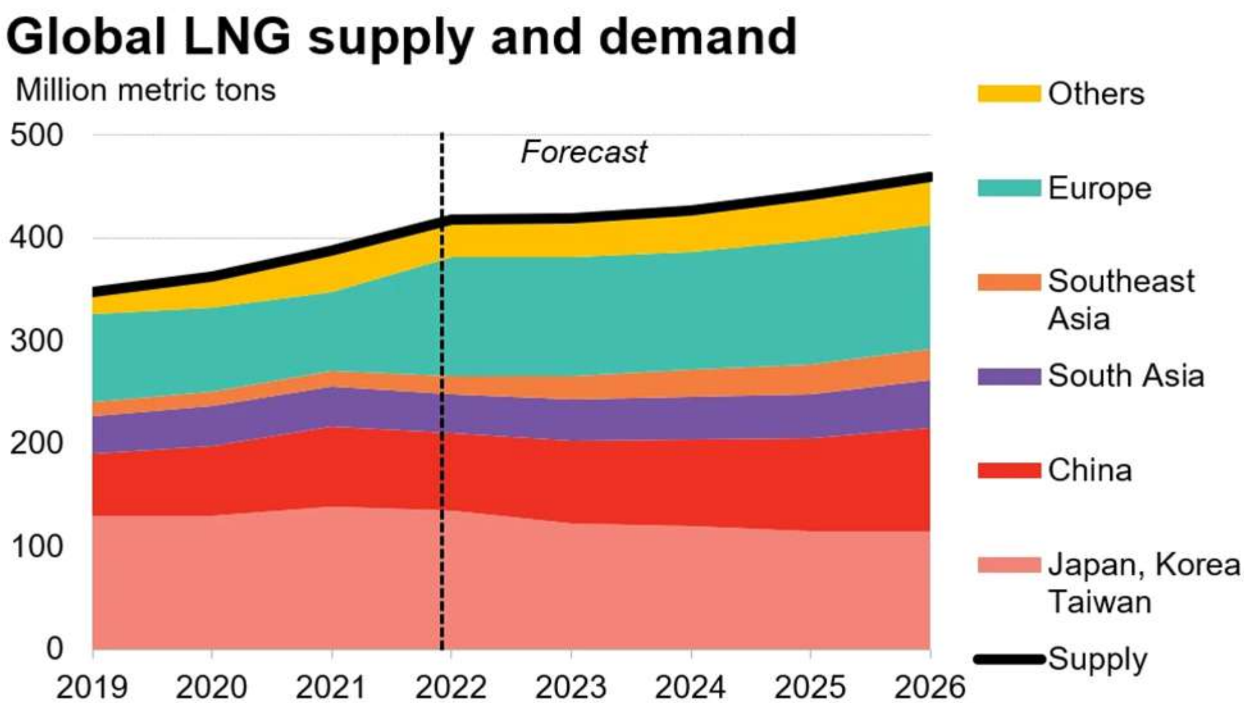
Appendix

Figure 1: Global LNG supply and demand



Source: Bloomberg, 2022

Social Cost of Carbon-di-oxide emission:

Base social cost of CO_2 = \$43 in 2009 (Wadud & Khan, 2011)
Average inflation rate for 14 years (2009 to 2023)= 5.5%

Adjusted social cost= Base social cost × (1+ average inflation rate)^14
≈ \$45 × (1.055)^14
≈ \$45 × 1.93272466
≈ \$95.2 (rounded to two decimal places)

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