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2030

POWER SECTOR ANALYSIS

MUJIB CLIMATE PROSPERITY PLAN

MUJIB CLIMATE PROSPERITY PLAN – DECADE 2030:

POWER SECTOR ANALYSIS

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TABLE OF CONTENTS

Executive Summary	1
1. Status of Bangladesh Power Sector	19
1.1. Brief History	20
1.2. Supply and Demand Scenario	21
1.3. Historical and Current Energy Mix	23
2. Cost Analysis, Trend of Thermal Plants, and Implied Inflection Points	26
2.1. Based on Ownership: Publicly vs. Privately Owned	27
2.2. Based on Type of Load Served: Base Load vs Peaking Plants	28
2.3. Fuel-Wise Analysis of Thermal Power Plants	30
2.4. Cost Analysis	31
2.5. Per-Unit Cost Analysis	33
2.6. Cost Trend and Implied Inflection Points	35
2.7. Impact of Various Factors on Annual Plant Factor	41
2.8. Efficiency of the Current System	43
2.9. Access to Electricity	44
3. Resource analysis	45
3.1. Fossil Gas	46
3.2. Liquid Petroleum	47
3.3. Coal	48
3.4. Imported electricity	49
3.5. Liquefied Fossil Gas	50
3.6. Renewables	51
4. Effect of Subsidies and Costs to Government	57
5. Renewable Energy in Policy Documents of Government	61
5.1. Power System Master Plan 2016 (Baseline Scenario)	62
5.2. NDC Commitments and Targets	63
5.3. Bangladesh Perspective Plan 2021-2041	64
5.4. Bangladesh Delta Plan 2100	65
6. Cost of Electricity Generation Pattern of Different Energy Sources	66
7. Econometric Analysis of Electricity Consumption Drivers and Elasticity	69
7.1. Energy and Macroeconomic Forecasts	70
7.2. Description of Energy, Electricity, and Macroeconomic trends	72
7.3. Elasticity and Macroeconomic Drivers of Electricity Consumption	77
8. Increasing Renewables Share in the Energy Mix	81
8.1. Electricity Generation Mix 2025	83
8.3. Electricity Generation Mix 2030	85

9.	Renewable Energy Share in Different Scenarios	87
9.1.	General Assumptions	88
9.2.	Potential VRE Technologies Considered in MCPP	89
9.3.	Scenario 1: Mujib Climate Prosperity Plan-Maximal (MCPP-M)	92
9.4.	Scenario 2: Mujib Climate Prosperity Plan-Realistic (MCPP-R) Scenario	93
9.5.	Scenario 3: Nationally Determined Contributions Scenario ("NDC Scenario")	94
9.6.	Cost Savings	96
10.	Investment Requirements and Implementation Plan	99
10.1	Investment Requirement	100
10.2.	Implementation Plan	105
11.	Number of Jobs by 2025 and 2030	109
12.	Reduction in Imported Fossil Fuel and its Effects on Trade Balance	
13.	External Trade Account	113
12.1.	Macroeconomic Impact of Fossil Fuel Utilization in Bangladesh	114
12.2.	Impact of Fuel Imports and Oil Price on External Trade Balance	115
13.	Extension and Modernization of Grid to Support High Shares of Distributed Renewable Energy	117
13.1.	The Benefits of Extension and Modernization of the Grid	118
13.2.	Investment Size of Grid Upgrade and Modernization	122
13.3.	Investment in Storage	124
14.	Policy De-risking and Regulatory Framework	125
14.1.	Overview of the De-risking Renewable Energy Investment Methodology	126
14.2.	Sampling and Data	127
14.3.	Assumptions about Risk Modeling	128
14.4.	Cost of Capital Assumptions	130
14.5.	Description of risk environment	131
14.6.	Public Instruments Selection	134
14.7.	Impact of Public Instruments of Financing Costs	135
14.8.	Baseline Energy Mix Levelized Costs and Emissions	138
14.9.	Assumptions for Solar PV Investment in Bangladesh	141
14.10.	Levelized Cost	143
14.11.	Evaluation of Performance Metrics	144
14.12.	Summary	147
15.	Bangladesh Power System Flexibility Assessment	148
15.1.	Background	149
15.2.	Methodology	150
15.3.	Results	154
15.4.	Discussion	157

15.5.	Conclusion.....	159
16.	Endnotes.....	168
17.	References.....	171

LIST OF FIGURES

Figure 1-1: Historical Trend of Installed Power Generation Capacity of Bangladesh.....	21
Figure 1-2: Historical Trend of Net Energy Generation in Bangladesh.....	21
Figure 1-3: Demand and Supply Trend of the Bangladeshi Power Sector.....	22
Figure 1-4: Historical Trend of Fuel-Wise Installed Capacity.....	24
Figure 1-5: Historical Trend of Fuel-Wise Net Energy Generation.....	24
Figure 1-6: Latest Energy Mix of Bangladesh for (a) Installed Capacity, (b) Net Generation.....	25
Figure 1-7: Latest Plant Technology Wise Breakdown of Installed Capacity (MW).....	25
Figure 2-1: Comparison between Public and Private Sector Thermal Power Plants of Bangladesh: (a) Number of Plants, (b) Installed Capacity, and (c) Net Electricity Generation.....	27
Figure 2-2: Fuel-Wise Analysis of Base Load Plants of Bangladesh: (a) Number of Plants, (b) Installed Capacity, and (c) Net Electricity Generation.....	28
Figure 2-3: Fuel-Wise Analysis of Peak Load Plants of Bangladesh: (a) Number of Plants, (b) Installed Capacity, and (c) Net Electricity Generation.....	29
Figure 2-4: Overall Fuel Mix of Thermal Power Plants of Bangladesh: (a) Number of Plants, (b) Installed Capacity, and (c) Net Electricity Generation.....	30
Figure 2-5: Fuel Cost Compared to Total Generation according to Fuel Type (in Million BDT/GWh).....	31
Figure 2-6: Composition of Plant Costs according to Fuel Type.....	32
Figure 2-7: Plant Factor according to Fuel Type.....	32
Figure 2-8: Fuel-Wise Per-Unit Generation Cost of Thermal Power Plants in Bangladesh.....	34
Figure 2-9: Trend of Cost Composition of Thermal Power Plants (BDT).....	35
Figure 2-10: Cost Trend and Composition of Gas Power Plants.....	36
Figure 2-11: Cost Trend and Composition of HFO Plants.....	37
Figure 2-12: Cost Trend and Composition of HSD Plants.....	37
Figure 2-13: Cost Trend and Composition of Coal Plants.....	38
Figure 2-14: Levelized cost of electricity (LCOE) Trend of Solar PV Power Plants in Bangladesh.....	39
Figure 2-15: Trend of Transmission and Distribution System Loss since FY2008–2009.....	43
Figure 2-16: Historical Trend of Electricity Access in Bangladesh.....	44
Figure 3-1: Historical Trend of Fossil Gas Reserve, Production and Consumption.....	46
Figure 3-2: Historical Trend of Liquid Petroleum Production, Import, and Consumption.....	47
Figure 3-3: Historical Trends in Coal Production, Import, and Consumption.....	48
Figure 3-4: Electricity Import Cost Trends.....	49
Figure 3-5: Photovoltaic Power Potential in Bangladesh (Source: ESMAP).....	51
Figure 3-6: Wind Speed Distribution over Bangladesh at 30m, 80m, 100m, and 120m.....	53
Figure 3-7: Battery Cost Deflation Steeper than Wind/Solar.....	55

Figure 4-1: Trend of Subsidies in the Power Sector (2010–2020).....	58
Figure 4-2: Trend of Electricity Costs and Tariffs.....	59
Figure 4-3: Trends of Total Loss in and Budgetary Support to the Power Sector.....	60
Figure 6-1: Projected Cost of Generation (BDT/kWh).....	68
Figure 7-1: Energy and Electricity Consumption Trends in Bangladesh.....	72
Figure 7-2: Per Capita Energy and Electricity Consumption Trends in Bangladesh.....	73
Figure 7-3: Electricity Consumption of Different Sectors (Kilotons Oil Equivalent).....	73
Figure 7-4: Energy Consumption of Different Sectors (Kilotons Oil Equivalent).....	74
Figure 7-5: Share of Value Added of Different Sectors to the GDP.....	75
Figure 7-6: Value Added of Different Sectors (USD).....	75
Figure 7-7: Electricity Intensity of Different Sectors (KTOE/USD of GDP Value Added).....	76
Figure 7-8: Elasticity of Electricity Consumption from Value Added in the Services Sector.....	77
Figure 7-9: Elasticity of Electricity Consumption from Value Added in the Industry Sector.....	77
Figure 7-10: Elasticity of Electricity Consumption from Value Added in the Agriculture Sector.....	78
Figure 8-1: Energy Mix-2025 Scenario A (Without VRE).....	83
Figure 8-2: Energy Mix-2025 Scenario B (With VRE).....	84
Figure 8-3: Energy Mix 2030 Scenario A (Without VRE).....	85
Figure 8-4: Energy Mix 2030 Scenario B (With VRE).....	86
Figure 8-5: Cost Reductions for Lithium-Ion Batteries.....	86
Figure 9-1: Scenario-Wise Installed RE Generation Capacity.....	95
Figure 9-2: RE Share (Generation) in 2030 Energy Mix.....	95
Figure 9-3: RE Share (Generation) in 2025 Energy Mix.....	95
Figure 9-4: Cost Savings and Grant Requirements for Solar Irrigation Pumps.....	97
Figure 9-5: Cost Savings in Different Scenarios.....	98
Figure 10-1: Utility Scale Solar PV (Cost per MWp in USD Million).....	100
Figure 10-2: Floating Solar PV (Cost per MWp in USD Million).....	101
Figure 10-3: Rooftop Solar (Cost per MWp in USD Million).....	101
Figure 10-4: Cost of Pumping System.....	102
Figure 10-5: Year-Wise Wind Installation Cost per MW.....	102
Figure 10-6: Investment Requirement by 2025 and 2030 in USD Million.....	103
Figure 10-7: Fee-for-Service Model.....	107
Figure 10-8: Ownership Modality.....	107
Figure 11-1: Estimated Share (%) of Human Resource Requirement during the Lifetime of a PV Project of 50MW.....	111
Figure 11-2: Distribution of Human Resources Required to Install and Connect a 50MW Solar PV plant, by Occupation.....	111
Figure 11-3: Distribution of Human Resources Required to Operate and Maintain a 50 MW Solar PV plant, by Occupation.....	112
Figure 12-1: Trends of Oil Price and Energy Imports with External Trade Balance.....	114
Figure 13-1: Types of Modernized Ancillary Services and Associated Products.....	119
Figure 13-2: Reduction in Transmission and Distribution Loss in Bangladesh (% of Generation).....	120

Figure 13-3: Recent Monthly Outage Hours of Grid-tied Ground-mounted Solar PV Projects in Bangladesh (Data collected from the plants by the authors).....	120
Figure 13-4: Average Monthly Grid Outage Hours per PV Plant from August 2019 to July 2020 (Authors' calculations).....	121
Figure 13-5: Potential Battery Storage Uses and Combinations.....	122
Figure 14-1: Impact of Risk Categories on Financing Costs for Equity Investors for Solar PV Investments in Bangladesh, Business-as-Usual Scenario.....	133
Figure 14-2: Impact of Risk Categories on Financing Costs Debt Investors for Solar PV Investments in Bangladesh, Business-as-Usual Scenario.....	133
Figure 14-3: Effect of De-risking on Cost of Equity.....	134
Figure 14-4: Effect of De-risking on Cost of Debt.....	134
Figure 14-5: LCOE Change of Solar PV due to De-risking, Compared to Baseline.....	143
Figure 14-6: Investment Leverage Ratio Effect.....	144
Figure 14-7: Savings Ratio Effect.....	145
Figure 14-8: Affordability Effect of De-risking.....	146
Figure 14-9: Carbon Abatement Effect of De-risking.....	146
Figure 15-1: Nodes of the Grid in Bangladesh.....	151
Figure 15-2: Main Challenges of the Power System and Flex Tool Analysis Done.....	153
Figure 15-3: VRE Curtailment at Different Levels of VRE Penetration.....	158
Figure 15-4: NDC 2025 Scenario Duration Curve for Energy Demand and Net Load (Lines) together with Unit Capacities.....	159
Figure 15-5: NDC 2025 Scenario Ramp Duration Curve for Demand and Net Load (Change Between Two Time Periods) as well as Upward Ramping Capabilities of Units.....	159
Figure 15-6: MCCP-R 2025 Scenario Duration Curve for Energy Demand and Net Load (Lines) together with Unit Capacities.....	160
Figure 15-7: MCCP-R 2025 Scenario Ramp Duration Curve for Demand and Net Load (Change Between Two Time Periods) as well as Upward Ramping Capabilities of Units.....	160
Figure 15-8: MCCP-M 2025 Scenario Duration Curve for Energy Demand and Net Load (Lines) together with Unit Capacities.....	160
Figure 15-9: MCCP-R 2025 Scenario Ramp Duration Curve for Demand and Net Load (Change Between Two Time Periods) as well as Upward Ramping Capabilities of Units.....	161
Figure 15-10: NDC 2030 Scenario Duration Curve for Energy Demand and Net Load (Lines) together with Unit Capacities.....	161
Figure 15-11: NDC 2030 Scenario Ramp Duration Curve for Demand and Net Load (Change Between Two Time Periods) as well as Upward Ramping Capabilities of Units.....	161
Figure 15-12: MCCP-R 2030 Scenario Duration Curve for Energy Demand and Net Load (Lines) together with Unit Capacities.....	162
Figure 15-13: MCCP-R 2030 Scenario Ramp Duration Curve for Demand and Net Load (Change Between Two Time Periods) as well as Upward Ramping Capabilities of Units.....	162
Figure 15-14: MCCP-M 2030 Scenario Duration Curve for Energy Demand and Net Load (Lines) Together with Unit Capacities.....	162
Figure 15-15: MCCP-M 2030 Scenario Ramp Duration Curve for Demand and Net Load (Change Between Two Time Periods) as well as Upward Ramping Capabilities of Units.....	163
Figure 15-16: VRE Curtailment According to Node in 2025.....	163
Figure 15-17: VRE Curtailment According to Node in 2030.....	163
Figure 15-18: Units Producing Reserves in the System, According to Nodes in 2025.....	164
Figure 15-19: Units Producing Reserves in the System, According to Nodes in 2030.....	164
Figure 15-20: Unit-Wise Generation to Meet Demand in the Three Scenarios in 2025.....	165

Figure 15-21: Unit-Wise Generation to Meet Demand in the Three Scenarios in 2030.....	166
Figure 15-22: Node-Wise Utilization Rate of Units in 2025.....	167
Figure 15-23: Node-Wise Utilization Rate of Units in 2030.....	167

LIST OF TABLES

Table 1.....	15
Table 2: Comparative Per-Unit Cost Analysis of the Public and Private Power Plants.....	33
Table 3: Fuel-Wise Cost Analysis of Thermal Power Plants in Bangladesh.....	34
Table 4: Mean and Standard Deviations of Cost Components of Different Types of Thermal Plants.....	38
Table 5: Distribution of the Age of Thermal Plants.....	41
Table 6: Plant Features and Retirement Opportunities.....	42
Table 7: Comparison of Historic Per-Unit Cost of Electricity Generated from Various RE Sources in Bangladesh.....	55
Table 8: RE Potential in Bangladesh under PSMP 2016.....	62
Table 9: Generation Cost (BDT/kWh).....	68
Table 10: Results of Ridge Regression of Macroeconomic Drivers of Electricity Demand.....	80
Table 11: Solar PV Capacity Installed as of 2020 in Bangladesh from Different Sources.....	82
Table 12: LNG and HFO Share in Total Generation.....	83
Table 13: Coal, LNG, and HFO Share in Total Generation.....	85
Table 14: Installation Projection of Solar Irrigation Pump.....	90
Table 15: Mujib Climate Prosperity Plan-Maximal (MCPM-M).....	92
Table 16: Mujib Climate Prosperity Plan-Realistic (MCPM-R) Scenario.....	93
Table 17: Interim Nationally Determined Contributions Scenario (NDC Scenario).....	94
Table 18: Cost Savings under Different Scenarios.....	97
Table 19: Year-to-Year Cost per MWp for Solar and Wind (in USD Million).....	103
Table 20: Investment Requirement by 2025 and 2030 (BDT Crore).....	103
Table 21: Summary of Total Job Creation in the Three Scenarios up to 2025 and 2030.....	112
Table 22.....	118
Table 23: Cost Components of VRE Grid Integration up to 2030 (Monetary figures are in million USD) (Authors' calculations).....	123
Table 24: Cost of Capital Assumptions.....	130
Table 25: Qualitative Investor Feedback on Risk Categories for Renewable Energy Investment in Bangladesh.....	131
Table 26: Results of Survey on the Risk Reduction Effectiveness of Different Policy and Financial Instruments on Cost of Equity.....	135
Table 27: Results of Survey on the Risk Reduction Effectiveness of Different Policy and Financial Instruments on Cost of Debt.....	135
Table 28: Cost Estimates of De-risking Instruments (Author's Calculation).....	136
Table 29: Modeling Assumptions for Baseline Energy Technology: Bangladesh Fuel Mix.....	138
Table 30: Modeling Assumptions for Baseline Energy Technology: Bangladesh Technology Mix.....	139
Table 31: Modeling Assumptions for Operating Margin.....	139

<i>Table 32: Modeling Assumptions for Building Baseline Energy Technologies.....</i>	<i>140</i>
<i>Table 33: Solar PV Technology Specifications Assumptions.....</i>	<i>141</i>
<i>Table 34: The Modeling Assumptions for Solar PV Terms of Finance.....</i>	<i>142</i>
<i>Table 35: Node-Wise Capacities and Shares of Different Fossil Fuels, Nuclear, and Imports in the Scenario Years of 2025 and 2030.....</i>	<i>150</i>
<i>Table 36: Cost and Technical Assumptions according to Fuel/Technology.....</i>	<i>151</i>
<i>Table 37: Parameter Assumptions about Penalties and Carbon Cost.....</i>	<i>152</i>
<i>Table 38: Node-Wise Installed Capacities of Solar and Wind for Each Scenario-Year.....</i>	<i>152</i>
<i>Table 39: Fuel-Wise Cost and CO2 Content.....</i>	<i>153</i>
<i>Table 40: Transmission Capacities between Node Pairs.....</i>	<i>154</i>
<i>Table 41: Flexibility Enablers of the Bangladesh Power System.....</i>	<i>154</i>
<i>Table 42: Flex tool Results Comparison of the Three Scenarios for 2025.....</i>	<i>155</i>
<i>Table 43: Flex tool Results Comparison of the Three Scenarios for 2030.....</i>	<i>156</i>
<i>Table 44: Flexibility Indicator Comparison of the Three Scenarios for 2030.....</i>	<i>156</i>

LIST OF ABBREVIATIONS

ADB	Asian Development Bank
BADC	Bangladesh Agriculture Development Council
BAU	Business As Usual
BcF	Billion Cubic Feet
BDP 2100	Bangladesh Delta Plan 2100
BDT	Bangladeshi Taka
BMDA	Barind Multipurpose Development Authority
BPDB	Bangladesh Power Development Board
BREB	Bangladesh Rural Electrification Board
CDM	Clean Development Mechanism
CPI	Consumer Price Index
CSP	Concentrated Solar Power
CST	Concentrated Solar Thermal Technology
DAE	Department Of Agriculture Extension
DFI	Development Finance Institutes
EPC	Engineering, Procurement, And Construction
ESMAP	Energy Sector Management Assistance Program
ESS	Energy Storage System
FIT	Feed In Tariff
GCF	Green Climate Fund
GDP	Gross Domestic Product
GED	General Economics Division
GEF	Global Environment Facility
GHG	Greenhouse Gas
GHI	Global Horizontal Irradiance
GoB	Government Of Bangladesh

GW	Giga Watt
GWh	Giga Watt-Hour
HFO	Heavy Fuel Oil
HSD	High-Speed Diesel
IEA	International Energy Agency
IEEFA	Institute For Energy Economics And Financial Analysis
IFC	International Finance Corporation
IPP	Independent Power Producers
IRENA	International Renewable Energy Agency
KTOE	Kilotons Of Oil Equivalent
LCOE	Levelized Cost Of Electricity
LNG	Liquefied Natural Gas
LoI	Letter Of Intent
MCPP-M	Mujib Climate Prosperity Plan-Maximal
MCPP-R	Mujib Climate Prosperity Plan-Realistic
MMst	Million Short Tons
MoEFCC	Ministry Of Environment, Forest And Climate Change
MoPEMR	Ministry Of Power, Energy And Mineral Resources
MW	Mega Watt
NDC	Nationally Determined Contribution
NGPL	Natural Gas Plant Liquids
NREL	National Renewable Energy Laboratory
OECD	Organisation For Economic Co-Operation And Development
PGCB	Power Grid Company Of Bangladesh
PPA	Power Purchase Agreement
PSMP	Power System Master Plan
PV	Photo-Voltaic
QRPP	Quick Rental Power Plants
RDA	Rural Development Authority
RE	Renewable Energy
RMG	Readymade Garment
SEZ	Special Economic Zones
SHS	Solar Home Systems
SIP	Solar Irrigation Pump
TWh	Terawatt-Hour
UNDP	United Nations Development Programme
UNFCCC	UN Framework Convention On Climate Change
US¢	Us Cents
USAID	United States Agency For International Development
USD	Us Dollar
VRE	Variable Renewable Energy
WAPDA	Water And Power Development Authority
WB	The World Bank
Wp	Peak Watt



Executive Summary



Chapter 1: Status of the Bangladesh Power Sector

Starting from a small generation capacity of 547MW in 1971, the Bangladesh power sector has grown to meet the demands of a growing economy and population, and installed capacity now stands at almost 22 GW. The entry of the private sector into the power sector played a crucial role in this capacity expansion. The bulk of the capacity additions took place after 2007-2008, when the sector was liberalized to include more generation from private power plants to meet the shortfall in supply and to reduce load shedding. Generation from the private sector exceeded the public sector in 2010. In 2009, daily load shedding was 1107 GWh, which was reduced to 32 GWh by 2018.

The Bangladesh energy mix primarily comprises fossil gas, in both installed capacity and net generation. Until FY1984–1985, hydro was the second most dominant energy source in terms of net generation. However, liquid fuels like high-speed diesel (HSD) and heavy fuel oil (HFO) have replaced hydro as the second-biggest contributors to the energy mix. Due to falling domestic reserves of natural gas, Bangladesh added coal to its fuel mix in 2005–2006. Bangladesh also started importing electricity from India in 2013–2014. In 2017, the country added its first ever solar photo-voltaic (PV) project to the grid. Although the initial plan was for imported coal and fossil gas to replace expensive oil and diesel, in the medium term they will replace cheap domestic gas in the power system, so the average cost of generation is likely to go up again. If this trajectory is to be sustained, more government subsidies or higher power tariffs for consumers may be required.

Bangladesh is building the Rooppur Nuclear Power Plant, which is to be commissioned in 2025. At present, fossil fuel power plant technologies consist of reciprocating engines (38%), combined cycles (36%), steam turbines running on the Rankine cycle (15%), and gas turbines (4%)



Chapter 2: Overview of Cost Analysis of Thermal Power Plants

The share of liquid fuel-based power supply grew from only 8% in FY2010 to 29% in FY2015, and over 30% in FY2018. This indicates a major primary fuel constraint in Bangladesh. This constraint increased the average supply cost of power by 41% between FY2015 and FY2020, from BDT6.10/kWh to BDT8.6/kWh. This situation further worsened the financial condition of the power sector. If the reliance on imported fuel oil, LNG, and coal continues in the future, it will increase the production cost of electricity, unless efficiency and other cost measures are taken.

While the total number and installed capacity of private plants is higher than public ones, public plants' net generation of electricity is higher, as most peaking power plants are private and run only during peak load periods. The number of base load and peaking power plants is roughly equal in the public sector, but most private plants are meant to serve the peak load. This has major financial implications, as many power plants receive capacity payments regardless of whether they are used or not. This results in an increased cost of generation, leading to significant financial losses for BPDB, which are typically covered by a government subsidy. In FY2018–2019, the subsidy for BPDB increased to almost USD 1 billion.

Fossil fuel power plants in Bangladesh use four types of fuel: gas, coal, diesel, and furnace oil. Fuel costs are highest for furnace oil-based plants relative to electricity generation in 2019–2020. In aggregate, estimated fuel cost in 2019–2020 alone was approximately BDT 148 billion, equivalent to USD 1.72 billion. Plant costs can be classified into three main parts: fuel costs, fixed costs, and variable operation and maintenance costs. Of these, fuel costs and fixed costs comprise the biggest portions. In coal plants, fuel costs are higher compared to fixed costs, whereas in diesel plants, fixed costs are proportionally highest. Fixed costs in furnace oil are also relatively high because liquid-fuel-based plants operate at low utilization factors. Gas-powered plants have the highest plant factors, followed by coal. Diesel plants have the lowest plant factors, although they have high fixed costs. Lower generation levels relative to high fixed costs translate to high per-unit costs. Fuel costs are lowest on a per-unit basis for gas-based power plants, and highest for diesel-based.

The per-unit generation of private thermal plants is nearly 1.72 times higher than that of public plants. However, the per-unit generation cost of peaking plants is almost four times higher in the private sector. The fuel cost and fixed cost are much higher for peaking plants than base load plants. This is due to the large number of private peaking plants that are powered by expensive liquid petroleum fuel, and that remain less utilized while still receiving fixed capacity payments. In FY2019–2020, the overall thermal efficiency of the public-owned power plants was 39.72%. There has been a slow but continuous reduction in transmission and distribution since 2008.

Chapter 3: Resource Analysis

Bangladesh has a declining reserve of natural gas, its primary fuel in power generation. The country is facing a shortage of nearly one billion cubic feet (Bcf) gas per day at present, and demand is much higher. The government plans to meet the shortfall by importing liquefied natural gas (LNG). As imported natural gas is at least four times more expensive than domestic natural gas, this may increase tariffs. It is important to note that the use of natural gas is neither an incremental decision, nor is it economical without scale. Natural gas requires major infrastructure investment, which in turn will require from consumers the same capital-recovery guarantees as coal-, diesel-, and oil-fired power plants.

Liquid petroleum, which has been the country's second-largest source of energy and power, also has to be imported. The national demand for coal is currently met by a combination of imports and domestic production. Bangladesh has made use of several ranks of coal, including bituminous, sub-bituminous, lignite, anthracite, and metallurgical coke. At present, total coal reserves in the country are 322.98 million short tons (MMst). Nearly two thirds of coal reserves are used for power generation. The remaining portion is used for general purposes, such as brick manufacture, household use, etc. Although coal was once considered the best choice for low-cost generation, in August 2020, the Ministry of Power, Energy and Mineral Resources revised its plans with respect to 26 planned coal plants.

Bangladesh has been importing electricity from India since 2013, and at present 9.34% of its electricity generation is from India, via the Bheramara–Baharampur HVDC interconnections and the Tripura–Cumilla HVDC interconnections. BPDB has plans to import 500 MW of power from Nepal by 2026. Another 1,496 MW of electricity is to be imported from Jharkhand, India, by 2022. There is also potential for importing hydroelectricity from Bhutan through India. Since most of this imported power comes from hydropower plants, such regional interconnections will help Bangladesh improve domestic energy security and reduce emissions. Bangladesh could also import ultra-low-cost solar energy from India.

Bangladesh has two main sources of renewable energy (RE), the most promising of which is solar energy. The country receives moderate levels of solar radiation on a daily basis (GHI $\approx$ 4.5 kWh/m²), which can be converted into reasonable sources of energy in the form of concentrated solar or photovoltaic solar power. Studies of wind energy technical potential in Bangladesh have found that 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 concentrated in the southern coastal areas of the country, not excluding unsuitable lands or lands already occupied.

Other RE sources are hydro and geothermal. The hydropower potential of Bangladesh is greatly limited by geographical as well as geopolitical factors. There is limited mini- and micro-hydro potential on the Sangu, Matamuhuri, and Bakkhali rivers, which needs detailed feasibility assessment. There are also a few thermal gradient sites across Bangladesh, in areas such as Hazipur, Bakhrabad, Titas, Habiganj, Rashidpur, Biani Bazar, and Kailas Tila.

A study of tidal energy potential in Mongla, Cox's Bazaar, and Sandwip revealed that tidal energy could be tapped in these areas, especially Sandwip, if turbine construction is combined with flood control barrages. Wave energy could have some potential in coastal Bangladesh, but detailed feasibility studies have not taken place. There is potential for the use of bioenergy in Bangladesh, but actual quantities from heterogeneous sources have not been precisely estimated. There could potentially be nearly 373.7 TWh of electricity from a total of 213.8 million tons of biomass if there was the infrastructure to put such resources to use. Some small-scale projects have already been implemented in Bangladesh to convert poultry and dairy waste and agricultural residues (rice husk) into electricity.





Chapter 4: Effects of Subsidies and Costs on the Government

The current power system is built on the premise that fossil fuel is cheap and reliable. Global fossil fuel subsidies amount to USD 3.1 trillion per year, which is over 20 times the level of support to RE. Much funding is dedicated to subsidizing loss-making HSD and HFO power plants. In some years, subsidies can reach as high as 35% of revenues. Subsidies are paid out for losses, which are incurred for a variety of reasons, including volatile fuel costs, the cost of electricity delivered to consumers being higher than electricity tariffs charged, and high fixed-capacity payments. Losses can also occur due to shortfalls in revenue collection on electricity sales. Costs are trending upward, including generation cost and average supply cost, and are always significantly higher than the average bulk tariff, which cannot be raised at the same rate as the increase in costs.



Chapter 5: RE in Government Policy Documents

This chapter reviews several documents related to energy and environmental policies in Bangladesh. They are summarized as follows:

The Power System Master Plan 2016 (PSMP): This document was prepared with the aim of formulating a comprehensive energy and power development plan up to the year 2041, covering energy balance, power balance and tariff strategies. It set goals for fuel diversification with an emphasis on increasing the role of RE in the power generation mix. The PSMP states 10% of total installed capacity should come from RE sources. The sources of RE included are solar rooftops, solar parks, solar home systems, solar irrigation pumps, wind parks, biomass, biogas, waste to energy, small hydropower, and mini- and micro-grids.

Nationally Determined Contributions: The Government of Bangladesh ratified the Paris Agreement in September 2016, and its Nationally Determined Contribution (NDC) was registered on the UN Framework Convention on Climate Change (UNFCCC) NDC Registry. The government has committed to reducing GHG emissions in three sectors: power, industry, and transport. To achieve the emission reduction targets, the NDC projected that the power sector will have to reduce emissions by 5% below business-as-usual level by 2030, or by 15% below business-as-usual GHG emissions by 2030 if sufficient and appropriate support is received from developed countries.

Perspective Plan of Bangladesh 2021-2041: In this document, the government proposes Vision 2041, which sets out an aim to eliminate extreme poverty and attain the status of upper middle-income country by 2031, and high-income country by 2041. The document sets targets including the capacity to meet the energy demands of an upper-middle- and high-income economy, ensure sustained and universal energy access, ensure efficient supply of electricity at a globally competitive price, and achieve 100% energy security. The Perspective Plan also mentions that Bangladesh's fuel mix should change from an excessive reliance on fossil fuel towards a balanced combination of low-cost fuel and RE. This can be achieved by importing hydro and solar power from neighboring countries such as Nepal, Bhutan, and India.

Bangladesh Delta Plan 2100: This policy document was launched by the Planning Commission in October 2018. It proposed a target of generating 30% of total energy from renewable sources by 2041, and to develop long-term RE policies as well as strategies, and to formulate a master plan for the next 50 years to harness potential RE sources with the help of private- and public-sector investments in renewables. It plans to promote research on the development of technology in the field of RE in universities and research institutions and build capacity for its application. A further objective of the Delta Plan is to enhance green growth through research and development of RE technologies, including a Clean Development Mechanism (CDM), and devise innovative financing packages for grant funding and low-interest financing to address affordability for both grid and off-grid RE projects.



Chapter 6: Cost of Electricity Generation Pattern of Different Energy Sources

Different methodologies have been used to derive the generation cost (BDT/kWh) for different sources of electricity for the years 2020, 2025, and 2030. A devaluation factor of 1.41% per annum for USD to BDT has been used where applicable. The generation cost of coal, gas, liquid fuel, imported power, and local hydro have been collected from BPDB for 2020, and forecasted price for the years 2025 and 2030 has been derived from the rate of change of generation cost calculated in 'Revisiting PSMP 2016'. Generation cost for LNG-based power plants has been derived from Gas Sector Master Plan 2017, with an escalation factor based on the trend of the last five years. For nuclear power plants, the cost of electricity has been collected from media briefings. The cost of electricity for rooftop solar and solar from independent power producers (IPPs) has been derived from the current market price in Bangladesh and the global price trend of equipment. For floating solar, the cost of electricity is usually slightly higher than utility-scale solar projects. The tariff on onshore wind power plants has been determined from recent bids on a wind project in Bangladesh, and the tariff for offshore wind power has been determined using global and local tariff differences between onshore and offshore wind. The generation cost for the proposed import of hydroelectricity from Bhutan is considered equivalent to a similar project developed by India.



Chapter 7: Econometric Analysis of Electricity Consumption Drivers and Elasticity

In this section, we analyze how macroeconomic factors affect the total electricity consumption in Bangladesh, and how they affect the peak demand for electricity. Econometric models are used to explore the relationships.

With respect to total energy consumption, we find that the most important drivers of the electricity consumption are total GDP, the GDP per capita and the contribution of services to GDP. Agricultural production also has a small effect. The electricity consumption of the sector is low compared to industry or service sectors, and so the impact is less strong. The share of industry overall, and manufacturing in particular do not appear to have a significant impact on the electricity consumption. This may be because the industrial sector is lowering the rate of growth of energy intensity by increasing energy efficiency in electricity, compared to other sectors. We find that services are a highly electricity intensive sector. However, as the per capita income of the country increases, it will also lead to greater electricity consumption.

Among the drivers of peak demand of electricity, we find that the total GDP, GDP per capita, services value added and industry value added are highly significant drivers of peak generation, whereas the manufacturing value added is also a significant driver. However, the agricultural output plays no significant role in determining the peak generation. This may be because the timing of agricultural demand is flexible, as irrigation can take place on a flexible timetable.

As before, the biggest impact comes from the value added from services, followed by the per capita income and the total GDP. This implies that the services sector drives not only the volume of electricity consumption but also the pattern. The same is true for the per capita GDP. As the average income of the country rises, the people consume more electricity, which drives up the peak generation during peak hours. Compared to these drivers, the value added from the industrial and manufacturing activities has a smaller positive significant impact. This can be attributed to the fact that manufacturing and other industrial activities can take place in shifts throughout the day, and some of the demand is met by captive power plants. The government has issued licenses of 2600 MW of gas based and 600 MW of liquid fuel based captive generation capacity to various industries which have highly sensitive production processes, and cannot tolerate any lapse in electricity supply. Therefore, these industries provide some of their own electric power, and so do not strongly affect the peak generation from the grid.

Chapter 8: Increasing Renewable Share in the Energy Mix

This section addresses the maximum possible RE share envisaged for 2025 and 2030. According to the PSMP 2016, peak electricity demand in Bangladesh is likely to shift to daytime, with the country's advancement towards industrialization relying on steady economic growth. Average hourly electricity demand for 2025 and 2030 was determined using data on peak electricity demand and estimated daily load curve from PSMP 2016. As per PSMP 2016, forecasted average electricity peak demand is 19,874 MW and 27,393 MW for the years 2025 and 2030 respectively. A 24-hour average energy mix was developed by comparing peak demand and the 24-hour normalized load curve. Information on capacity additions and retirement of fossil fuel-based power plants up to 2025 and 2030 was taken from the BPDB website and the PSMP 2016.

For both reference years, two scenarios have been considered. Scenario A reflects no penetration of solar PV and wind as sources of variable renewable energy (VRE) and Scenario B reflects maximum possible VRE penetration. The supply-demand model relies on several assumptions about technology use and economic replacement of HFO, HSD, and coal-based power plants. These are summarized as follows:

- Solar PV and wind power replace expensive fuel during the day
- Plant factor of at least 50% at any given point for coal and gas
- Plant factor of at least 90% at any given point for nuclear power plants
- Gas-based power plants used optimally due to low cost of generation and marginal greenhouse gas (GHG) emission
- Plans to import power from India
- Hydropower import from Bhutan considered for 2030
- Offshore and onshore wind power plants both considered
- Energy storage system (ESS) considered for 2030.

The proposed energy mix as derived from the supply-demand model assumes a maximum 4,080 MW of installed capacity in 2025, with the bulk of the capacity additions from solar PV. In 2030, the proposed energy-mix under Scenario B involves an RE capacity of 10,090 MW, with supply from RE assumed to replace HFO and HSD generation in 2025. Under Scenario A, in 2030, HFO, HSD, and coal are considered potential sources of replacement.



Chapter 9: Renewable Energy Share in Different Scenarios

This chapter relies on the maximum possible RE penetration outlined in the previous section. Considering maximum RE capacity additions from the previous section, three scenarios were developed to articulate RE penetration in the future. Background assumptions in formulating such scenarios involve technological progress, socioeconomic factors, and cost reductions of RE technology. Bangladesh has been a role model in disseminating off-grid electricity solutions to rural populations. In addition to solar home systems (SHS), solar irrigation systems are considered a possible solution for irrigational water supply, and have been accepted in rural communities. In addition, rooftop solar PV on industrial roofs is thought to be a potential supplementary solution to solar parks, which require large scale continuous barren land. Wind energy is moderately available and is also considered a potential technology. Importing hydroelectricity from Bhutan has been considered due to its scarcity in Bangladesh. With this background, proposed scenarios are:

1. Mujib Climate Prosperity Plan-Maximal Scenario ("MCCP-M Scenario")
2. Mujib Climate Prosperity Plan-Realistic Scenario ("MCCP-R Scenario")
3. Nationally Determined Contributions Scenario ("NDC Scenario")

MCCP-M Scenario involves 80% of the maximum envisaged RE capacity limit, while MCCP-R involves 50%, in terms of installed capacity in MW. Both utility-scale and rooftop solar are proposed to play a major role in achieving these targets. With more than 950 MW utility-scale committed projects and the potential of solar PV in industries, the MCCP-M scenario with capacity addition of 8,080 MW by 2030 is an attainable option to meet the government's target of achieving 10% generation from renewables. MCCP-Realistic suggests renewable capacity additions of 2,620 MW and 5,030 MW in 2025 and 2030, respectively. For the NDC Scenario, capacity additions of 1,150 and 2,180 MW have been suggested for 2025 and 2030, respectively. An energy storage system (ESS) has also been suggested where the renewable energy share exceeds 10% of generation at a given point of time.

In terms of capacity share, RE penetration estimates for 2030 range from 6% (NDC Scenario) to 19% (MCCP-M Scenario). RE contributes 10% of total electricity generation under the MCCP-M scenario, while in the NDC scenario RE makes up only 3% of total generation. Cost savings and investment requirements in these scenarios were also noted. It was found that attaining 10% generation from renewables (MCCP-M) would reduce generation costs by BDT 8,125 crore annually.



Chapter 10: Investment Requirements and Implementation Plan

This chapter covers investment requirements; RE technologies are capital-intensive relative to conventional power plants. It also addresses potential implementation plans. Technologies such as solar parks, floating solar, solar irrigation, rooftop solar, and wind farms (onshore and offshore) are prospective areas of RE intervention under various scenarios. Investment requirements for implementing the scenarios have been identified, taking the current and projected installation costs for 2025 and 2030 into consideration.

Solar panels and inverters are expected to gradually decrease in cost. Based on the prevailing rates in Bangladesh, current PV and inverter prices are estimated at US\$21 per Wp (peak Watt) and US\$8 per Watt, respectively. According to Fraunhofer, the price of PV panels and inverters will be US\$15.86 per Wp and US\$3.4 per Watt, respectively, by 2050; year-to-year average PV price has been estimated based on this. All other components have been estimated to increase in cost by a nominal 1%. In addition to the components required in a typical utility-scale solar project, floating solar projects require additional investments in floats and moorings. Cost per MWp of floating solar is forecasted to be USD 0.5 million in 2030. Solar rooftop projects in Bangladesh are experiencing a steady uptake, and the forecasted capital cost per megawatt peak (MWp) of solar PV rooftop project is USD 0.49 million. Offshore wind power plants are costlier compared with onshore wind projects and other RE technologies such as hydro and solar PV. It is forecasted that installation cost per MW of offshore wind projects will decline from USD 6.0 million to USD 3.7 million. In terms of onshore wind projects, cost reductions would lead to an installation cost per MW of USD 0.94 million by 2030.

The investment required up to 2030 to implement proposed capacity shares of various RE technologies has been calculated based on capital cost forecast models. The estimate is BDT 8,819 crore to BDT 26,675 crore in additional investment in 2025 and BDT 18,720 crore to BDT 69,664 crore in 2030.

This section also discusses the use of pre-existing business models in achieving renewable energy targets. A standard capital expenditure and operational expenditure model is being used for rooftop solar installation in industrial areas in Bangladesh. All the ground-mounted solar and wind projects currently or presumably soon-to-be operational in Bangladesh have been installed under a power purchase agreement (PPA), wherein the government buys electricity from the generating agency with a 20-year tariff. Most of these projects are financed through a combination of equity (20%) and loan investment (80%). Equity investment comes from private companies, and loan financing largely from development finance institutes (DFI) such as the Asian Development Bank (ADB), the World Bank (WB), and the International Finance Corporation (IFC). Solar irrigation projects are grant-based, with a hybrid financing structure involving private sector investment as equity and grants from the government or development partners such as ADB, WB, KfW, and concessionary loans.



Chapter 11: Number of Jobs by 2025 and 2030

The renewable energy sector is likely to create many jobs in Bangladesh in the installation, operations and maintenance stages of projects. Installation and connection jobs are likely to be temporary, while operations and maintenance jobs are likely to last through the project life of 20–25 years. According to the analysis, by 2030 in the maximal scenario, around 33,000 new jobs will be created in the renewable energy sector as a whole. The Interim NDC scenario has the most conservative targets which is estimated to create around 9,000 jobs by 2030.



Chapter 12: Reduction in Imported Fossil Fuel and its Effects on Trade Balance, External Trade Account

In addition to job creation, there will be several macroeconomic benefits from expanding the renewables sector to replace fossil fuels. Bangladesh is an oil-importing country and is consequently sensitive to oil supply and prices. Although it had historically produced fossil gas for local consumption in electricity production, fossil gas reserves are decreasing, even as demand increases. It therefore will rely increasingly on imports in the future, unless it invests in RE capability. An analysis of the historical expenditures on fossil fuel imports in Bangladesh and oil prices, and the effect they have on the external trade balance, inflation rate, consumer price index (CPI), total reserves, and current account balance is as follows:

- Net energy imports do not have a significant impact on external trade balance, although there is a non-significant negative effect.
- Oil price is a highly significant predictor of external trade balance. A one dollar increase in oil price decreases the external trade balance by 0.05%. This is a relatively small but significant impact.
- Energy imports are not a significant predictor of inflation in Bangladesh, although they have a positive, non-significant effect.
- Oil price changes have a positive and significant impact on inflation. A one dollar increase in oil prices increases inflation by 0.087%.
- Energy imports are a marginally significant predictor of CPI. A 1% increase in energy imports increases the CPI by 0.4 points.
- Oil price is also an insignificant predictor of CPI. A one dollar increase in oil prices increases the CPI by 0.058 points.
- Energy imports have a significant and sizable effect on the total reserves. Increasing the import share of energy by 1% reduces reserve capacity by the equivalent of 0.26 months of imports.
- Oil price rises have a negative effect on reserves but are not a significant predictor.
- Net energy imports as a share of energy use have a highly significant impact on the current account balance as a share of GDP. A 1% increase in net energy imports decreases the current account balance by 0.28%.
- Oil prices also have a significant impact. A one dollar increase in the price of oil decreases the share of current account balance by 0.02%.

Chapter 13: Extension and Modernization of the Grid to Support High Shares of Distributed RE

Modernizing the grid will benefit not only cost-effective renewables integration, but will also improve efficiency in fossil-fueled generation, which will lead to lowered demand for gross generation as waste is reduced. Reduction in transmission and distribution loss can reduce administrative costs, electricity theft, and overall consumption of fuel, and enable easier collection of electricity bills from customers.

Bangladesh knows from experience that a weak grid infrastructure can lower generation in existing RE PV power plants. This is due to frequent tripping of the line, and consequent hours of maintenance/repair time during sunlight hours. This grid outage, rather than the efficiency of the solar panels or the level of solar radiation, drives the decline in productivity. Transmission lines in Bangladesh are also vulnerable to damage during periods of heavy rain and storms. Grid- and transmission infrastructure-related problems have been identified as the leading cause of low productivity in existing PV plants in Bangladesh, which can potentially cause losses for the plants or increase idle capacity payments for the government.

At present, Bangladesh is in phase one of renewables grid penetration, which requires no grid upgrade or storage needs. However, for the coming decade, the power system will move on to phase two, and at most phase three. In these phases, issues include random fluctuations in power demand, and increasing demand after sunrise or rising net load at sunset. These issues can be addressed by short-term frequency control and changes in the supply-demand system regulation. We consider that in the coming decade the additional costs needed for the projected levels of VRE generation to be reserve capacity costs, grid upgrading costs, and grid connection costs. Storage investments will provide added grid integration support. Storage investment is driven by several factors, notably an intent to bring down transmission charges and provide grid resilience. A storage system can address the variable nature of solar and wind power, which is not always available when needed, or is produced in quantities that cannot be fully used at a particular time. Given the low levels of VRE grid penetration at present, Bangladesh is not likely to need grid integration investment by 2025 but will need it by 2030. Investment amounts are presented in the following table.

Installed capacity (MW) in 2030		8,080	5,030	2,180
Generation (MWh)		12,604,800	7,846,800	3,400,800
Projected investment in installed capacity (Million USD)		6,640	4,194	1,784
Grid connection cost (Million USD)	5% of project investment	410	239	110
Grid upgrade cost (Million USD)	up to 3.6 USD per MWh	45	28	12
Profile cost	Negligible for projected levels	NA	NA	NA

Table 1

Chapter 14: Policy De-risking and Regulatory Framework

This analysis follows the methodology set out by UNDP, in the report entitled “Derisking Renewable Energy Investment: A Framework to Support Policymakers in Selecting Public Instruments to Promote Renewable Energy Investment in Developing Countries”. A series of stakeholder meetings were conducted with participants of the power sector in Bangladesh, including investors, financiers and government organizations. A survey was conducted of sixteen project developers and four financiers, and both local and international firms were represented. The findings of the survey were used to provide inputs into the de-risking model, which provided the resultant LCOEs in the business as usual (BAU) scenario and the post de-risking scenario assuming the MCCP-M 2030 case. The benchmark developed country for comparison was Germany.

The survey revealed that the highest impact risk categories were found to be permits risk, power market risk and grid infrastructure risk and financial sector risk. Low levels of risk originate from social acceptance risk and resource and technology risk. All the instruments for reducing the associated risk has a high degree of effectiveness. Implementing all of them can result in an overall significant reduction in cost of capital. However, the selection of the instruments depends on their cost effectiveness. If all the risk reduction measures could be implemented, the total cost of equity could be brought down by 5.529 percentage points and the total cost of debt can be decreased by 3.45 percentage points.

The de-risking analysis for renewables in Bangladesh reflects some of the new realities about the competitiveness of renewables with respect to fossil fuels in the present time. The analysis of the LCOE shows that the LCOE of solar is lower than the baseline mix of fossil fuels, the introduction of de-risking instruments decreases the LCOE of PV, but the benefits to investment leverage ratio are not there. This is because, if the LCOE of solar PV in the baseline scenario was higher than the fossil fuels, there would be a price premium of the FIT or PPA payments, which would then be eliminated if the LCOE was reduced due to de-risking. However, if the LCOE in the baseline scenario is already lower compared to fossil fuels, there is no price premium savings. Therefore, the investments in the de-risking instruments increases the overall costs of investments in renewables, and therefore decreases the investment leverage ratio. The present value of incremental costs of solar PV relative to the baseline is actually negative, considering that the LCOE of solar PV is lower than the baseline fossil fuel mix, and so the savings is also negative. The savings ratio therefore shows that although money is not saved by avoiding the incremental costs of renewables, but rather electricity is produced at an even lower cost, thus increasing the cost advantage of renewables. As a result of de-risking, the cost of solar PV falls further, making the carbon intensive fossil fuel generation an even more costly option, and avoiding carbon emissions an even cheaper outcome.



Chapter 15: Bangladesh Power System Flexibility Assessment

A flexibility assessment for the power system of Bangladesh was conducted using the IRENA FlexTool software, in order to assess the readiness of the power system to accommodate higher levels of penetration of variable renewable electricity. The analysis were done for the three scenarios of NDC, MCCP-R and MCCP-M, for each of the years 2025 and 2030.

The results of the analysis show that there is no loss of load or excess load in any of the 2025 or 2030 scenarios, and the curtailment is a minuscule share of total VRE generation. The highest cost in 2025 is for the NDC scenario, and the least cost is in the MCCP-M scenario.

In the scenarios of 2030 the highest share of VRE is again in the MCCP-M case. However, the share of VRE in electricity generation does not increase as sharply from the MCCP-R to the MCCP-M case. In 2030, the curtailment levels are minute for the NDC and the MCCP-R scenarios, but becomes noticeable in the MCCP-M case. Again, like 2025, the highest cost in 2030 is for the NDC scenario, and the least cost is in the MCCP-M scenario.

In the 2025 scenarios, there is no loss of load, excess load, reserve inadequacy, insufficient inertia, model leakage or spill, and a minute amount of curtailment of VRE. There is a small amount of capacity inadequacy (between 1,115 and 1,005 MW). The same pattern can be seen in the 2030 scenarios, with a bit higher capacity inadequacies (between 1,791 and 1,661 MW). The VRE generation matches the demand well. The VRE curtailment occurs mostly in Khulna, Barishal and Rajshahi in the 2025 scenarios. In 2030, the same nodes are involved in curtailment, but there is a small share of curtailment in Sylhet. In Dhaka, Cumilla, Rangpur and Mymensingh, HFO oil provides the reserves in all scenarios. In Chittagong, it is HFO followed by hydro and gas. Similarly, in Rajshahi, Barishal and Khulna, HFO oil is the top provider of reserve, followed by gas. This is not an ideal situation, as HFO should be phased out in the long run, with better options like gas or storage or some other means of energy carriers. Reserves are produced in Rangpur, Mymensingh and Khulna only in the NDC scenarios in 2025, but in all scenarios in 2030.

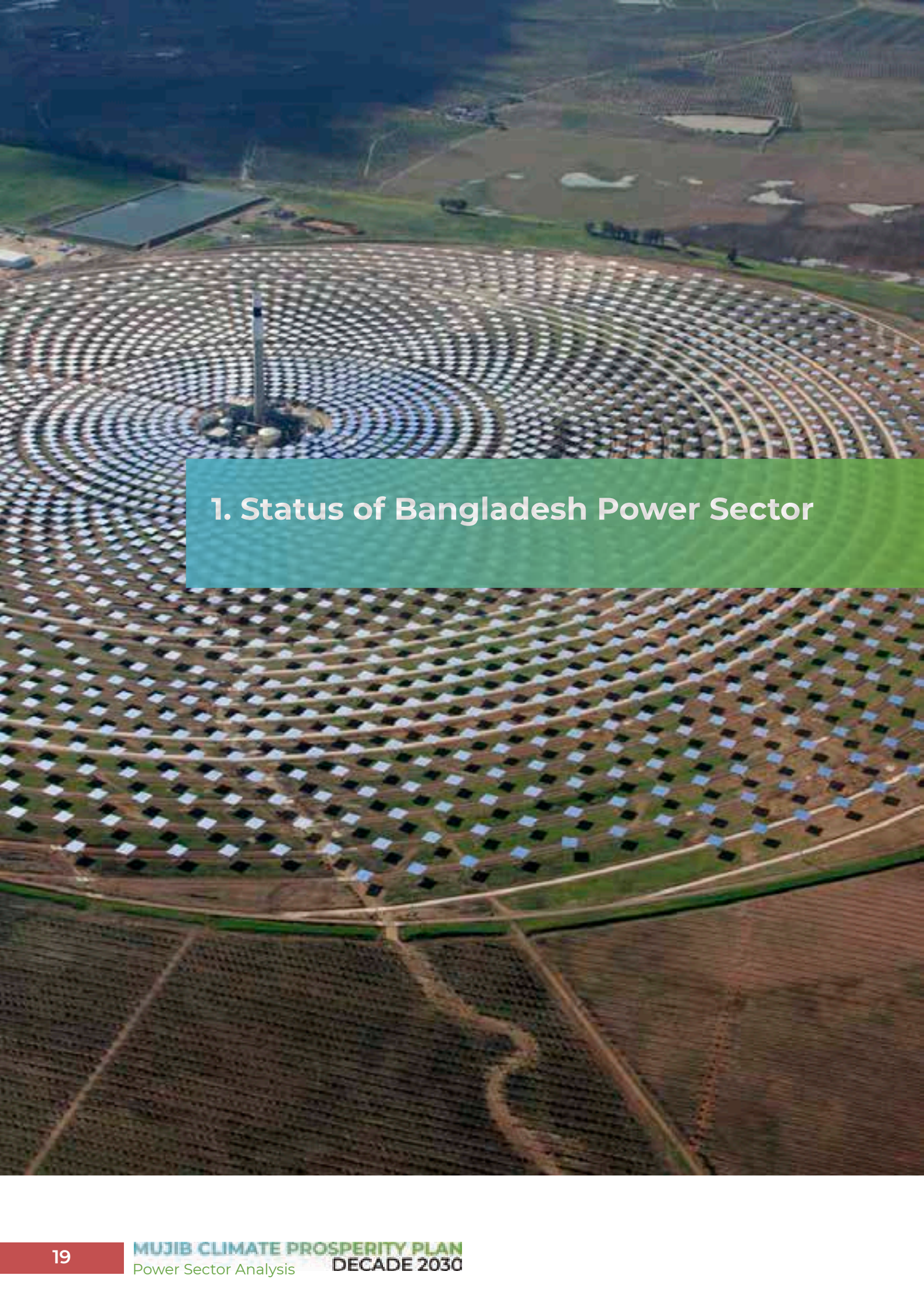
The share of solar in the mix increases noticeably in the MCCP-R scenario and more in the MCCP-M scenario in 2025, and more so in 2030. There is a minute contribution from wind energy. In the MCCP-M scenario, there is a small amount of curtailment. The contribution of HFO is imperceptible in 2025, and a small share in 2030.

The rate of utilization of PV is low in Barisal and Khulna in 2025, but it increases in Barisal in 2030, while remaining low in Khulna. Wind utilization is comparable to PV utilization. The rates of utilization in a particular year are almost the same in all the scenarios. The curtailment of VRE only starts when the share is above 6%, and occurs in the highest VRE penetration scenario of MCCP-M 2030.

According to the analysis of FlexTool, the least cost option is the MCCP-M option for 2025 and 2030. The system does not have significant flexibility issues under the scenarios analyzed.

The analysis does not recommend additional investments in storage and transmission for the time being. Therefore, based on the results of the analysis, additional capacities of solar and wind can be incorporated into the power system.





1. Status of Bangladesh Power Sector



1.1 Brief History

Bangladesh gained independence in 1971, but electricity development in the region started in 1901 at Ahsan Manzil, at the residence of the Nawab of Dhaka. Later, in 1930, a powerhouse was set up in Dhanmondi, and commercial distribution began. In 1959, the Water and Power Development Authority (WAPDA) was created to take control of the electricity generation system from the private sector. In 1972, after independence, the government created the Bangladesh Power Development Board (BPDB), effectively separating the duties and responsibilities of water and power from WAPDA.

The BPDB started its journey with 547 MW installed capacity, equivalent to a net electricity generation of 683 GWh (FY1971–1972). After 20 years of gradual and steady progress, the sector underwent substantial reform in the 1990s, with a noticeable effect on both the installed capacity and total net generation of the power sector. The changes are apparent in Figure 1-1 and Figure 1-2, which illustrate the historical trend of cumulative total installed power and net generation of the Bangladesh power sector (excluding captive power) from FY1970–1971 until FY2019–2020.

The participation of the private sector in energy generation was incentivized by policies such as the Policy Guideline for Enhancement of Private Participation in the Power Sector, Policy Guideline for Small Power Plant (SPP) in Private Sector, Policy Guideline for Power Purchase from Captive Power Plant, etc. Following the launch of Private Sector Power Generation Policy in 1996, the private sector began participating in generation in FY1999–2000. The subsequent revisions around 2007–2008 resulted in a significant rise in installed capacity as well as generation.

Private sector-supported generation surpassed that of the public sector as early as 2010. Then the Government of Bangladesh (GoB) launched the Power System Master Plan 2010, and in it stated its short-term strategy of using quick rental power plants (QRPPs) to further reduce the gap between demand and supply by backing the private sector. The decision to opt for QRPPs drew criticism from experts and some segments of the public due to its high cost, but ultimately it reduced power scarcity significantly.

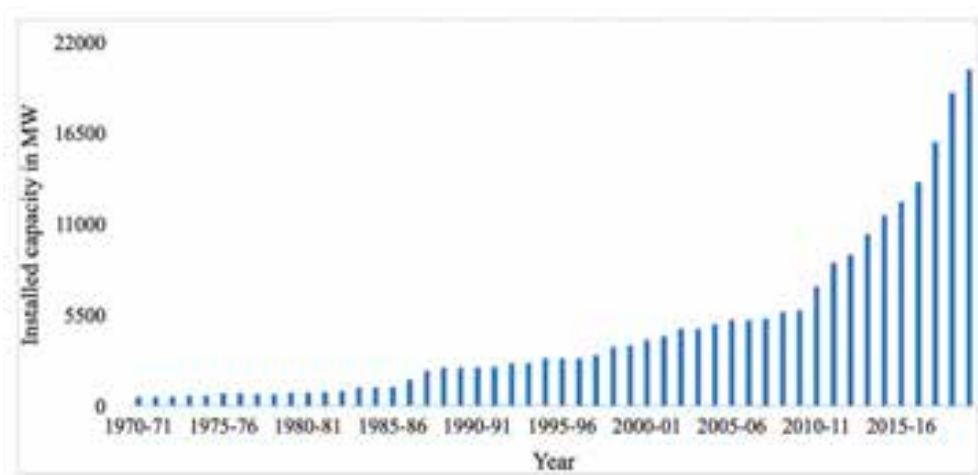


Figure 1-1: Historical Trend of Installed Power Generation Capacity of Bangladesh

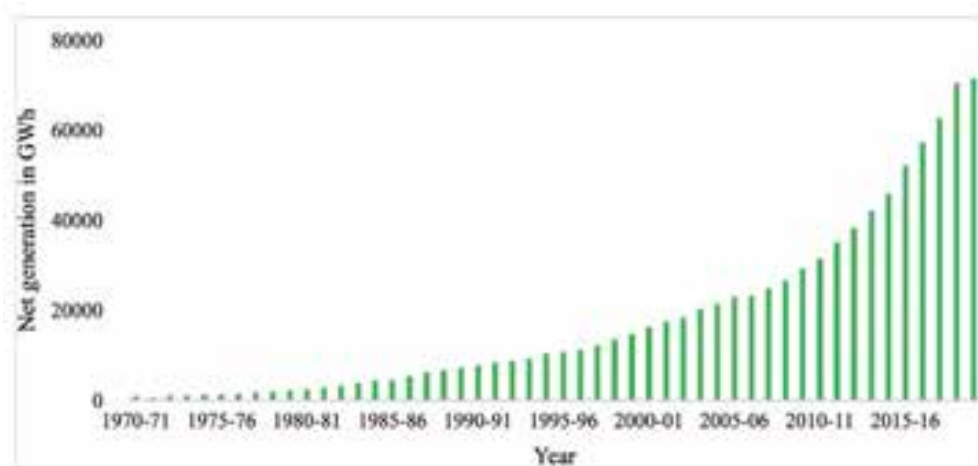


Figure 1-2: Historical Trend of Net Energy Generation in Bangladesh

1.2. Supply and Demand Scenario

By the end of FY2019–20, the installed capacity of the power sector stood at 20,383 MW and net generation was 71,419 GWh. Along with installed capacity and net generation, access to electricity, grid coverage, and consequently the level of consumption increased significantly over the years. The per capita generation and consumption of electricity in Bangladesh at the end of FY2019–2020 was 426 kWh and 378 kWh respectively. The electricity access rate was 97% (Bangladesh Power Development Board, September, 2020).

One of the sector's growth was the need to meet increasing demand for electricity. In 2009, daily load shedding was 1,107 GWh, which was reduced to 32 GWh by 2018. Figure 1-3 shows the historical trend of demand and supply from the very beginning until FY2019-20. In figure 1-3, the curve representing energy not served is important to note: it shows that the gap in energy served started to diminish only recently. However, the figure also shows that in the last few years, installed capacity was mostly able to reach forecasted demand. That said, timely support for transitioning the energy system to the cost-effective technologies that are currently reshaping global power markets would foster more reliable and competitive power.

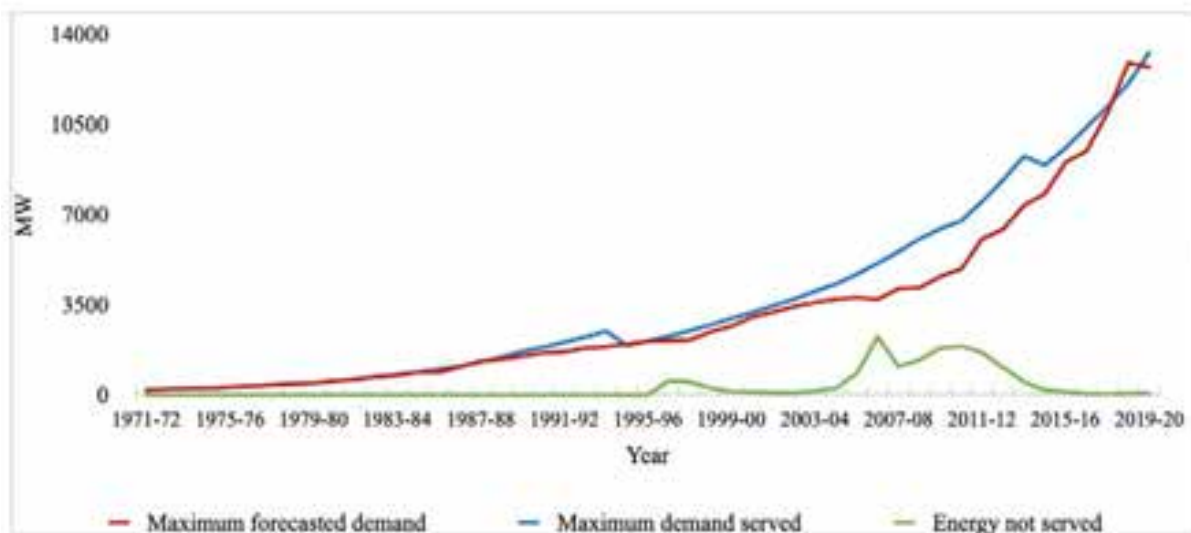
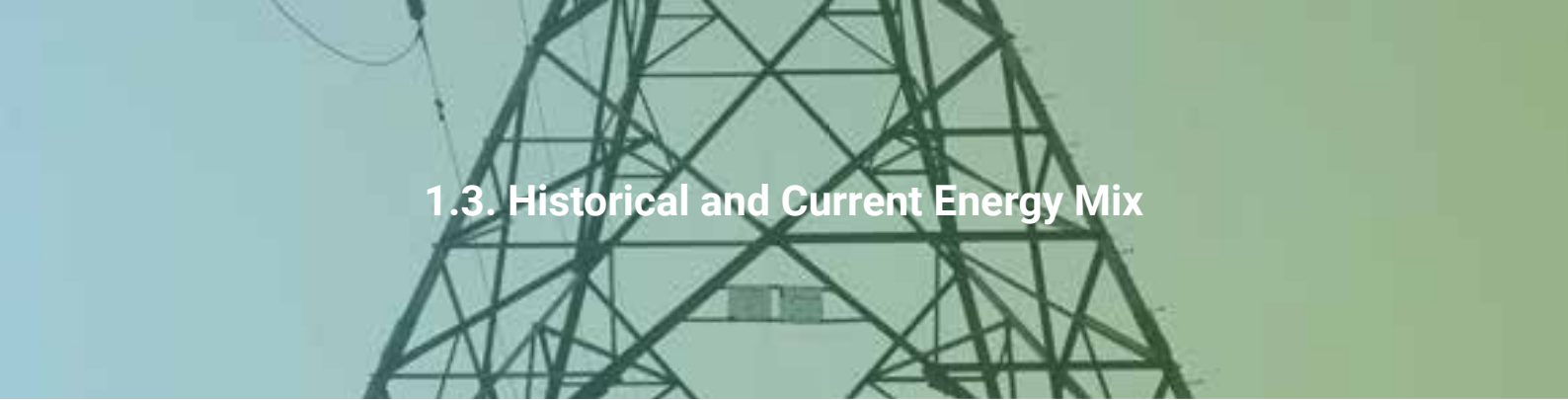


Figure 1-3: Demand and Supply Trend of the Bangladeshi Power Sector



1.3. Historical and Current Energy Mix

The energy mix of Bangladesh has always been dominated by fossil gas, in both installed capacity and net generation. The dominance of fossil gas is clearly visible in the historical trends in the energy mix as shown in Figure 1-4 and Figure 1-5. Net generation-wise, fossil gas' share rose above 80% in FY1989–2000 and remained so until as late as FY2011–2012. Until FY1984–1985, hydro was the second most dominant energy in the net generation mix. In terms of installed capacity, however, liquid fuels, i.e., HSD, and HFO, which were introduced to the fuel mix in FY 1973–1974, were consistently in the top two.

The country's energy mix consisted of these four types of fuel. This trend of usage continued until FY2005–2006, when the mix started to change significantly, mostly due to falling domestic gas extraction and production. This led to the introduction of coal. From 2010, the percentage of liquid fuels began to increase considerably. In FY2013–2014, another important shift took place: the importation of energy from India. In 2017, the country added its first ever solar PV project into the grid. While there is still little overall development of renewable-based generation, domestic renewable electricity has a deflationary price trajectory that makes it preferable to imported electricity from fossil-fueled power plants. Figure 1-6 gives a detailed breakdown of the latest energy mix (FY2019–2020) for both installed capacity and net generation.

It is important to note that although the initial plan was for imported coal and fossil gas to replace expensive oil and diesel, in the medium term they will replace cheap domestic gas, so the average cost of generation is likely to go up again. If this trajectory is to be sustained, there may be a need for more government subsidies or higher power tariffs for consumers, or a mix of both.

The launch of the Rooppur Nuclear Power Plant, to be commissioned in 2025 (MoEFCC, 2021) brings nuclear power into Bangladesh's energy mix. The PSMP 2016 highlights the need to diversify the mix to ensure energy security. While previous plans pointed to imported coal, the most recent policy documents take into consideration technology modernization. They favor imported electricity for regional energy security and renewable sources, and consider the benefits of new technology in improving the cost-effectiveness of the power sector and ameliorating the country's vulnerability to climate change.

Power Plant Types

In terms of installed capacity, reciprocating engines and combined cycles dominated the energy mix in FY2019–2020, covering nearly 38% and 36% of capacity respectively. They were followed by steam turbines running on the Rankine cycle (15%), and gas turbines (4%) (Figure 1-7).

It should be noted that large-scale thermal power plants are typically powered by fossil fuels; nuclear and large-scale renewable-based (solar/wind) power plants will diversify and

modernize the energy mix.

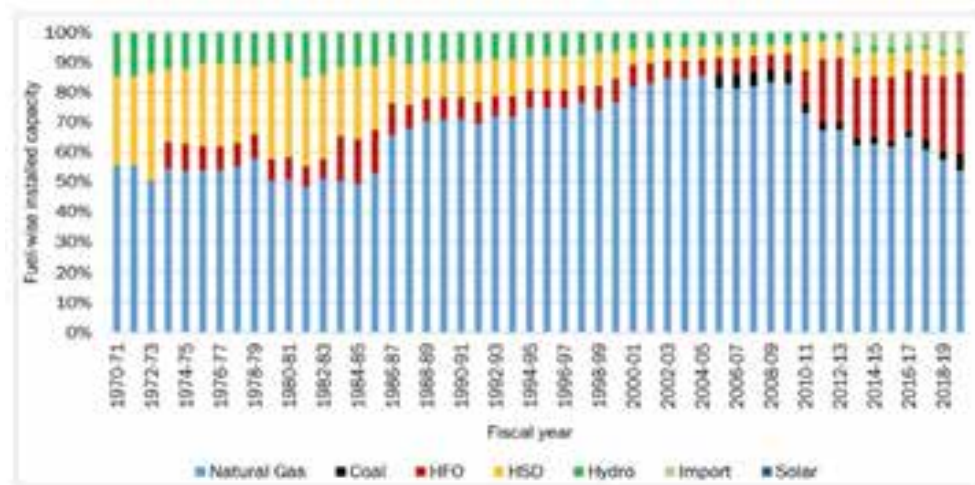


Figure 1-4: Historical Trend of Fuel-Wise Installed Capacity

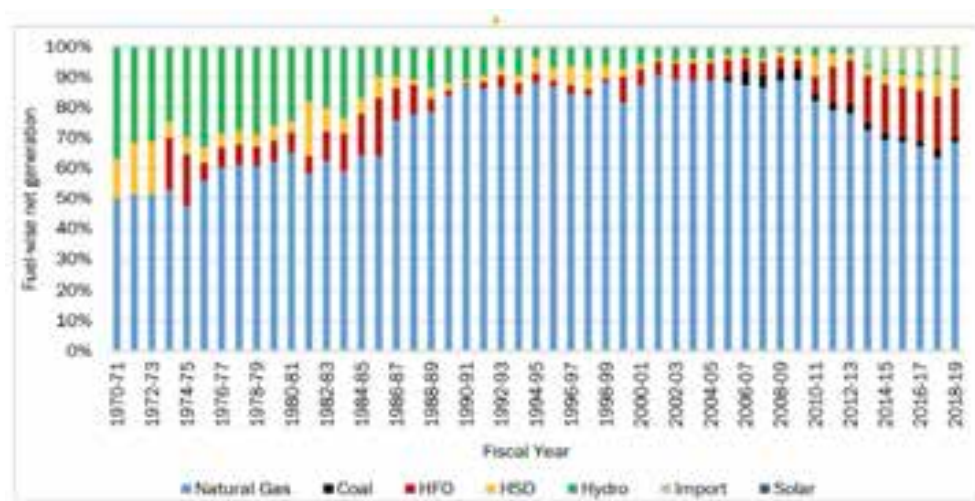
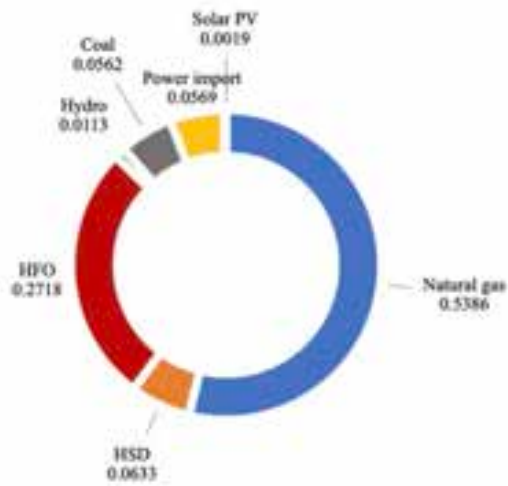
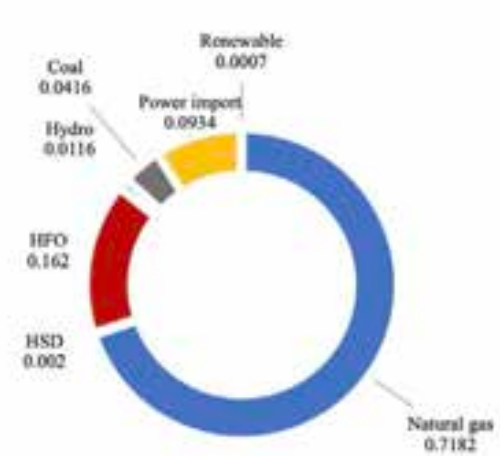


Figure 1-5: Historical Trend of Fuel-Wise Net Energy Generation

Fuel-Wise National Installed Capacity, FY2019-20



Fuel-Wise National Total Net Generation, FY2019-20



(a)

(b)

Figure 1-6: Latest Energy Mix of Bangladesh for (a) Installed Capacity, (b) Net Generation

Technology wise Installed Capacity (MW)

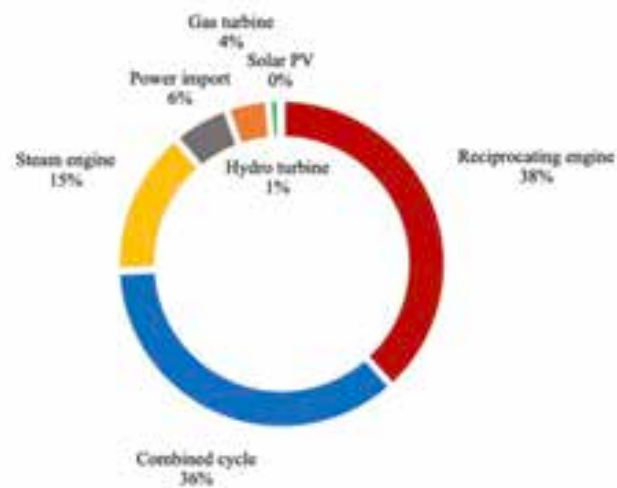


Figure 1-7: Latest Plant Technology Wise Breakdown of Installed Capacity (MW)



2. Cost Analysis, Trend of Thermal Plants, and Implied Inflection Points

Liquid fuel-based power supply has grown from 8% of Bangladesh's energy mix in FY2010 to 29% in FY2015 and over 30% in FY2018. This has progressively increased the average supply cost of power and strained power sector finances. The average cost of power surged from BDT6.10/KWh in FY2015 to BDT8.6/KWh in FY2020, which amounts to 41% between the periods. It appears that the increasing reliance on imported fuel oil, higher priced LNG and imported coal will continue in the future, and so will increase the production cost of electricity unless efficiency and other cost measures are taken.¹

2.1. Based on Ownership: Publicly vs. Privately Owned

The following graphs show comparative scenarios between publicly and privately owned thermal power plants in Bangladesh (Bangladesh Power Development Board, September, 2020). The points of comparison are number of plants, installed capacity, and net electricity generation. The graphs also distinguish between base load and peaking power plants.

Figure 2-1 shows that while the total number and installed capacity of private plants is higher than public ones, public plants' net generation of electricity is higher, which means private plants may be inefficiently used. The base load and peaking plant distinction reveals, for example, that the portions of public plants that supply base and peak load are almost comparable. The breakdown of installed capacity and net generation show that almost 77% of the public capacity are base load plants that supply nearly 31 GWh of electricity. This generation is more than double the amount that is generated by only seven privately owned base load plants. The majority of the private plants are meant to serve the peak load. Total installed capacity of the 73 privately owned peaking plants is 6,866 MW. The data also shows that the average capacity per peaking plant is lower compared to base load plants. This major data point highlights major financial implications as many power plants are receiving capacity payment regardless of whether they are used or not. This results in an increased cost of generation leading to significant financial losses for BDPB that are typically covered by a government subsidy. In FY 2018–2019, the subsidy for BDPB increased and reached almost USD1 billion.

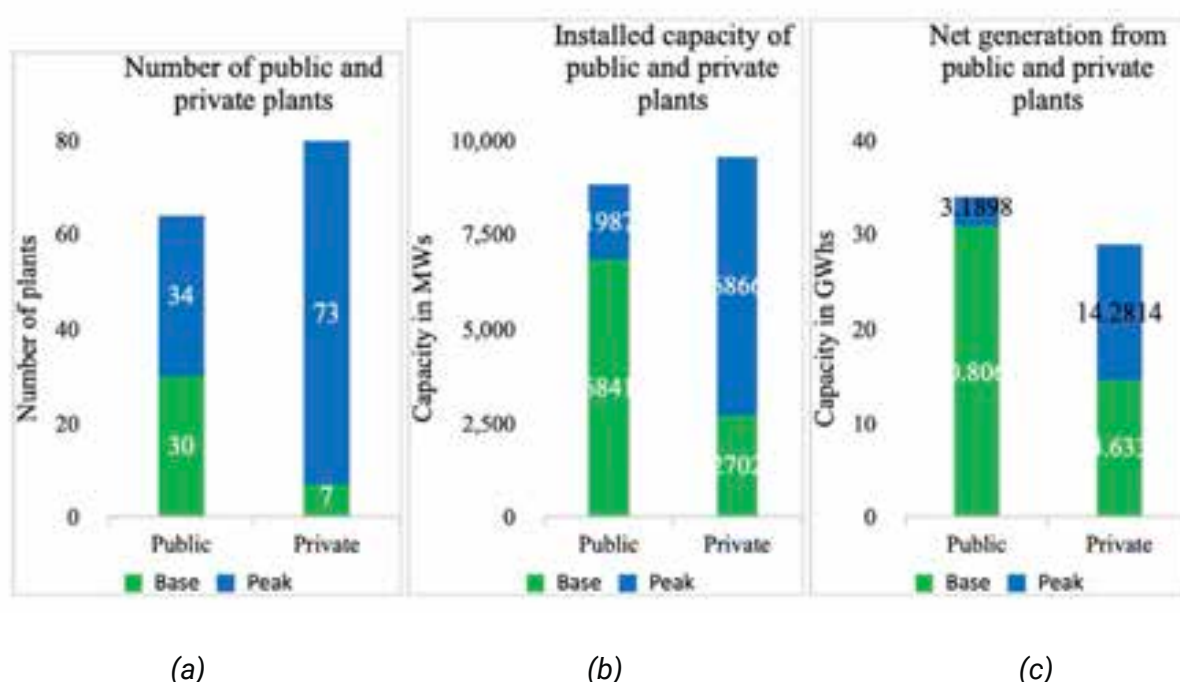


Figure 2-1: Comparison between Public and Private Sector Thermal Power Plants of Bangladesh: (a) Number of Plants, (b) Installed Capacity, and (c) Net Electricity Generation

2.2. Based on Type of Load Served: Base Load vs Peaking Plants

The following pie charts show the fuel-wise breakdown of the number, installed capacity, and net generation of thermal base load plants. All the charts show that fossil gas is the dominant fuel when it comes to base load plants. Other important sources of base load power are the imported electricity and thermal plants powered by coal.²

The following pie charts show the fuel-wise breakdown of the number, installed capacity, and net generation of thermal peak load plants. The charts reveal that the peaking load is served mainly by three types of fuel, namely fossil gas, HFO, and HSD. Unlike the base load plants, the dominant peaking plant fuel is HFO. The extremely small portion of HSD in the net generation chart is largely due to the very low plant factor of the HSD-powered peaking plants.

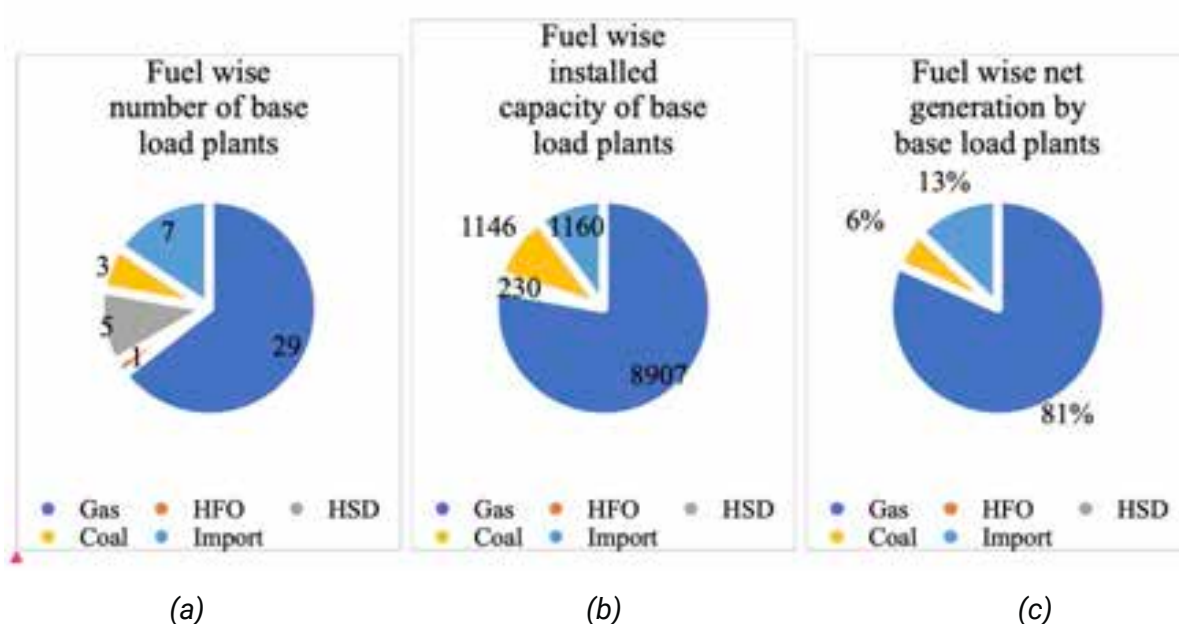


Figure 2-2: Fuel-Wise Analysis of Base Load Plants of Bangladesh: (a) Number of Plants, (b) Installed Capacity, and (c) Net Electricity Generation.

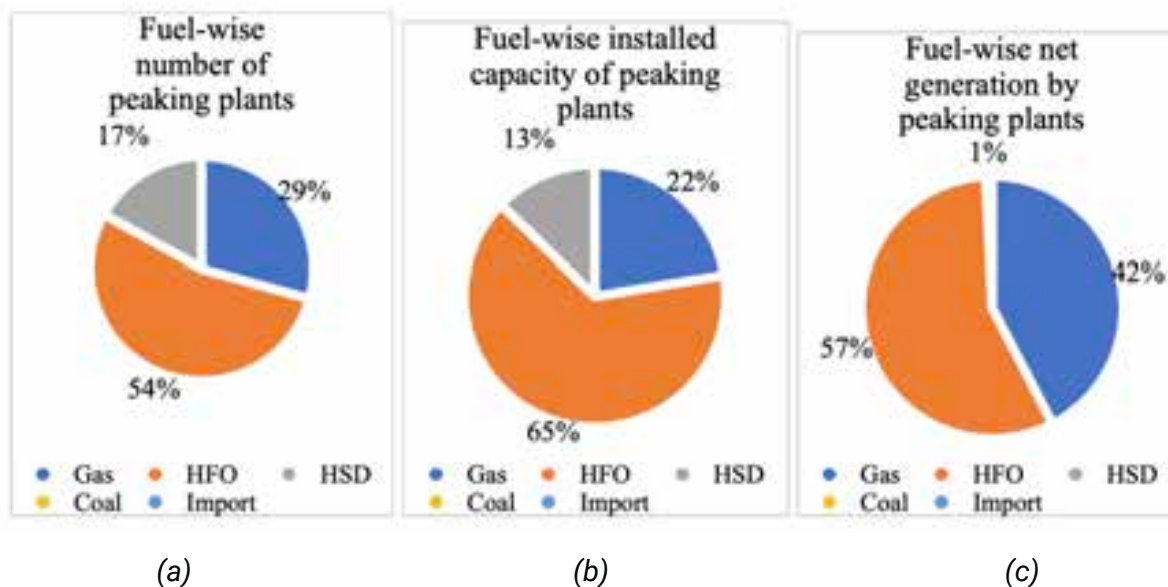


Figure 2-3: Fuel-Wise Analysis of Peak Load Plants of Bangladesh: (a) Number of Plants, (b) Installed Capacity, and (c) Net Electricity Generation.



2.3. Fuel-Wise Analysis of Thermal Power Plants

The following pie charts show the latest overall fuel mix of Bangladesh's thermal power plants in terms of plant number, installed capacity, and net electricity generation.

Figure 2-4 makes clear that fossil gas is the main fuel powering the thermal power plants in Bangladesh at present, followed by HFO. Notably, the fraction of electricity generated by HSD is extremely negligible (in fact not visible at all) on the net generation pie, mainly due to low utilization of HSD-powered plants. HFO-powered plants, the majority of which are peaking plants meant to operate for limited periods only, are also responsible for a small share of net generation. Given this trend, it may be prudent to replace HSD- and HFO-powered plants with lower-cost alternatives.

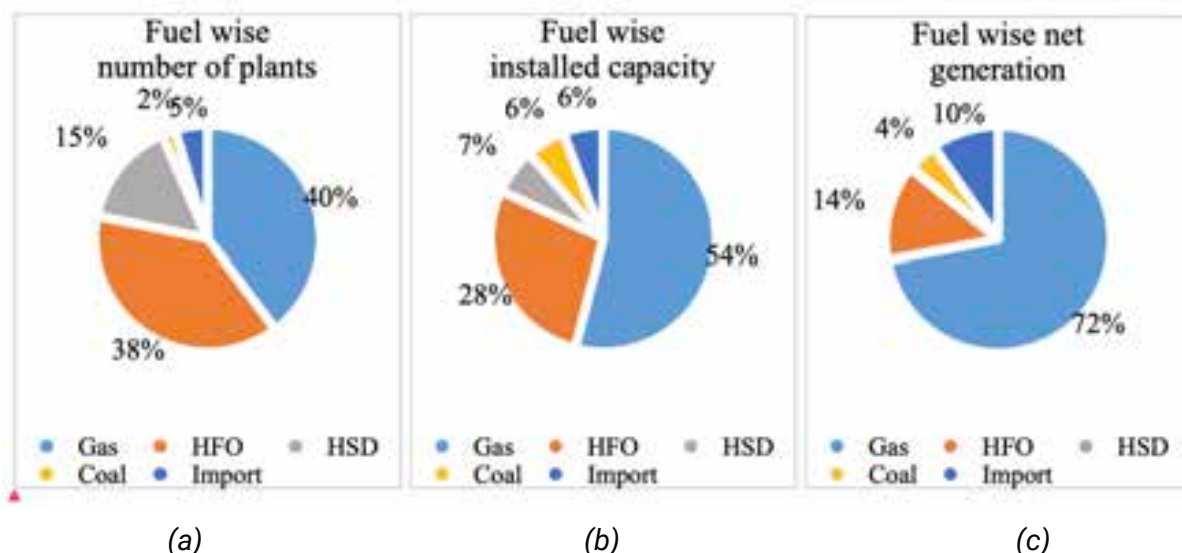


Figure 2-4: Overall Fuel Mix of Thermal Power Plants of Bangladesh: (a) Number of Plants, (b) Installed Capacity, and (c) Net Electricity Generation

2.4. Cost Analysis

This section provides a cost breakdown of thermal power plants according to the types of fuel used. In the fossil fuel-based power plants in Bangladesh, there are four types of fuels used: gas, coal, diesel, and furnace oil. Among them, we can see that fuel costs are the highest for furnace oil-based plants, relative to the electricity generation in FY2019–2020 (Figure 2-5). In aggregate, estimated fuel costs in FY2019–2020 alone were approximately BDT 145 billion, equivalent to USD 1.7 billion.

Plant costs can be classified into three main parts: fuel cost, fixed cost, and variable operation and maintenance. Of these, fuel costs and fixed costs comprise the biggest portions. In coal plants, fuel costs are higher compared to fixed costs, whereas in diesel plants, fixed costs are the highest in proportion (Figure 2-6). Fixed costs in furnace oil are also relatively high because liquid fuel-based plants operate at low plant factors.

We can see that the plant factor of plants varies significantly according to fuel type. In Bangladesh, gas-powered plants have the highest plant factors, followed by coal. However, diesel plants have the lowest plant factors, although they have high fixed costs (Figure 2-7). The lower generation levels relative to the high fixed costs translates to high per-unit costs. The fuel cost for the gas-based power plants on a per-unit basis is the lowest and for diesel-based power plants are the highest.

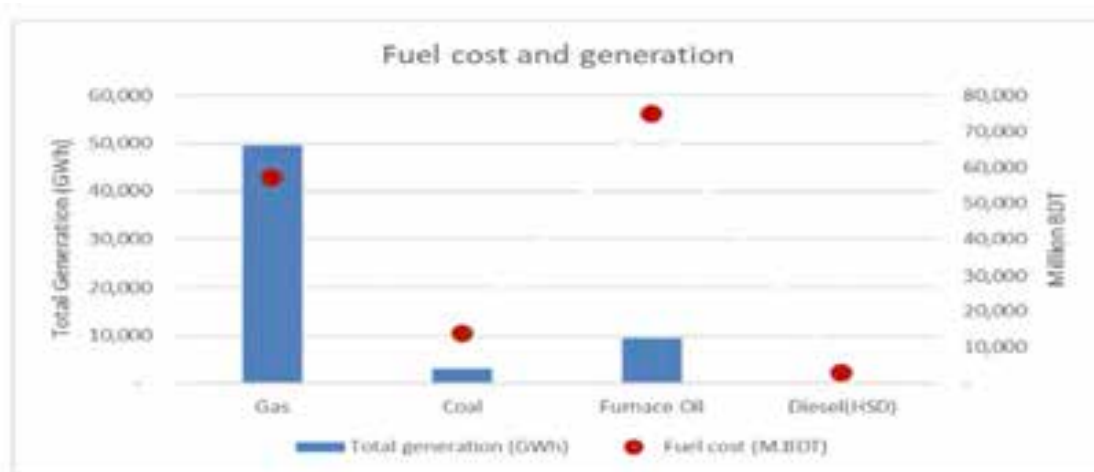


Figure 2-5: Fuel Cost Compared to Total Generation according to Fuel Type (in Million BDT/GWh)

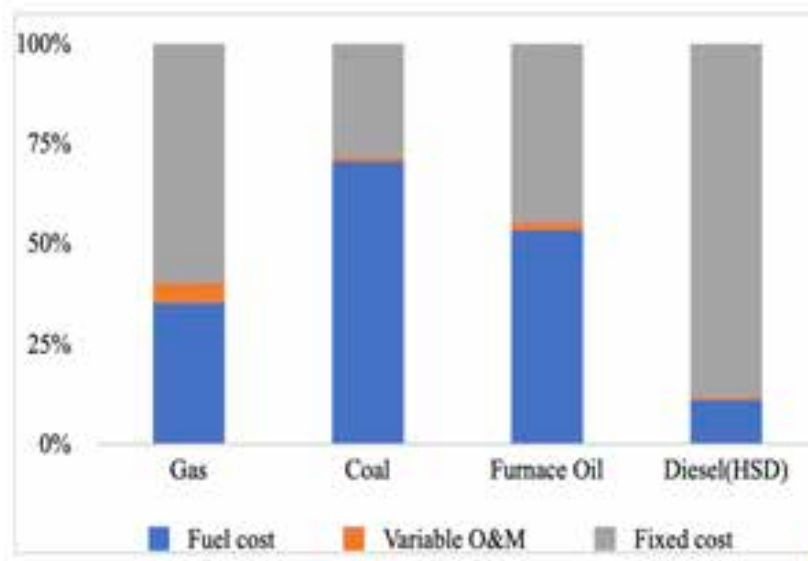


Figure 2-6: Composition of Plant Costs according to Fuel Type

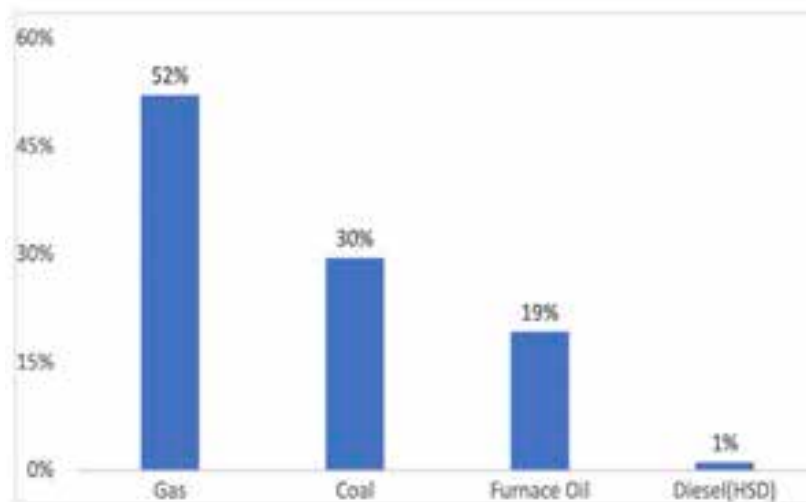


Figure 2-7: Plant Factor according to Fuel Type

2.5. Per-Unit Cost Analysis

The following table shows per-unit comparative cost analysis of the public and private power plants.

Parameter	Public			Private		
	Total	Base	Peak	Total	Base	Peak
Number of plants	67 ¹	30	34	83 ¹	7	73
Capacity (MW)	8,828	6,841	1,987	9,568	2,702	6,866
Net Generation (GWh)	34,006	30,806	3,189	28,915	14,633	14,281
Fuel cost per kWh (BDT)	1.65	1.42	3.89	3.18	1.22	5.20
O&M cost per kWh (BDT)	0.17	0.16	0.32	0.18	0.08	0.27
Fixed cost per kWh (BDT)	2.33	2.09	4.69	3.79	1.64	5.99
Per-unit gen. cost (BDT)	4.15	3.66	8.90	7.15	2.94	11.46
Total generation cost (M. BDT)	141,245	112,867	28,378	206,747	43,051	163,657

Table 2: Comparative Per-Unit Cost Analysis of the Public and Private Power Plants

¹The total includes some plants which are used as both base load and peaking plants.

Table 2 shows that per-unit generation of private thermal plants is nearly 1.72 times higher than that of public plants. However, the per-unit generation cost of peaking plants is much higher compared to base load plants in both sectors; almost four times higher in the private sector. Further breakdown of the per-unit generation cost shows that both the fuel cost and fixed cost is much higher for peaking plants than base load plants. This significant difference is due to the large number of private peaking plants that are powered by expensive liquid petroleum fuel and that remain less utilized while having fixed capacity payments. Fixed costs include capital recovery, debt service costs, depreciation, and fixed human resource expenses. Variable expenses include maintenance materials and human resource expenses of temporary staff. The following graph and table show the fuel wise per-unit generation cost and its individual components.

The data shown in Figure 2-8 and Table 3 supports the earlier findings. The per-unit fixed cost of HSD plants is the highest. It is important to note that a fair cost estimate for peaking is the cost of a liter of bunker oil-fired diesel divided by four (kWh per liter), so in this case, the per-unit generation cost for a peaking plant can be estimated at BDT 25; seven times higher than the expected rule of thumb. This is because these plants have very high fixed cost and capital recovery requirements but operate at a very low plant factor and so do not generate enough

electricity to bring down the per-unit fixed cost. The per-unit fuel cost is also highest for the HSD plants, followed by HFO plants. A displacement strategy for HSD and HFO to reduce the cost of peaking power may be prudent for the future of the power sector market.

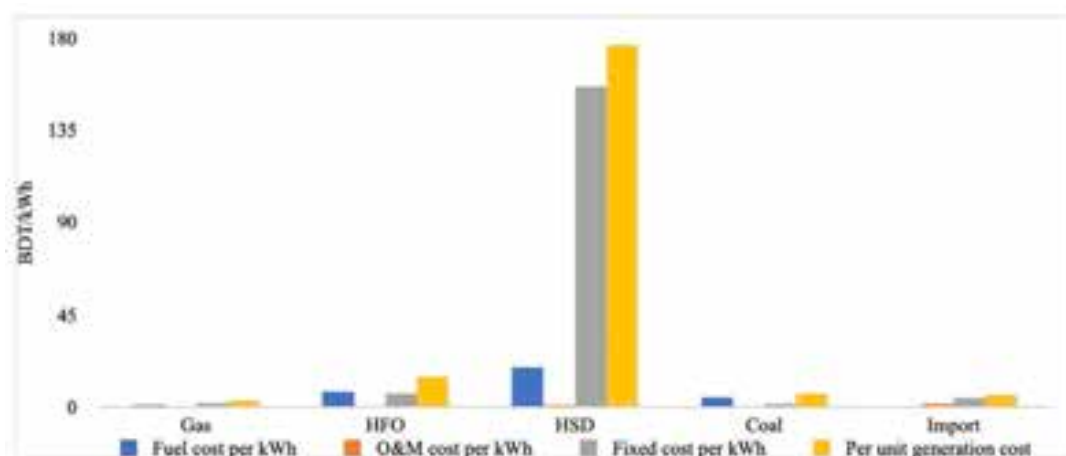


Figure 2-8: Fuel-Wise Per-Unit Generation Cost of Thermal Power Plants in Bangladesh

	60	58	23	3	7
Number of plants	60	58	23	3	7
Capacity (MW)	10,839	5,591	1,330	1,146	1,160
Net Generation (GWh)	49,518	9,461	139	2,967	6,673
Capacity utilization factor (%)	52	19.3	1.2	29.55	65.66
Fuel cost (M. BDT)	56,895	74,765	2,688	13,826	0
Fuel cost per kWh (BDT)	1.15	7.90	19.28	4.66	0
O&M cost (M. BDT)	7,434	2,784	142	208	11,103
O&M cost per kWh (BDT)	0.15	0.29	1.02	0.07	1.66
Total fixed cost (M. BDT)	96,917	63,369	21,804	5,615	28,989
Fixed cost per kWh (BDT)	1.96	6.70	156.36	1.89	4.34
Total generation cost (M. BDT)	161,002	140,919	24,635	19,650	40,092
Per-unit gen. cost (BDT)	3.25	14.89	176.66	6.62	6.01

Table 3: Fuel-Wise Cost Analysis of Thermal Power Plants in Bangladesh

2.6. Cost Trend and Implied Inflection Points

In this section we will examine the per-unit cost of electricity production for thermal power plants, and then explore how unit cost varies according to the type of cost and the type of fuel used. Based on this data, we can make some inferences about the inflection points of fossil fuel costs relative to renewables costs, i.e., when renewables will become competitive enough to replace fossil fuels. The inflection points can be explored with the following assumptions:

- When the average cost of RE is less than the variable and fixed cost of fossil fuel, RE is best suited to meet incremental capacity.
- When peak demand is met by fossil fuel and the average cost of RE is less than the variable cost of fossil fuel, RE can displace existing fossil fuel capacity.
- When the average cost of RE plus recovery cost from existing fossil fuel contracts are less than the trust cost of generation of fossil fuels, all fossil fuel generation can be displaced.

However, cost is not the only criterion to take into consideration, as there are the issues of technological suitability to serve the load of base and peak periods.

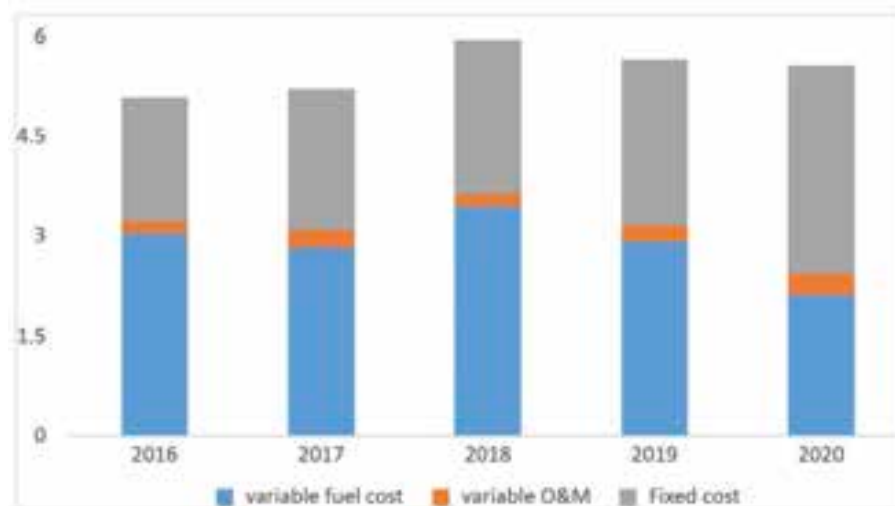


Figure 2-9: Trend of Cost Composition of Thermal Power Plants (BDT)

The fixed cost of thermal power plants increased significantly in 2020 (Figure 2-9). This is because there were more capacity payments, despite lower use and lower cost of fuel due to low demand during the COVID-19 lockdowns. However, the available data of five years, including the unusual pandemic year, does not allow us to extrapolate cost components or amounts into the future. Even in 2018, fuel costs were higher than in other years.

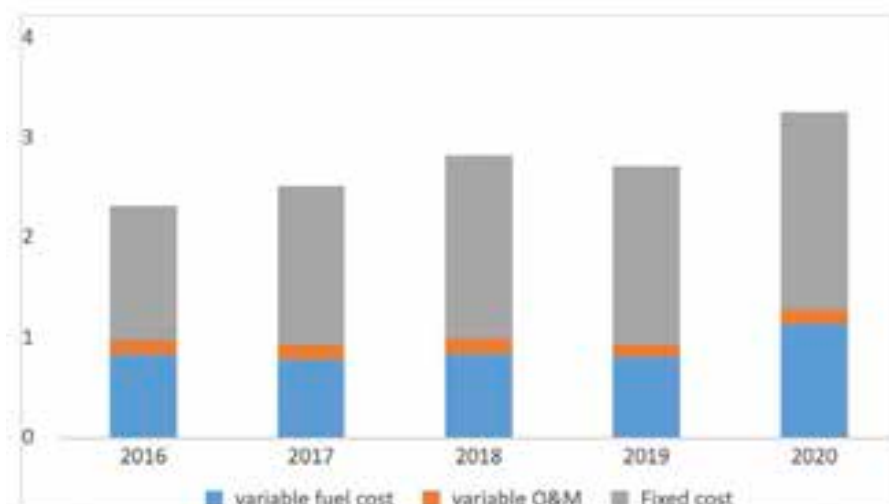


Figure 2-10: Cost Trend and Composition of Gas Power Plants

The highest costs were fixed costs even though these plants are usually base load (Figure 2-10). This is because fuel costs are lower as gas is cheaper than other fuels. In the years prior to the pandemic, the price of gas varied between 0.79 and 0.85 BDT/unit.

The cost per unit of electricity for HFO plants has risen significantly in the pandemic year but was also growing in the previous three years (Figure 2-11). Fixed costs have also been increasing. In the pandemic year, although HFO plants spent the least in fuel costs per unit, lower usage led to a sharp increase in the fixed cost, leading to an overall increase in costs. This reveals one weakness of the system: HFO plants become a cost burden in times of low use.

Figure 2-12 shows that the fixed cost component of HSD plants rose several fold in 2020. This shows that capacity payments rose drastically despite lower use. This also highlights the cost volatility of HSD plants. Compared to what are considered fixed costs, the fuel cost per unit of electricity is relatively stable.

Figure 2-13 shows that the cost of coal electricity per unit has been decreasing in the last five years, and the constant decline is in the fuel cost, whereas fixed costs fluctuate from year to year.

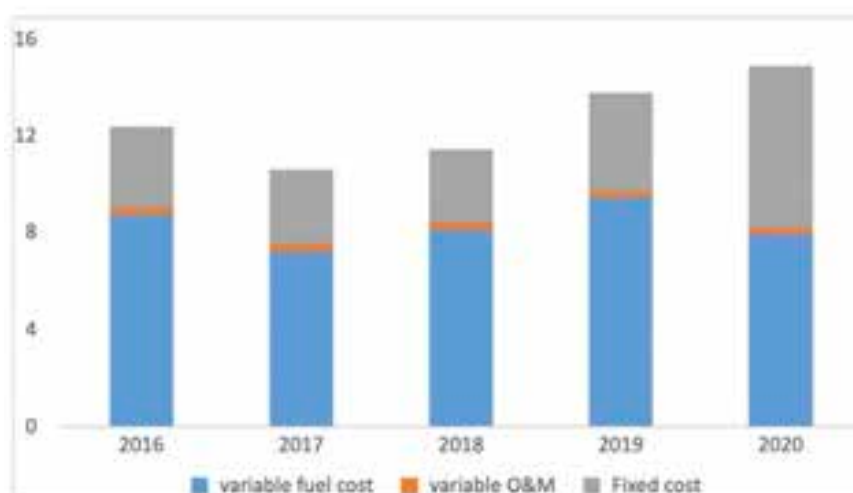


Figure 2-11: Cost Trend and Composition of HFO Plants

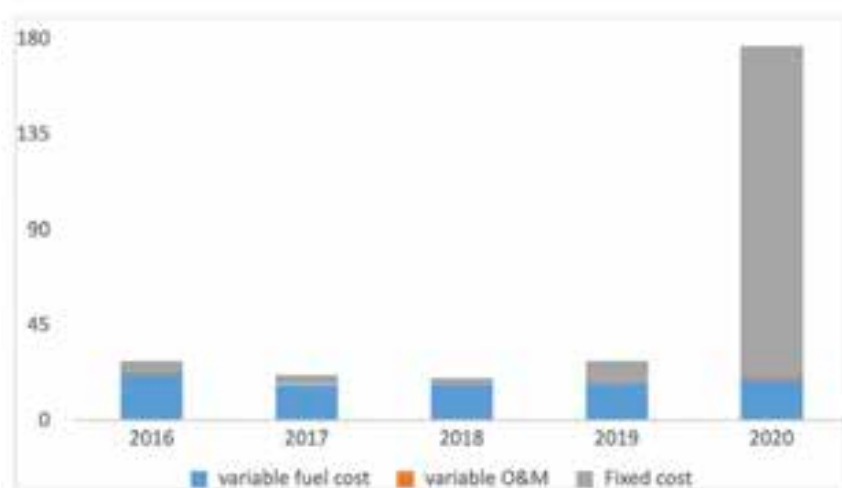


Figure 2-12: Cost Trend and Composition of HSD Plants



Figure 2-13: Cost Trend and Composition of Coal Plants

The following table (Table 4) shows the mean and standard deviation of the various cost components of the different types of thermal power plants. The data reveals that overall, fixed costs fluctuate almost as much as variable fuel costs. Moreover, in gas, HFO, and HSD plants, fixed cost actually has much greater variability than fuel costs. Only in the coal plants do the fixed costs have lower variability than the fuel costs. Therefore, we will consider the average cost as well as the standard deviation in order to determine the inflection points. Furthermore, considering that in most technologies, including low-cost ones like gas, fixed cost is more volatile than fuel cost, it is not meaningful to apply the traditional definitions of fixed and variable costs in the case of power plants in Bangladesh.

Plant fuel	All thermal		Gas		HFO		HSD		Coal	
BDT/unit	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev
Variable fuel cost	2.874	0.479	0.890	0.147	8.274	0.859	18.168	2.236	5.582	0.844
Variable O&M	0.242	0.058	0.142	0.013	0.306	0.032	0.470	0.340	0.282	0.165
Fixed cost	2.388	0.473	1.696	0.241	4.040	1.545	36.228	67.218	1.984	0.470
Total	5.504	0.347	2.728	0.354	12.618	1.727	54.866	68.186	7.850	0.919

Table 4: Mean and Standard Deviations of Cost Components of Different Types of Thermal Plants

At present, the cost of grid-connected solar is BDT 8.6 for an unsolicited project, and for a solicited project (through a bidding process), the recorded cost was BDT 6.45, according to the LOI issuance. Bangladesh's first ever grid-connected solar park came into operation in 2017.

If we consider the overall average costs of the thermal power sector, we can see that the cost of RE must fall below BDT 5.5 on average in order to be more competitive than thermal power. However, much thermal power generation is to serve base load needs and comprises gas and

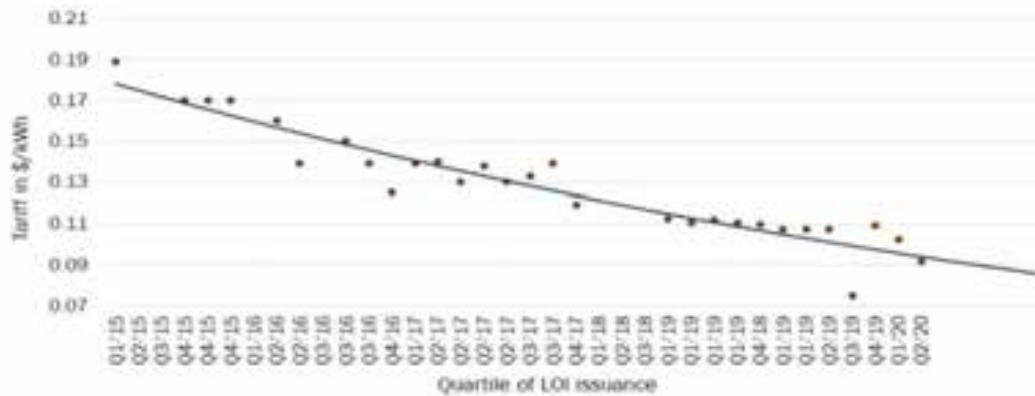


Figure 2-14: Levelized cost of electricity (LCOE) Trend of Solar PV Power Plants in Bangladesh (According to the LOI Issuance)

coal power plants, which are not likely to be replaced soon. Moreover, the average total cost of gas per unit of electricity production is BDT 2.73, and for coal it is BDT 7.85. The variable fuel cost of coal is on average BDT 5.582 per unit. At this rate, among the base load technologies, it will be feasible to replace coal among the fossil fuel technologies, if the cost of renewables falls below the average total variable cost of coal, which is BDT 5.864. However, the fossil fuels most eligible for replacement are liquid fuel plants. The average variable cost of HFO (BDT 8.58) is already higher than the latest levelized cost of electricity (LCOE) of renewables in Bangladesh. This is even more applicable in the case of HSD plants, where the total variable cost (BDT 18.638) is already far higher than the LCOE of renewables.

Putative variable costs are not the only variable cost components of the plants; fixed costs have greater variability than fuel and operation and maintenance costs in all technologies except coal. Therefore, we must modify the initial assumptions of our analysis and repeat the analysis including the total cost of each technology (variable and fixed). Under these assumptions, we find that as the average cost of RE is already lower than the fixed and variable cost of HFO and HSD, RE can meet incremental capacity in place of HFO and HSD. RE can also meet incremental capacity in place of coal if the LCOE of renewables falls below BDT 7.85, which is already the case for some projects. In order to replace gas, the LCOE of renewables must fall below BDT 2.73. However, this is a more remote prospect, as gas serves base load, and any RE substitute should therefore include storage in order to have the capability to provide base load service. To date, there is no actual RE project with storage, so no practical benchmark is available for comparison. In fact, in order to replace HFO, HSD and coal, RE with storage is also required.

For RE to displace existing fossil fuel capacity, the average cost of RE should be lower than the variable cost of fossil plants. If we consider fuel costs and operation and maintenance to be the major variable costs of fossil fuel plants, we can see that this inflection point will occur for coal at BDT 5.864, for HFO at BDT 8.58, and for HSD at BDT 18.638. We can say that this inflection has occurred for HSD already, and the inflection point for HFO is also in progress, with coal not far behind. However, for a more accurate estimate, the cost of storage should be included for RE. We estimate the cost of storage at BDT 10.74/kWh for 2020. Accordingly, the total cost of renewables and storage was BDT 17.19 (solicited) to 19.34 (unsolicited) at present. Therefore, if we include renewables and storage, we can say that the inflection point for HSD presently exist. However, the cost of HFO at present is competitive with respect to RE plus storage, so it will not be replaced in the near future; nor will coal and gas. According to our estimates, the cost of renewables with storage will be BDT 14.04 in 2025, and BDT 11.90 in

2030. If the cost of HFO remains the same, the inflection point will occur between 2025 and 2030.

When the average cost of RE plus recovery cost from existing fossil fuel contracts are less than the trust cost of generation of fossil fuels, then all fossil fuel generation can be displaced. However, in order to estimate this inflection point, we must know the recovery cost from fossil plant contracts. The capacity payment and recovery cost contracts of fossil fuel plants in Bangladesh are confidential, and the relevant data is not directly available. Moreover, our investigation has revealed that this recovery cost varies according to the type of fuel, the estimated operating life and contract period (PPA tenure) of the plant.

We have approximate estimates for the capacity payments of different types of fossil fuel power plants, which can range from USD 10–USD 12 for gas plants, up to USD 20 for coal plants per kW per month. In the case of gas plants, the contract period is 15 years for reciprocating engine technology, and 22 to 25 years for combined cycle technology. In the case of coal plants, the contract period is up to 20 years. For HSD plants, the capacity payment ranges between USD 15–17 per kW per month, where the average contract period is for five years. In the case of HFO plants, capacity payments are USD 12–13 per kW per month, and the usual contract period is also five years. As different plants have different generation capacities and different remaining time in their contract periods, the compensation for each plant will be different. Therefore, it may be more feasible to replace HFO and HSD plants that are near the end of their contract period, which will minimize the present value of capacity payments.



2.7. Impact of Various Factors on Annual Plant Factor

The rapid increase in installed capacity in recent years means that most of the plants are relatively young, built in the last 10 years. Only 10 power plants out of 140 major plants are more than 30 years old.

Age Group (Years)	Installed Capacity (MW)	%	Generation Capacity (MW)	%
40 +	210	1%	181	1%
31 – 40	1,112	6%	978	5%
21 – 30	1,078	6%	959	5%
11 – 20	2,257	12%	2,082	11%
01 – 10	14,778	76%	14,744	78%
Total	19,435		18,944	

Table 5: Distribution of the Age of Thermal Plants

The following table (Table 6) sets out some key factors to consider in relation to the retirement of plants and the energy transition process.

The effects of various plant characteristics (age, fuel type, plant technology, location, ownership type, plant's role, etc.) on the annual plant factors of the thermal power plants has been assessed. Effects of the following plant features have been tested:

- Plant age: This is the plant's age in years.
- Fuel type: This can be gas, coal, furnace oil, and diesel. Gas is the reference fuel.
- Plant technology: Technologies considered are steam turbine, combined cycle power plants, combustion turbine, and reciprocating engine. The reference technology is steam turbine.
- Plant location: These are various divisions in Bangladesh. Dhaka is considered the reference division.
- Ownership type: This can be public or private.
- Role in grid: This can be base load or peaking.

Summary of the analysis is as follows:

- Plant age has a small but significant impact on plant factor: a one-year increase in the age of the plant lifts plant factor by 0.004%. Older plants are gas-based, whereas the recent plants are furnace oil- or diesel-based, and these overall have lower plant factors.
- Combined cycle power plant (CCPP) plants have higher plant factors.

- HSD and HFO plants have lower plant factors.
- Publicly owned plants have lower plant factors.

Plant feature	No. of plants	Installed capacity MW	Fuel composition, and role
Contract period > 30 years	10	1,924	1,010 MW (5 public plants) of gas plants are to retire by 2025, 210 MW (1 gas plant) to retire in 2026.
Age > 30 years	10	1,924	602 MW to retire by 2025. All public, mostly gas-based, 560 MW of base load.
Retirement before or in 2025	48	5,019	
Retirement between 2026-2030	13	1,433	
Plants with plant factor < 0.1	26	2,380	These are mostly fuel oil and HSD peaking plants, out of which 12 plants (1,132 MW of private, 132 MW of public) to retire by 2025.
Plants with plant factors between 0.1 and 0.2	10	2,871	These run mostly on fuel oil, where 3 plants (300 MW) are to retire by 2025, and 5 plants (514 MW) are to retire by 2030.

Table 6: Plant Features and Retirement Opportunities



2.8. Efficiency of the Current System

In FY2019–2020, the overall thermal efficiency of publicly owned power plants was 39.72% (Bangladesh Power Development Board, September, 2020). The transmission and distribution losses, as shown in Figure 2-15, shows a slow but continuous reduction since 2008. Annual target setting and close monitoring has helped mitigate the loss of efficiency.

The generation costs of quick rental power plants (QRPPs) were once considerably higher than those of other plants; this gap has shrunk but not disappeared over the last few years. There is also an ongoing issue with substantial capacity charges but low capacity factor.

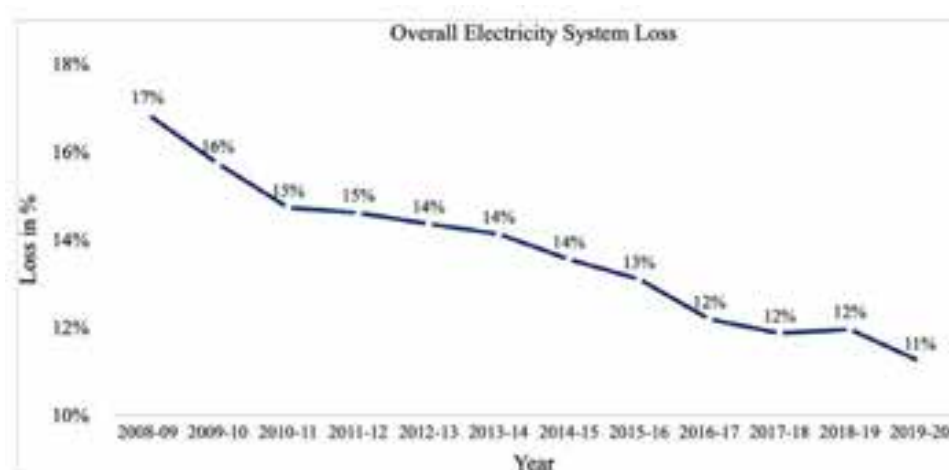


Figure 2-15: Trend of Transmission and Distribution System Loss since FY2008–2009
(Source: BPDB)

The efficiency of energy usage is slowly improving as well. This is a result of robust economic growth backed by the expansion of less energy-intensive export industries such as the ready-made garment (RMG) sector. The government set a target to enhance energy efficiency by 20% by 2030 in the Energy Efficiency and Conservation Masterplan up to 2030. Therefore, demand for electricity in Bangladesh will likely undergo significant change. According to the PSMP 2016, changes in economic activities will influence both the structure and composition of electricity demand. For instance, it is likely that industrial demand and demand in commercial and public service capacities (e.g., special economic zones and other services) will rise significantly. The rapidly declining cost of rooftop solar and energy efficiency measures means that the demand curve should shift where there is a higher incidence of peak demand— after sunset, for example.

The PSMP predicts peak electricity demand under the base case to be 23,000 MW in 2025 and 30,000 MW in 2030. Demand management will need to evolve, electricity quality will need to improve, and efforts should be made to improve user efficiency.

2.9. Access to Electricity

The first target of SDG 7 is to ensure universal access to modern energy in Bangladesh. The indicators of this target are access to electricity and access to clean fuels for cooking. Access to energy has both quantitative and qualitative aspects. The following sections discuss energy access-related indicators in detail.

Bangladesh has been consistently progressing towards electricity access for all households by 2021. Short- and long-term measures for strengthening the supply side of the country have been implemented. Historical trends in electricity access, in terms of percentage share held by the total, urban, and rural populations are shown in the following figures.

According to the Annual Report 2019–2020 of the power division of the Ministry of Power, Energy and Mineral Resources, in 2020, the nationwide access rate reached 97% (per capita generation 512 kWh/Yr), with a steeper rate of improvement in rural areas.

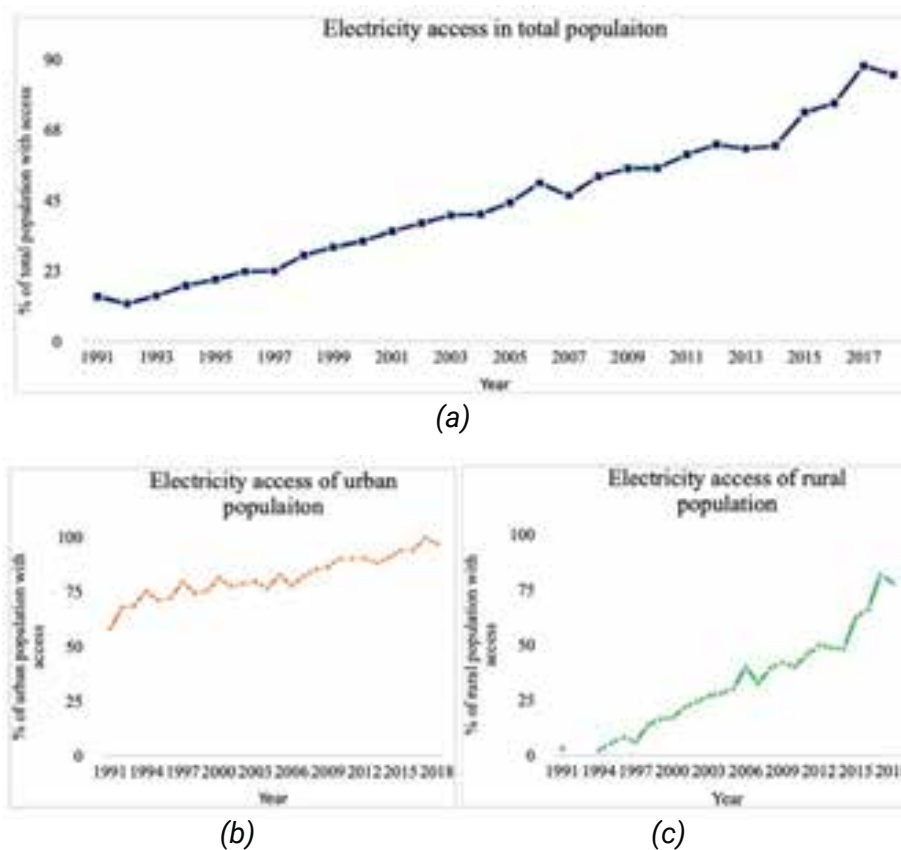


Figure 2-16: Historical Trend of Electricity Access in Bangladesh
(Source: World Bank's Global Electrification Database)



3. Resource analysis

3.1. Fossil Gas

Fossil gas is undoubtedly the dominant fuel in Bangladesh's power and energy sector. The historical trends of domestic fossil gas reserve, production, consumption, and corresponding emissions are shown in Figure 3-1. However, the country is facing a shortage of nearly 1 billion cubic feet (Bcf) of gas per day at present due to high demand (Moazzem & Ali, 2019). The government is planning to meet this demand by importing LNG. This may result in substantial increases in average tariff rates for gas, with imported LNG being at least four times more expensive than domestic fossil gas.³ It is important to note that fossil gas is neither an incremental decision nor is it economical without scale. Fossil gas requires major infrastructure investment which in turn will require from consumers the same capital-recovery guarantees as coal-, diesel-, and oil-fired generation.

Ongoing energy solutions might focus on reducing overall costs for consumers and the government, taking into consideration both the resources available to various consumer categories and the fact that the government may increase tariffs to limit subsidies in the future, contributing to expenditure savings to sustain a fiscal deficit of 5% of GDP.⁴

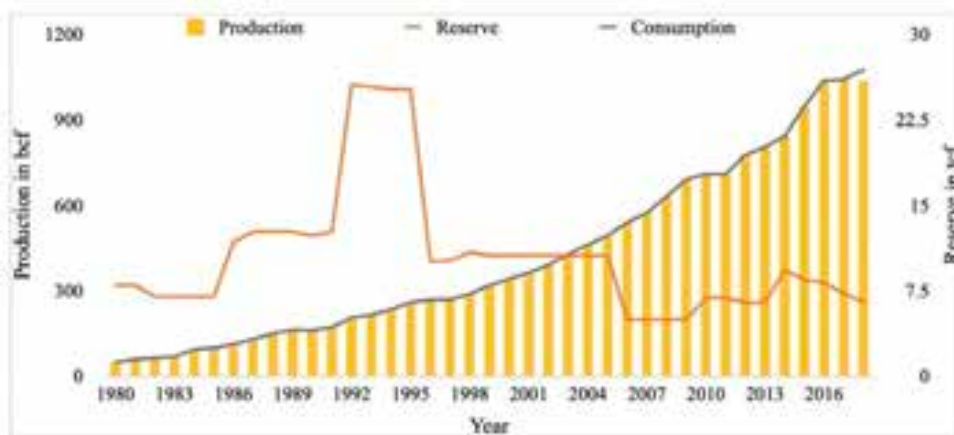


Figure 3-1: Historical Trend of Fossil Gas Reserve, Production and Consumption
(Source: EIA)

3.2. Liquid Petroleum

Liquid petroleum has been the second most important source of energy and power in recent years, and it is likely to remain so. Liquid petroleum products include crude oil, natural gas plant liquids (NGPL), crude oil with lease condensate, and refined petroleum products such as motor gasoline, jet fuel, kerosene, distillate fuel oil, residual fuel oil, liquefied petroleum gases, etc. Historical trends in liquid petroleum production, import, consumption, and the corresponding emissions are shown in Figure 3-2.

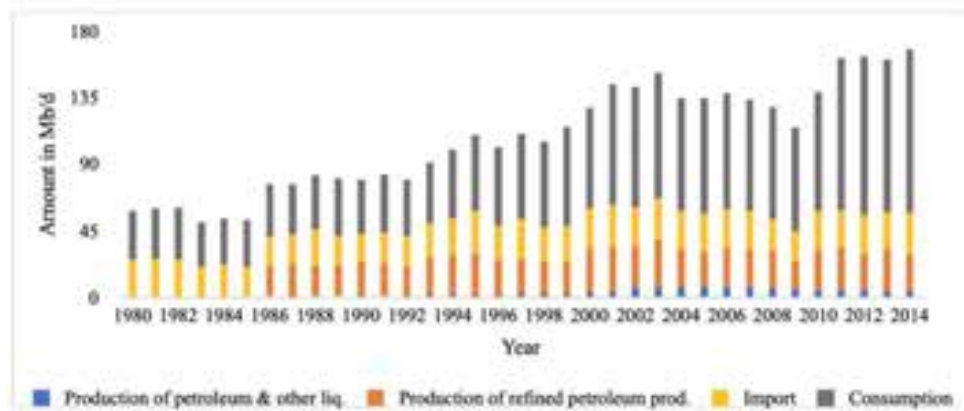


Figure 3-2: Historical Trend of Liquid Petroleum Production, Import, and Consumption
(Source: EIA)

3.3. Coal

The national demand for coal is met mainly by domestic production and partly by imported coal. Among the types of coal that have ever been consumed in the country are: Bituminous, Subbituminous, Lignite, Anthracite, and Metallurgical coke. At present, total coal reserves in the country amount to be 322.98 MMst. Nearly two thirds of coal reserves are used for power generation, and the remaining portion is given over to general use, such as in brickfields, households, etc. (Moazzem & Ali, 2019). Historical trends in coal production, import and consumption, and corresponding emissions, including intermediate and final products, are shown in Figure 3-3.

Coal is not only expensive and on an inflationary cost trajectory, but is also the least environmentally friendly fossil fuel. In August 2020, the MoPEMR revised plans for the construction of 26 coal plants⁵, and announced the replacement of the 350 MW Gazaria coal-fired power plant with much-needed grid upgrades to reduce system losses in the rural electricity system.⁶

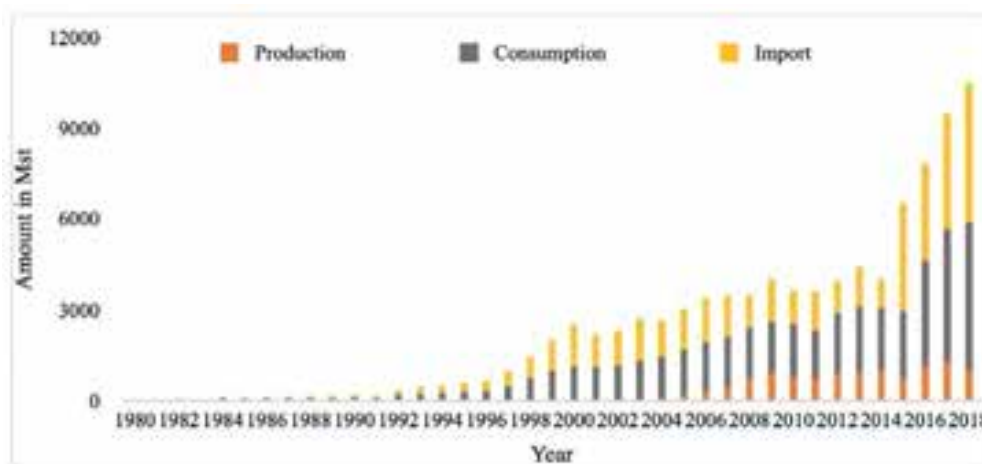


Figure 3-3: Historical Trends in Coal Production, Import, and Consumption
(Source: EIA)

3.4. Imported electricity

Bangladesh started importing electricity from India in 2013. By the end of FY2019–2020, Indian electricity made up 5.69% of Bangladesh’s energy mix in terms of capacity, and 9.34% of net generation (import). This electricity is imported via the Bheramara-Baharampur HVDC interconnection (capacity: 1,000 MW) and the Tripura-Cumilla HVDC interconnection (capacity: 160 MW). BPDB has plans to import 500 MW of power from Nepal by 2026. Another 1,496 MW of electricity is to be imported from Jharkhand, India by 2022 (MoEFCC, 2021). There is also great potential for importing hydroelectricity from Bhutan through India. Since most of this imported power comes from hydropower plants, such regional interconnections will help Bangladesh improve domestic energy security, reduce prices by taking advantage of RE, reduce its carbon footprint, and capitalize on India’s record-low solar power tariffs.

Electricity imports historically have raised energy security concerns and incurred higher costs than domestically sourced power (as seen in Figure 3-4), partly due to the fact that electricity imports continue even in times of significant overcapacity, and many local power plants remain unused most of the time. Time-of-use pricing and auction-style procurement could reduce costs; contract terms and greater domestic storage capacity could mitigate security concerns.

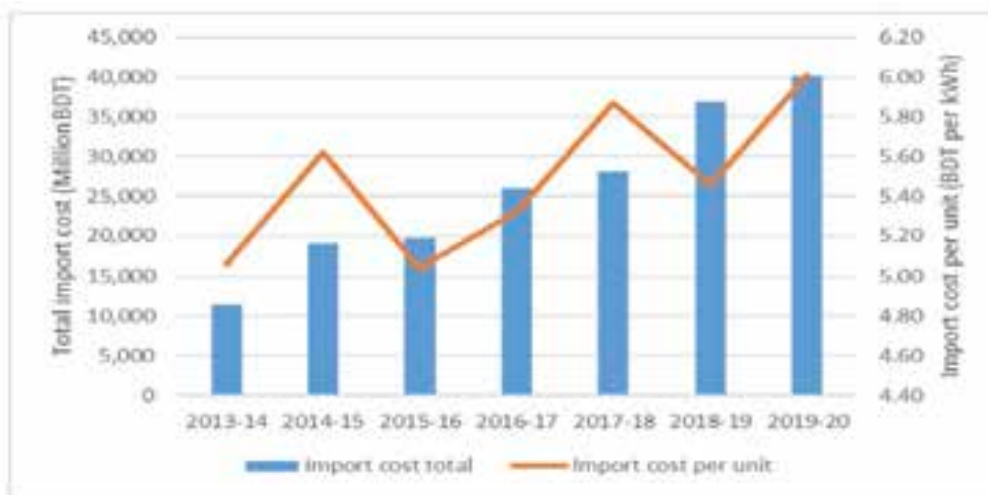


Figure 3-4: Electricity Import Cost Trends
(Source: BPDB annual reports FY2013–2014 to FY2019–2020)



3.5. Liquefied Fossil Gas

Bangladesh expects to add significant power capacity from imported coal and LNG in the 2020s. These new projects aim to meet increasing demand and replace the plants planned for retirement, including some of the most expensive generation units, powered by liquid petroleum fuels; they will thus reduce generation cost (Nicholas, 2021). However, cost will increase significantly where these new units replace plants powered by domestic LNG. According to BPDB's Annual Report 2019–2020, about 66% of the 5.5GWs of capacity scheduled for retirement in coming years is powered by domestic fossil gas (Bangladesh Power Development Board, September, 2020).

The price of fossil fuels dropped in the wake of the economic slump caused by the COVID-19 pandemic but has begun to increase again. This will be an ongoing challenge for countries like Bangladesh, especially since Asian LNG prices recently hit a two-year high (Nicholas, 2021) and Asian fossil gas spot prices have very recently spiked, rising more than 18-fold on prices of just six months ago. This volatility has led to tenders being cancelled in countries like Pakistan and Bangladesh because prices were impractically high (Robertson, 2021).

Some causes of this price peaking are reduction of operating drill rig activities (drop of 40% globally in 2020), financial instability in the oil and gas industry (especially in the US), and low levels of industry investment. The Institute for Energy Economics and Financial Analysis (IEEFA) further reported that a global drop in the operating drill rig count will significantly reduce onshore gas production in 2021, and contributing to ongoing gas price volatility (Robertson, 2021).

The effects of these remarkable price increases and anticipated gas market volatility cannot be underestimated. Price volatility is expected to increase in the future, affecting electricity prices and ultimately undermining Bangladesh's fiscal space.

3.6. Renewables

Bangladesh has two primary RE sources, the most promising of which is solar energy. The country receives moderate levels of solar radiation on a daily basis ($GHI \approx 4.5 \text{ kWh/m}^2$), which can be converted into reasonable sources of energy via either concentrated solar thermal technology (CST) or solar PV. According to IRENA, the cost of solar PV has fallen 82% since 2010, and the cost of CSP has fallen by 47%.⁷ While solar PV is increasingly proving itself to be technically and economically viable, the deflationary cost trajectory of CST cements its future in the energy mix, especially for industries that require thermal power, such as the cement and steel industries. A geographical distribution of PV power potential is shown in Figure 3-5.

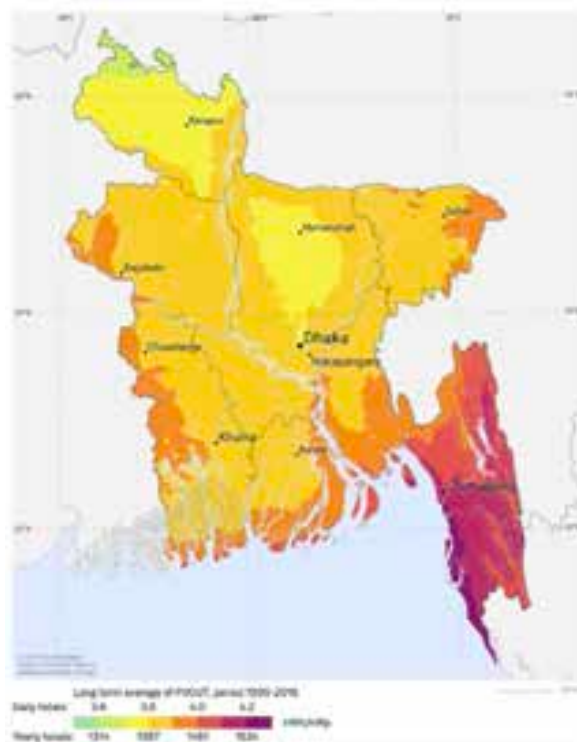


Figure 3-5: Photovoltaic Power Potential in Bangladesh
(Source: ESMAP)

The data in the figure represents long-term average values between 1999 and 2018. The south-eastern part of the country (including the Kaptai Lake area) holds higher PV power potential compared to the rest of the country, and the southern coastal belt, especially the Meghna estuary region, also has considerable PV power potential. For large-scale solar PV capacity deployment, the most suitable locations are likely in these regions.

Bangladesh's location on the delta of three major rivers and its many enormous water bodies, including lakes and ponds, creates potential for floating solar all over the country.⁸ The government has designated five locations suitable for installing floating solar: Kaptai Lake, Mohamaya Lake, Joydia Baor, Bukbahara Baor, and Khajura Baor.⁹ In 2019, the Asian Development Bank stated an aim to generate 200MW from floating solar over five years.¹⁰ Floating solar installations have shown they can withstand typhoons and winds up to 170 kilometers an hour.¹¹ As Bangladesh grapples with more intense climate impacts and looks to diversify its exports and improve the resilience of industries such as shrimp, it may be beneficial to consider the co-benefits that arise from floating solar. For example, for shrimp cultivation, floating solar modules can protect from predators and help maintain a lower water temperature, enhancing shrimp growth. Water-borne solar installations are quicker to build and can be ready in less than half the time of fossil fuel plants.

Wind energy may be a potential source of RE but remains underexplored. The most recent attempt was a study conducted by the Power Division of the MPEMR of Bangladesh through the National Renewable Energy Laboratory (NREL), with support from the United States Agency for International Development. The preliminary results of this technical potential analysis reported that “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” (Jacobson, et al., 2018). While the study emphasized that the findings are limited since they do not filter out unsuitable land (already developed or utilized, environmentally sensitive, etc.), the report highlights that wind resources do exist and merit detailed feasibility studies.

As a first step to qualify wind resource availability the project referred to above developed and launched a web tool for wind resource assessment. Figure 3-6 shows both onshore and offshore wind resource distribution in Bangladesh at four different altitudes. The southern part of Bangladesh has higher wind potential. Offshore wind farms yield many more full-load hours than onshore wind farms. Offshore wind is typically more consistent, balanced, and stable than onshore. Current wind turbine technology reduces variability, increases predictability, and decreases output spikes, which reduces the need for ancillary power generation for load balancing. This effectively translates to variable RE base load generation technology. Higher hub heights present a challenge in coastal areas prone to cyclones, but wind turbines are built with anemometers that trigger automatic shut-offs until wind speeds normalize.

Hydro and geothermal are other potential RE sources. Despite being a riverine country, the hydropower potential of Bangladesh is greatly limited by geographical and geopolitical factors. Power Cell commissioned a hydropower potential assessment study in the southeast part of Bangladesh from US consulting firm Stream Tech, Inc. The study showed very limited mini- and micro-hydro potentials on the Sangu, Matamuhuri, and Bakkhali rivers that need detailed feasibility assessments. There are a few thermal gradient sites across Bangladesh in areas such as Hazipur, Bakhrabad, Titas, Habiganj, Rashidpur, Biani Bazar, Kailas Tila, etc., but the proper assessment of the technical or even theoretical potential of geothermal energy is still far from realization (Baky, Rahman, & Islam, 2017). Considering the high exploration risk associated with geothermal energy, a portfolio approach with risk-sharing between the public and private sectors may be worth considering.

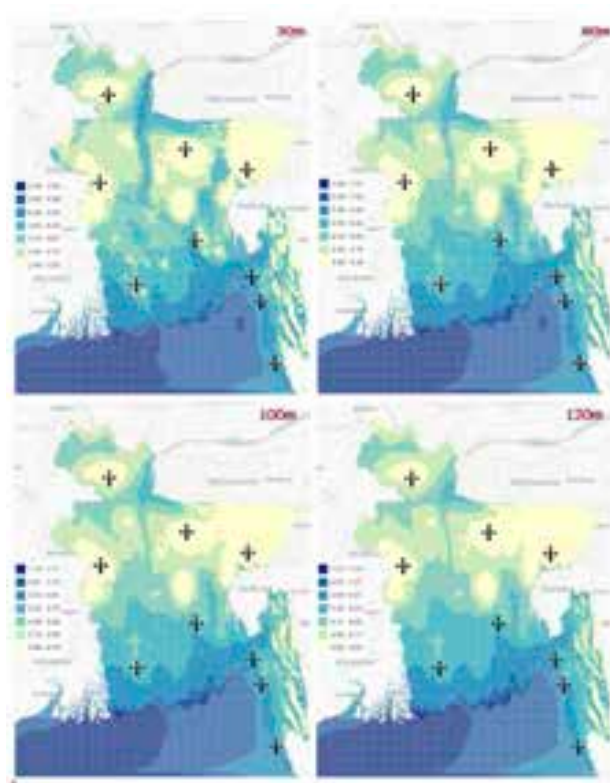


Figure 3-6: Wind Speed Distribution over Bangladesh at 30m, 80m, 100m, and 120m
(Source: RE Data Explorer, NREL, USAID)

Tidal waves occur on six major points on the coast of Bangladesh: the Pusur Entrance, the Haringhata Entrance, the Tentulia Entrance, the Shahbazzpur Entrance, the Hatiya River Entrance, and the Sandwip Channel Entrance. The tides in the Bay of Bengal originate in the Indian Ocean and approach Bangladesh, and after traversing the Swatch of No Ground and the Burma Trench reach Hiron Point and Cox's Bazaar. The tidal range in Bangladesh is at most half that of Canada, one of the highest ranges in the world. However, the amount of power produced is proportional to the square of the tidal range, meaning that small increases in tidal range lead to greater increases in power generated. The tidal pattern is predictable throughout the year and could be considered as a source of base load power. Tidal variation is low during January and rises until peaking during July and returning to its lowest level in December. The amount of tidal power generated would be proportional to tidal variation. Tidal energy has a seasonal pattern mirroring that of wind energy (Ali, Gupta, Arnab, & Ferdous, 2012).

A few feasibility studies have been conducted for tidal energy plants in Bangladesh, although no such plant yet exists. One such study was conducted for Mongla, Cox's Bazaar, and Sandwip. It was estimated that tidal energy could be tapped in these areas, especially Sandwip, with the barrages for controlled flow through turbines also serving as flood control (Khan, Shatter, Paul, Zishan, & Yousufe, 2012). The concurrent cost of flood control and power generation could allow tidal energy to benefit from the sunk cost of investment in flood management infrastructure (Hossain, Hossain, & Rahman, International Journal of Electrical, Robotics, Electronics and Communications Engineering). Another study was conducted for a village called Dhankhali in Barishal, comparing hybrid systems of PV, tidal-powered micro-hydro, diesel generator, and battery. It was found that the tidal-powered, micro-hydro, and diesel hybrid combination provided the lowest LCOE, followed by the tidal-PV-diesel hybrid system (Das, Yatim, Tan, & Lau, 2016).

Wave energy could have some potential in coastal Bangladesh, but detailed feasibility studies have not taken place. However, simulation-based studies using actual wave data have shown some theoretically promising results. One study compared different renewables and fossil fuel-based energy sources and found that wave energy has the lowest energy cost in the islands of Sandwip, Kutubdia, and St. Martin. This is because the power density of flowing water is higher than that of other mechanisms. The power extracted from waves depends on wave height and tidal period, which varies throughout the year, reaching the highest levels in the months of June, July, and August, and the lowest in February and March (Samrat, Rahaman, Al-Mamun, Adib, & Badhan, 2014). Some potential advantages of wave energy over other VREs like wind or solar energy are that wave energy is highly predictable, has many potential sites, and is regularly available and more scalable (Kowser, Islam, Uddin, Chakma, & Chowdhury, 2014).

Bioenergy may be a potential RE source. Biomass covers a wide range of materials, including firewood, agricultural crops, animal waste, municipal waste, etc. Biomass can be directly converted to useful forms of energy or converted into other forms of biofuels that can be stored and transported. Many studies have attempted to assess the biomass potential available in Bangladesh. But the inherently non-homogeneous nature makes the estimation of potential a complex and difficult task. One study stated that in FY2012-2013 nearly 373.7 TWh of electricity could have been generated from a total of 213.8 million tons of biomass (Baky, Rahman, & Islam, 2017). Some small-scale projects have already been implemented in Bangladesh to convert poultry and dairy waste and rice husk into electricity. However, mass-scale adoption of these technologies has not yet been possible due to technical and financial constraints. Long-term supply agreements for feedstock could help to de-risk this market.

Developments in RE and energy storage technology and their deflationary price trajectory will reduce the competitiveness and return on investment of fossil fuel assets, and, if adopted, offer Bangladesh's energy system improved pricing and reliability and reduced exposure to inflationary pressures and international volatility, undermining the financial case for large new commitments for imported fossil fuels. Currently, solar PV technology is the most commercially attractive for investors in Bangladesh—solar battery cost deflation is steeper than that of wind and solar power without storage—and has experienced a remarkable growth trend globally in the last few years. The global weighted average LCOE of large-scale solar PV plants has significantly dropped, while the market has grown and investment has increased.

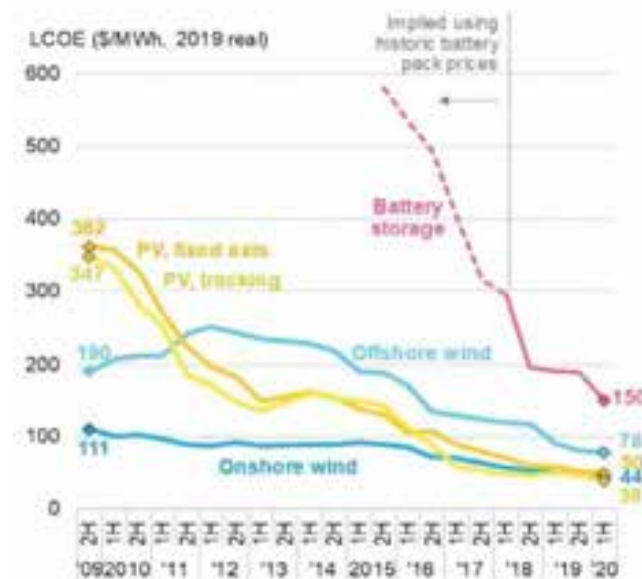


Figure 3-7: Battery Cost Deflation Steeper than Wind/Solar
(Source: Bloomberg New Energy Finance, <https://ieefa.org/ieefa-grid-scale-battery-costs-have-reached-a-tipping-point/>)

The following table shows a comparison of per-unit cost of various types of RE sources and technologies.

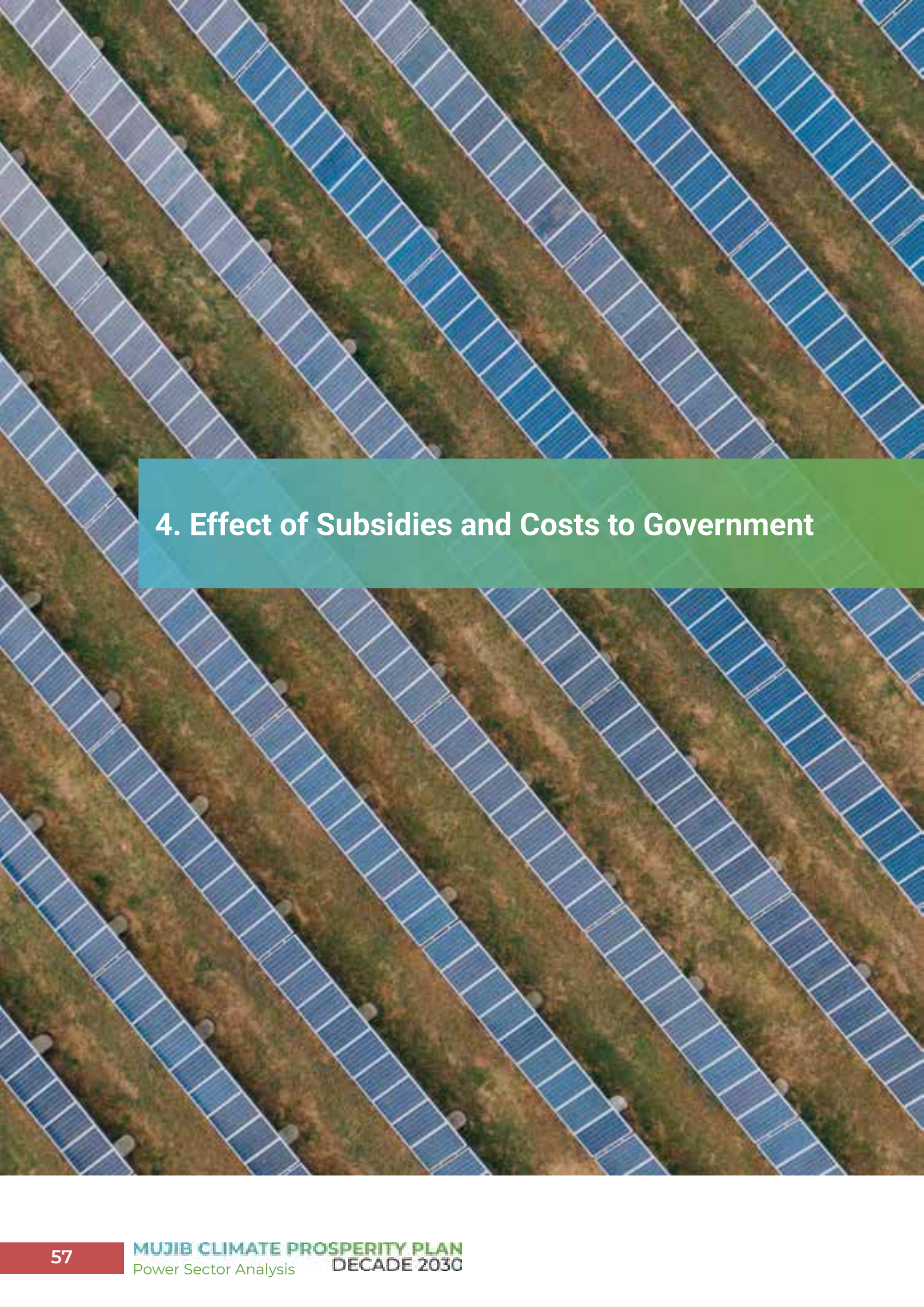
Technology	Cost per kWh	Citation
Rooftop solar PV	BDT 5.00	
Utility-scale solar PV	BDT 6.4 (Solicited-Rangunia 50 MW) – BDT 8.70 (Unsolicited Chandpur 7 MW)	Analyzing latest approved /implemented projects of Bangladesh
Wind	BDT 10.56 [55 MW at Mongla]	Ref: https://www.dhakatribune.com/bangladesh/2020/12/09/55mw-wind-power-project-wins-cabinet-body-approval
Micro-hydro (tidal) and diesel hybrid	BDT 15.19	(Das, Yatim, Tan, & Lau, 2016)
CSP without storage	BDT 10.77 - 13.57	(Shiraishi, Shirley, & Kammen, Geospatial multi-criteria analysis for identifying high priority clean energy investment opportunities: A case study on land-use conflict in Bangladesh, 2019)
CSP with storage	BDT 19.94 - 25.45	

Note: USD1 = BDT84.83

Table 7: Comparison of Historic Per-Unit Cost of Electricity Generated from Various RE Sources in Bangladesh

Installed solar generation capacity is generally expressed in DC (MWp). However, like conventional power generation sources, wind power generation capacity is expressed in AC (MW). RE targets in various policy documents, e.g., RE Policy 2008, NDC, PSMP, etc. are also expressed in MW. For convenience, the targets here are presented in MW (AC). MW and MW (AC) have been used interchangeably in this report, as have MWp and MW (DC).





4. Effect of Subsidies and Costs to Government

The current power system is built on the premise that fossil fuel is cheap and reliable. Fossil fuel subsidies cost the world USD3.1 trillion per year, which is over 20 times the level of support to RE.¹² Globally, continuing financial commitment to fossil fuels helps stifle economies. For example, replacing the costliest 500 GW of coal capacity with solar and wind would cut annual system costs by up to USD 23 billion per year and yield a stimulus worth USD 940 billion.¹³

In the context of health costs, direct and indirect fossil fuel subsidies are estimated to total trillions of dollars worldwide, comprising 6.5% of global GDP. Eliminating these subsidies could potentially reduce global carbon emissions by 22% and halve the number of air pollution-related deaths. Subsidies can be direct or indirect and include healthcare and environmental costs and subsidies to consumers and producers. The highest subsidies occur for coal, followed by petroleum and fossil gas (Coady, Parry, Sears, & Shang, 2017).

Bangladesh is no exception to fossil fuel subsidies, and large sums of money go to subsidies to maintain loss-making HSD and HFO power plants. In this analysis, only direct subsidies have been considered at the plant level. Figure 4-1 shows that the absolute amounts and percentages of subsidy payments can be quite high for the power sector. In some years, subsidies reach as high as 35% of revenues. Subsidies are paid out for losses, which are incurred for a variety of reasons, including fuel cost volatility leading to higher-than-anticipated fuel costs, the cost of electricity delivered to consumers being higher than electricity tariffs, and high fixed capacity payments. Losses can also occur due to shortfalls in revenue collection on electricity sales.



Figure 4-1: Trend of Subsidies in the Power Sector (2010–2020)

Various cost components are trending upward, including generation costs, average supply costs, maintenance and development costs, and debt servicing costs, which make up the total cost. This amount is always significantly higher than the average bulk tariff, which cannot be raised at the same rate as the increase in costs (Figure 4-2).

These ultimately lead to growing losses in the sector, which have to be covered by government subsidies (Figure 4-3).

Traditional PPAs, with capacity payments and the passed-on volatility of fuel costs, rely on the logic of maximizing extraction of good outcomes relative to low-cost financing terms. However, the pricing of worst-case scenarios means the delivery of more expensive and volatile power purchase outcomes. The optimization of renewable energy through a modernized grid can enable a constellation of investment with low cost of financing due to risk mitigation in the planning phase with storage and system balancing. In short, risk mitigation in the front end through the planning process may reduce the reliance of credit impaired off takers for traditional power purchase agreements and instead enable the ability to take advantage of a cost-effective and optimized power system that prioritizes affordability, domestic energy security, flexibility and resilience.

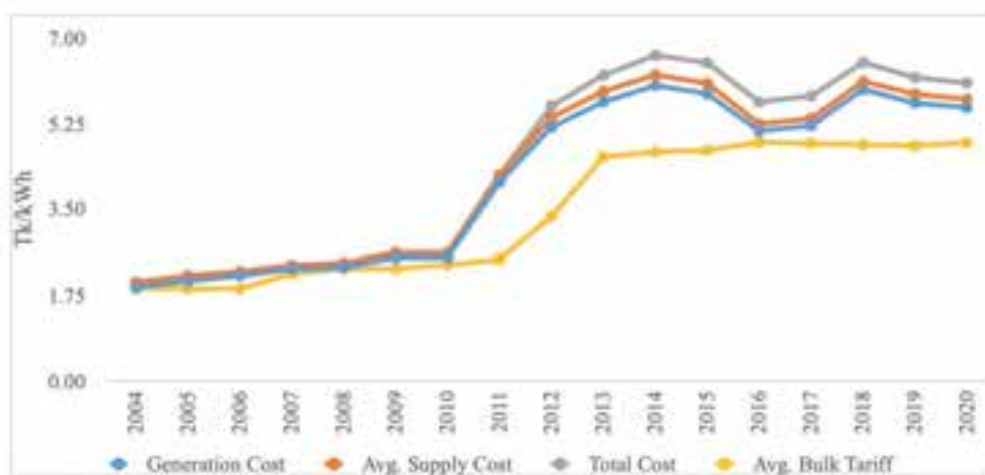


Figure 4-2: Trend of Electricity Costs and Tariffs

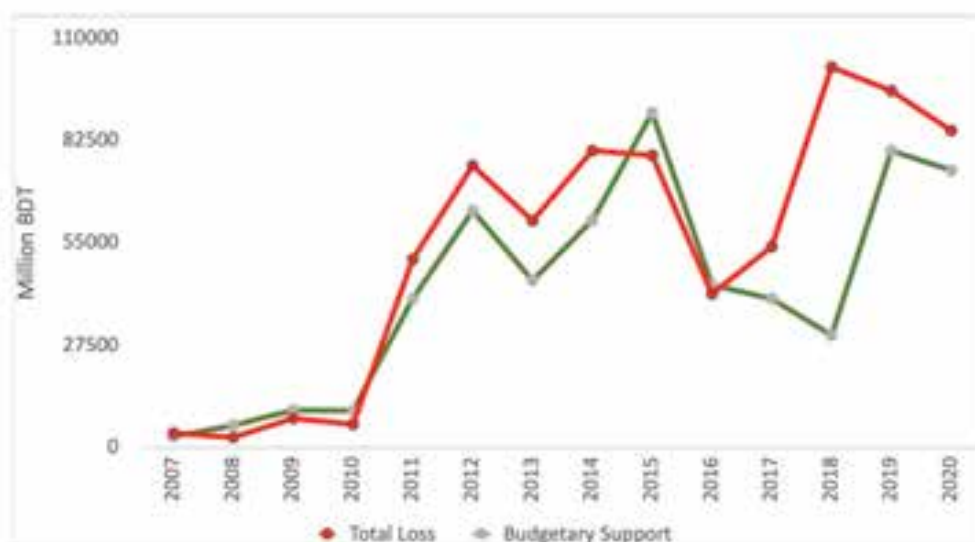
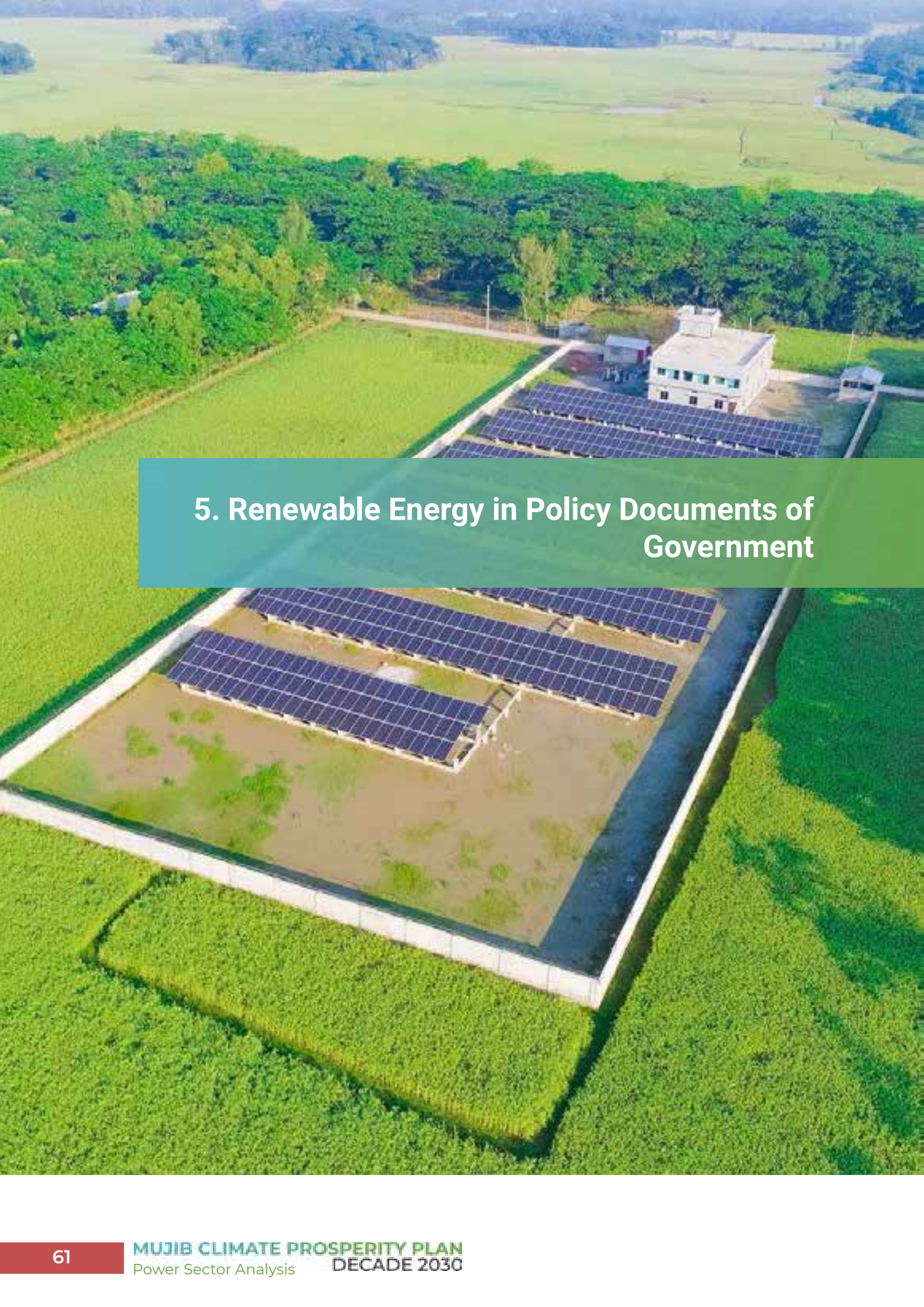


Figure 4-3: Trends of Total Loss in and Budgetary Support to the Power Sector





5. Renewable Energy in Policy Documents of Government

5.1. Power System Master Plan 2016 (Baseline Scenario)

The PSMP was prepared with the aim of formulating a comprehensive energy and power development plan up to 2041, covering energy balance, power balance, and tariff strategies. It set goals for fuel diversification with an emphasis on increasing the role of RE in the power generation mix. PSMP states 10% of total installed capacity should come from RE sources. The following have been recognized as potential RE sources in Bangladesh under PSMP 2016.

Solar parks	1,400	2,000
Solar Roof Top	635	860
Solar Home System	100	115
Solar Irrigation Pump	545	735
Wind park	637	1,250
Biomass	275	1,800
Biogas	10	40
Waste to Energy	1	6
Small Hydropower	60	200
Mini and Micro grids	3	4
Total	3,666	7,010

Table 8: RE Potential in Bangladesh under PSMP 2016

5.2. NDC Commitments and Targets

The Paris Agreement (Article 4, paragraph 2) requires each signatory party to prepare, communicate, and maintain successive Nationally Determined Contributions (NDC) that it intends to achieve with specific domestic mitigation and adaptation measures. Bangladesh signed the Paris Agreement in April 2016 and submitted its first NDC in September 2016. Initially, Bangladesh committed to reducing GHG emissions by 12 MtCO₂e (5%) in the unconditional scenario (i.e., implemented through its own resources and capabilities) and 24 MtCO₂e (15%) emission reduction in the conditional scenario (i.e., implemented with international support) from the power, transport, and industry sub-sectors of the energy sector (MoEFCC, 2021).

Each country is expected to update its NDCs every five years and submit enhanced emission reduction commitments; Bangladesh submitted the Interim Updated NDC on December 2020 where enhanced mitigation targets were set. Government targets to implement utility scale solar plants and wind projects as well as rooftop solar. The interim NDC also targets to disseminate improved cook stoves and establish waste-to-energy incineration plants





5.3. Bangladesh Perspective Plan 2021-2041

Bangladesh Vision 2041 aims to eliminate extreme poverty and attain the status of upper middle-income country by 2031, and of high-income country by 2041. In this regard, the Planning Commission launched the 'Making Vision 2041 a Reality: Perspective Plan of Bangladesh 2021-2041' (PP2041) in March 2020 (General Economic Division (GED), Making Vision 2041 a Reality: Perspective Plan of Bangladesh 2021-2041, 2020).

The targets set by this planning document include capacity to meet the demands of an upper-middle- and high-income economy, sustained and universal access, ensure efficient supply of electricity at a globally competitive price and achieve 100% energy security. Section 8.4 of the Perspective Plan mentioned that "the fuel mix will need to change from excessive reliance on fossil fuel towards a balanced combination of low-cost fuel and RE. More use of imported hydro and solar power from India, Nepal and Bhutan will help mitigate the domestic pressure on power production while also lowering carbon emission."

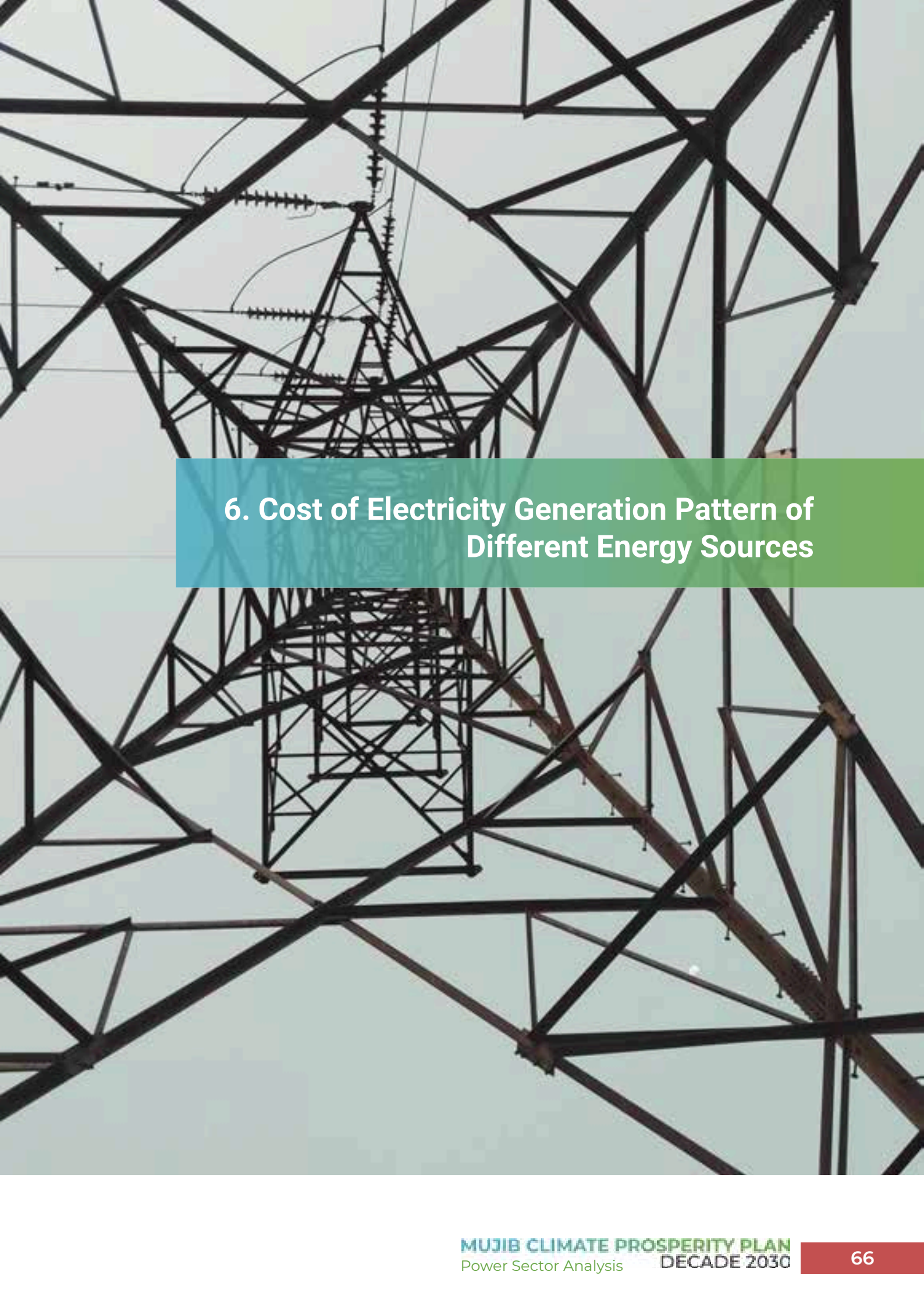


5.4. Bangladesh Delta Plan 2100

Another important addition in the energy policy landscape is the Bangladesh Delta Plan 2100 (BDP 2100), launched by the Planning Commission in October 2018. The BDP 2100 focused especially on RE technologies and recognized the country's significant potential to make use of these in the future. It proposed a target of generating 30% of total energy from renewable sources by 2041. Some strategies for RE development proposed in the Plan are as follows (General Economic Division (GED), Bangladesh Delta Plan 2100 (Abridged Version), 2018):

- Develop long-term RE policy and strategies, and formulate a master plan for at least 50 years to harness the potential of RE resources in the country using public and private sector investments
- Promote research on the development of technology in the field of RE in universities and research institutions, and build capacity for its application
- Enhance green growth through R&D of RE technologies, including the Clean Development Mechanism (CDM)
- Devise innovative financing packages for grant funding and low interest financing to address affordability for both grid and off-grid RE projects.





6. Cost of Electricity Generation Pattern of Different Energy Sources

In the following table, the per-unit generation cost has been derived in BDT/kWh using the following methodology:

- **Generation from coal, gas, liquid fuel, imported power and hydro:** weighted average generation cost in 2020 has been collected from BPDB. The periodical rate of change has been derived from the rate of change of generation cost calculated in Revisiting PSMP 2016 in USD. Subsequently, the USD to BDT devaluation factor of 1.41% per annum¹⁴ has been considered during the reference period.
- **Generation from LNG:** This has been derived from the Gas Sector Master Plan 2017. The price of the same has been escalating by 4.77% per year¹⁵ in the last five years. Notably, International Energy Agency (IEA) data from 2016 to 2019 shows a 12.27% increase in LNG price.¹⁶ Subsequently, the USD to BDT devaluation factor of 1.41% per annum has been considered during the reference period.
- **Generation from nuclear power:** According to an August 2020 media briefing from the Science and Technology Minister, Architect Yeafesh Osman, the power generation cost at the Rooppur Nuclear Power Plant will be between BDT 4 and BDT 4.50 per unit for at least the first two decades, which will be much lower than the cost at coal-fired plants but higher than that at gas-fired ones.¹⁷ The generation cost from nuclear power plants has been put at BDT 4.5 per unit. The USD to BDT devaluation factor of 1.41% per annum has been considered during the reference period.
- **Generation from solar rooftop:** The estimated generation cost of rooftop solar projects has been derived from prevailing market costs. It has been estimated to decline 20% in five years, though Bangladesh's market trends over the last three years show a much higher reduction.
- **Generation from solar IPP:** The generation cost from solar IPP depends on the prices of equipment, e.g., solar PV modules, inverters, cables, etc. Panels and inverters constitute about 30–35% of the project cost. Based on the projected cost of this equipment¹⁸ and other cost components, as well as operational expenses, the calculated tariff from solar IPP is estimated to be BDT 7.75 per kWh in 2025 and BDT 7.25 per kWh in 2030.
- **Generation from floating solar:** The generation cost for floating solar is usually slightly higher than that of utility-scale solar projects; this study places it at 3% higher. IEA¹⁹ anticipates an 11% decrease over five years.
- **Wind energy:** According to a recently bid wind power project, the tariff for onshore wind power projects in Bangladesh is BDT 10.56 per unit. Tariffs for offshore wind are determined using the global and local tariff difference between onshore and offshore²⁰ with a reduction of 5% per year.²¹ The USD to BDT devaluation factor of 1.41% per annum has been considered to calculate projected cost during the reference period
- **Hydro (imported):** In April 2019, India and Bhutan signed a contract for an India-financed hydropower project installed in Bhutan. The tariff was fixed at INR 2.4 per unit for 35 years. The tariff will be increased by 10% every five years until the loan is repaid and 5% thereafter. The equivalent BDT was used to find generation cost, with BDT 2.00/kWh as a wheeling charge to be paid to the Indian government. That tariff will be escalated by 5% per year.

	2020	2025	2030
Coal	6.62	7.35	8.13
Gas	3.25	4.05	5.09
LNG	12.20	16.52	22.36
HFO	10.31	12.86	16.08
HSD	23.33	28.93	36.48
Nuclear	4.50	4.83	5.18
Solar (rooftop)	5.00	4.29	3.68
Solar (IPP)	8.70	7.75	7.25
Solar (Floating)	9.00	8.59	8.20
Wind (Onshore)	10.56	10.76	10.96
Wind (Offshore)	12.36	12.59	12.83
Hydro (Import)	4.88	5.23	6.61

Table 9: Generation Cost (BDT/kWh)

The graphical representation of the costs is shown in the following figure.

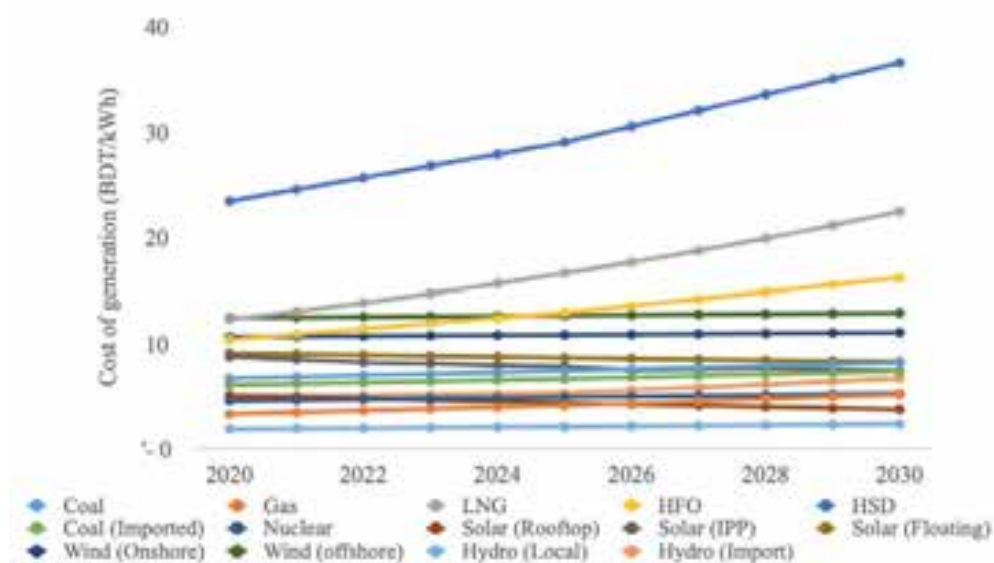


Figure 6-1: Projected Cost of Generation (BDT/kWh)



7. Econometric Analysis of Electricity Consumption Drivers and Elasticity

7.1. Energy and Macroeconomic Forecasts

There have been a few studies on Bangladesh's growing demand for energy in general and electricity in particular. The PSMP compared Bangladesh's growth in electricity demand concomitant with growth in GDP with other Asian countries that have undergone the same development process. Thailand served as the role model for Bangladesh; it is assumed that Bangladesh will reach upper middle-income status by 2041, although Vision 2041 aims at high-income status by 2041.

The MCCP's planning extends to 2030. The PSMP predicts a growth rate of 6.1% in real terms up to 2041. The projections of GDP are based on the projections of population and per capita income trends; final GDP is the product of these two variables. To arrive at the total energy demand of the country, the PSMP used historical data on total energy consumption in Bangladesh divided sector-wise, shares of energy types in total energy consumption, and historical trends in electricity consumption sector-wise. It assumed that energy demand will grow according to the historical rate. For the household sector, it projected per capita income elasticity in electricity consumption. For the energy-intense industrial, agricultural, and transport sectors the PSMP used the GDP elasticity method for peak demand projection.

In addition to this policy document, there have been numerous scholarly studies covering the relationship between electricity demand and macroeconomic factors in Bangladesh. Liddle and Huntington (Liddle & Huntington, 2020), in a sample of 17 countries over 56 years, including Bangladesh, show that the GDP elasticity of energy demand is lower than one, and there is no difference in this between OECD and non-OECD countries. They conclude that energy elasticities do not change with GDP per capita. This is due to worldwide improvements in energy efficiency. Munim, Hakim and Al-Mamun (Munim, Hakim, & Al-Mamun, 2010) show that the overall energy intensity of Bangladesh is increasing, but not all sectors are contributing to this increase. The energy intensity of the commerce and service sectors is decreasing, but in the agriculture sector, energy intensity is increasing. The transport sector is the least energy-efficient due to increasing mechanization of farming and irrigation.

Murshed (Murshed, Modeling primary energy and electricity demands in Bangladesh: An Autoregressive distributed lag approach, 2021) argues that both primary energy demand and electricity demand in Bangladesh are positively affected by the higher levels of economic growth, household consumption expenditure, industrialization, energy imports, urbanization, and institutional quality. Higher prices of crude oil and more income inequality inhibit overall energy demand in Bangladesh. Masuduzzaman (Masuduzzaman, 2012) argues that electricity consumption actually leads to more economic growth in the long term, so the direction of effect is both ways. Ahmad and Islam (Ahmad & Islam, 2011) show that electricity consumption has a short-term impact on economic activity in Bangladesh, but in the long term the relationship is bidirectional.

Hasan and Mozumder (Hasan & Mozumder, 2017) show that there is a U-shaped relationship between per capita energy and electricity use and per capita income. They find that as income

grows, households increase their energy expenditure less than proportionally, up to a threshold level of income. Beyond the threshold income, energy use increases as a proportion of income, particularly for electricity use. Murshed and Alam (Murshed & Alam, Estimating the macroeconomic determinants of total, renewable, and non-renewable energy demands in Bangladesh: the role of technological innovations, 2021) show that economic growth and household consumption positively affect energy and electricity demand, whereas technological innovation decreases it.



7.2. Description of Energy, Electricity, and Macroeconomic Trends

In this section, we look at energy and electricity consumption patterns in Bangladesh and the associated macroeconomic drivers. The data for sector-wise electricity and energy consumption are from the IEA (IEA, 2021).

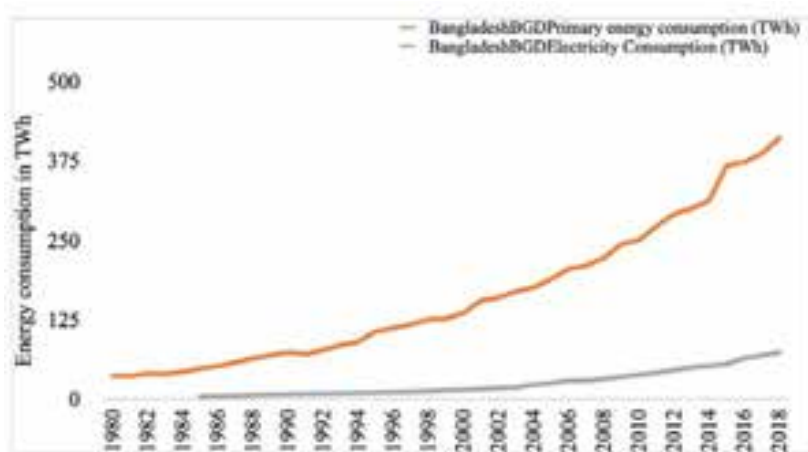


Figure 7-1: Energy and Electricity Consumption Trends in Bangladesh

Bangladesh has a growing energy and electricity demand, but the rate of growth of total energy is greater than the rate of growth of electricity, and so the share of electricity in total energy consumption is declining. This may be because the heating and transport sectors are using greater quantities of energy. Increasing the use of electricity for transport and for domestic cooking and heating is important to ensure cleaner and more efficient energy usage. Bangladesh emphasizes the distribution of liquefied petroleum gas for clean cooking, rather than electric stoves, so we don't anticipate the electrification of cooking in the near future. However, there is a greater number of electric vehicles in the road, and various routes on the metro rail are also expected to start operations in the coming decade, so we can expect some increase in the electrification of the transport sector. Also, many new vehicles are energy-efficient hybrids.

The per capita total energy and electricity consumption in Bangladesh follows a similar trend, with total energy use increasing at a faster rate than use of electricity. This may be because while there has been a great increase in electricity access and use in the country while appliances have also become more energy efficient. Other energy applications have not undergone this improvement.

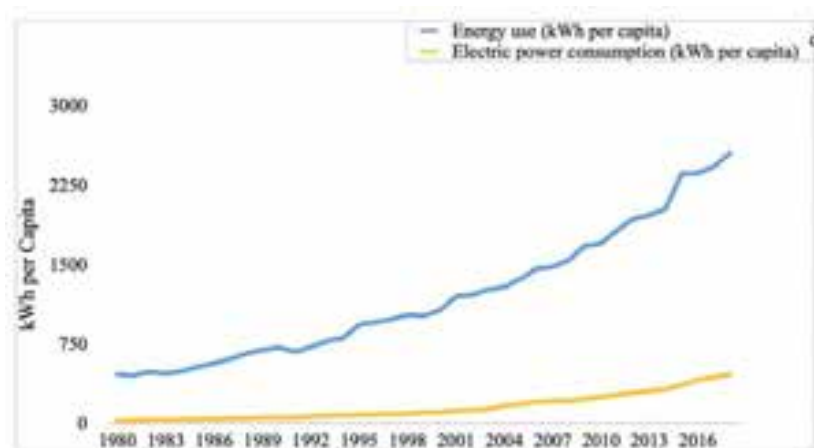


Figure 7-2: Per Capita Energy and Electricity Consumption Trends in Bangladesh.

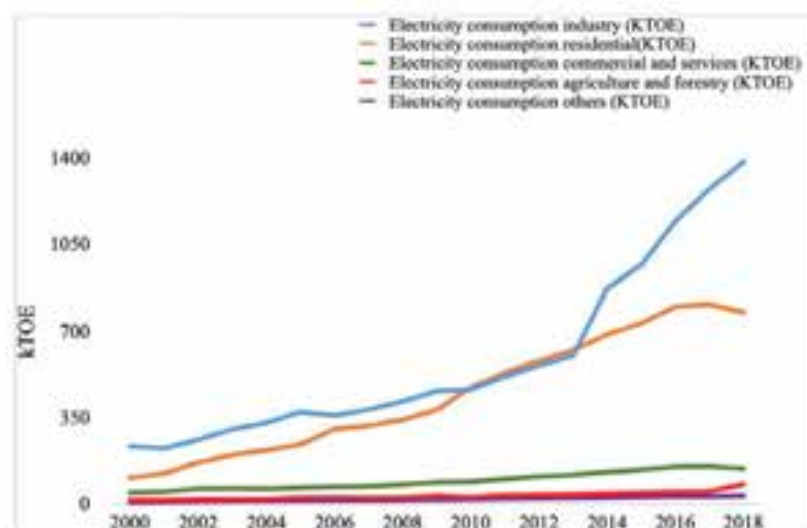


Figure 7-3: Electricity Consumption of Different Sectors (Kilotons Oil Equivalent)

The greatest increase in electricity consumption occurred in the industrial sector, followed by the residential sector. Electricity consumption in other sectors did not increase to extremely high levels, although it did rise to 472 kilotons of oil equivalent (KTOE) in 2018 from 46 KTOE in 1990, and 89 KTOE in 2000. Electricity consumption in agriculture remains low.

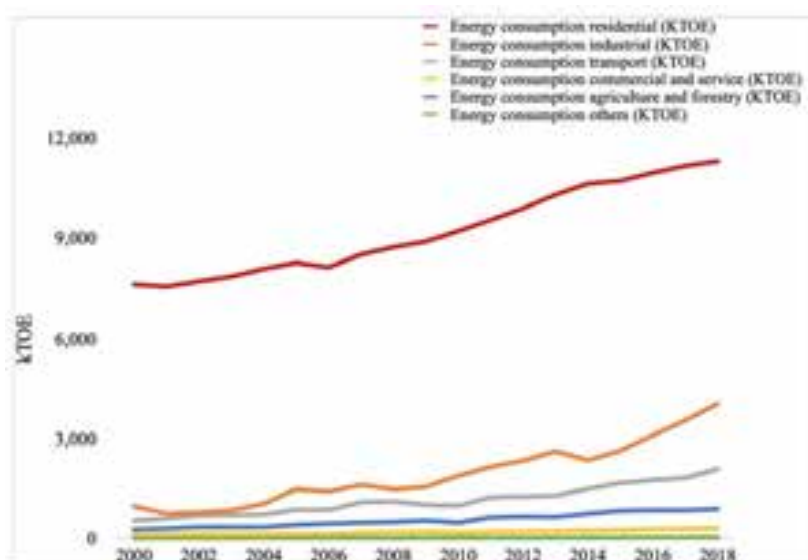


Figure 7-4: Energy Consumption of Different Sectors (Kilotons Oil Equivalent)

In contrast to electricity consumption, energy consumption in the household sector is the highest, much more than in the industrial sector. These two have higher rates of increase than other sectors. However, this includes all types of modern and traditional energy. The high levels of energy use in the household sector in this case can be attributed to the use of traditional biomass and inefficient traditional stoves, which provide low energy conversion.

The agricultural sector's contribution to GDP has been proportionately decreasing, while the contribution of industry and services has been proportionately increasing. Manufacturing is increasing in pace with industry. However, manufacturing, an energy-intensive activity, is not becoming proportionately a greater part of industry.

The greatest share of GDP comes from the services sector, followed by industry. The services sector is also increasing at the fastest rate, followed by the industrial sector. The agriculture sector, on the other hand, is growing at a constant rate and so in the long term will form a smaller share of GDP.

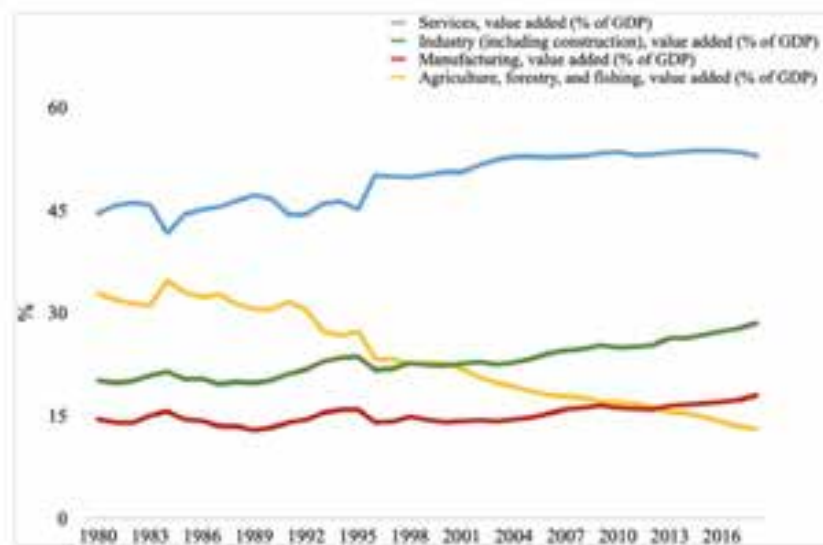


Figure 7-5: Share of Value Added of Different Sectors to the GDP

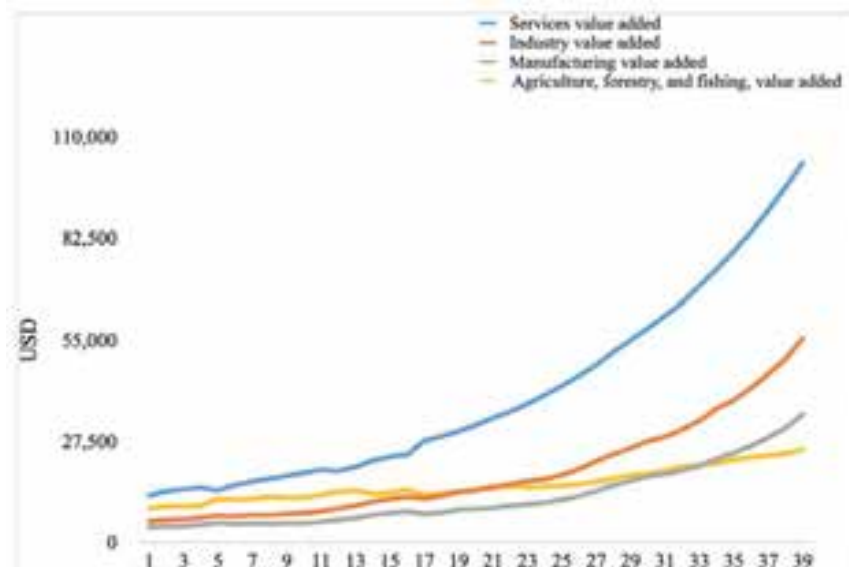


Figure 7-6: Value Added of Different Sectors (USD)

As expected, the electricity intensity of the industrial sector is the highest, and is also growing, although at a decreasing rate. This implies that industry is becoming more energy efficient over time. However, the agriculture sector is becoming more energy intensive, although the overall energy consumption of this sector is low compared to output. The services sector has stable electricity intensity.

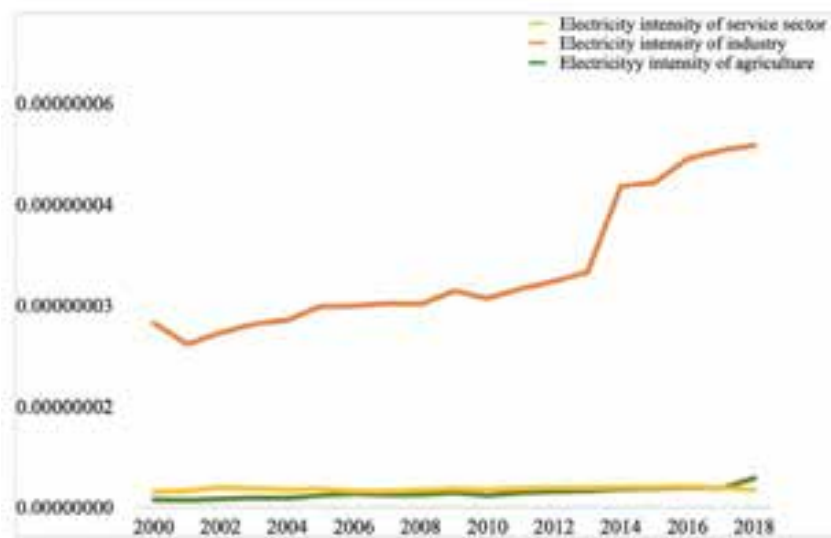


Figure 7-7: Electricity Intensity of Different Sectors (KTOE/USD of GDP Value Added)



7.3. Elasticity and Macroeconomic Drivers of Electricity Consumption

In this section, we explore the elasticity of the electricity demand of the main economic sectors. For this we have analyzed the relation between the electricity consumption of a sector with the value added from that sector. Our initial analysis shows that electricity consumption from the services sector has an elasticity of 1.29, indicating that increase in the output of the service sector increases its electricity consumption proportionately more (Figure 7-8).

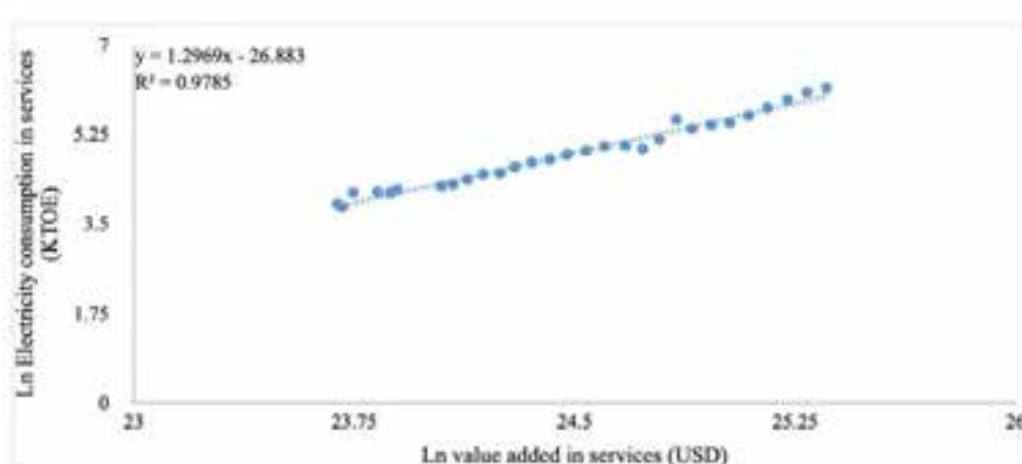


Figure 7-8: Elasticity of Electricity Consumption from Value Added in the Services Sector

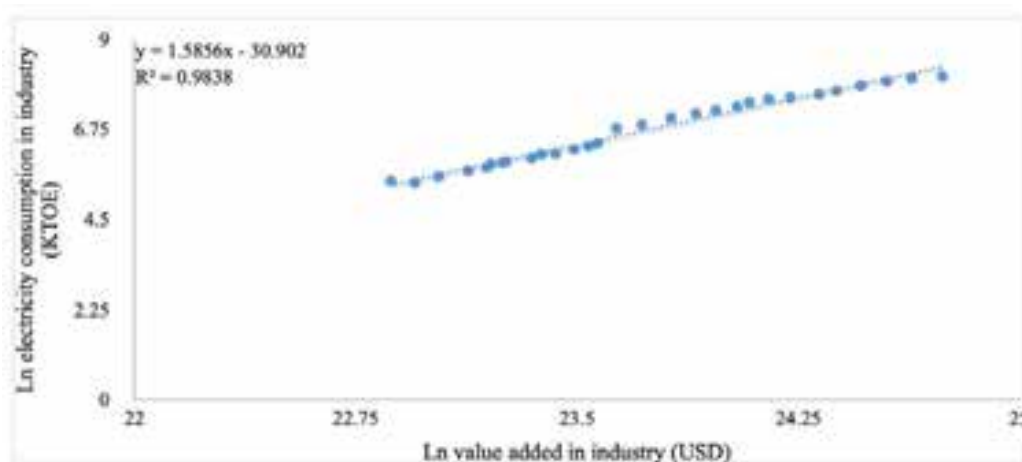


Figure 7-9: Elasticity of Electricity Consumption from Value Added in the Industry Sector

The elasticity of electricity demand from the industrial sector is even greater, as it has a value of 1.589 (Figure 7-9). The increase in production in the industrial sector leads to a much greater increase of the consumption of electricity. However, the greatest elasticity appears for the agricultural sector, where the value is 2.05 (Figure 7-10). This implies that the agricultural sector is becoming highly energy intensive, and more processes in the production and supply chain have become electricity intensive. There is more use of electric irrigation as well other mechanization in the harvesting and processing stages.

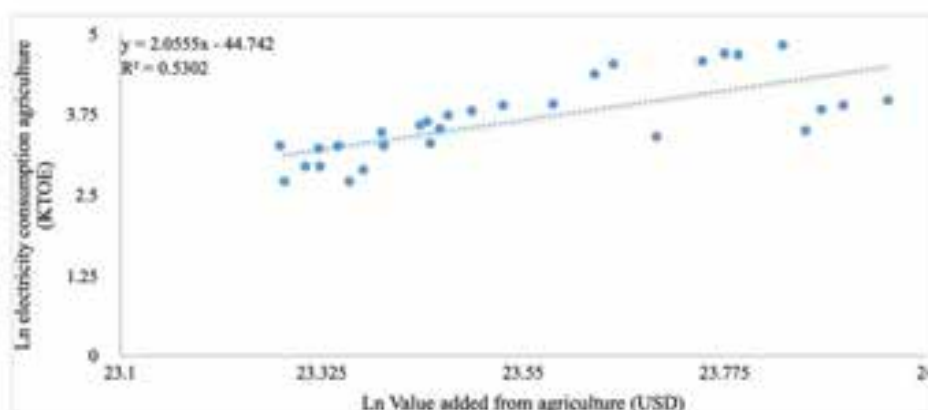


Figure 7-10: Elasticity of Electricity Consumption from Value Added in the Agriculture Sector

Next, we analyze how relevant macroeconomic drivers affect overall electricity consumption. We have selected the following drivers:

- GDP (constant 2010 USD)
- GDP per capita (constant 2010 USD)
- Share of services in GDP (%)
- Share of industry in GDP (%)
- Share of agriculture in GDP (%)
- Share of manufacturing in GDP (%)

The dependent variable is the electricity consumption in TWh. As there is a high degree of multi-collinearity in these variables, we have taken the logarithms and used ridge regression for analysis. The model can be represented as follows:

$$(1) \text{ Electricity Consumption} = a + b_1(\text{GDP}) + b_2(\text{GDP per capita}) + b_3(\text{Services share}) + b_4(\text{Industry share}) + b_5(\text{Agriculture share}) + e$$

From our results, we can see that the most significant drivers of electricity consumption are total GDP, GDP per capita, and the contribution of services to GDP. The total GDP and GDP per capita are significant at the 1% level, and the share of services is significant at the 5% level. A somewhat less significant driver is the share of agriculture in GDP. Although we have previously seen that agricultural production's elasticity of electricity demand is the highest, overall, the electricity consumption of the sector is low compared to other sectors, so the impact is less substantial. Industry overall, and manufacturing in particular, do not appear to have a significant impact on electricity consumption. This may be because the industrial sector is lowering its rate of growth of energy intensity compared to other sectors. The driver with the greatest impact is the service sector, with a coefficient of 1.37, followed by the per

capita GDP, which has a coefficient of 0.73. From this we can infer that services are highly electricity intensive. Rising per capita income will also lead to greater electricity consumption.

Next, we explore how the level of activity in each of the sectors affects the peak generation of the country, which depends on the peak demand. Here we have available data from 1997 to 2018. We analyze how the peak generation in any given year is affected by the level of output from each of the sectors, as well as the overall GDP and the per capita GDP. Here, the dependent variable is the peak generation of a year, measured in MW, and the explanatory variables are as follows:

- GDP (constant 2010 USD)
- GDP per capita (constant 2010 USD)
- Value added from services (USD)
- Value added from industry in GDP (USD)
- Value added from agriculture in GDP (USD)
- Value added from manufacturing in GDP (USD)

The model can be expressed as follows:

$$(2) \text{ Electricity Consumption} = a + b_1(\text{GDP}) + b_2(\text{GDP per capita}) + b_3(\text{Services share}) + b_4(\text{Industry share}) + b_5(\text{Agriculture share}) + e$$

The results of the regression analysis show that several explanatory variables are highly significant drivers of peak generation. The total GDP, GDP per capita, services value, and industry value added are highly significant drivers of peak generation. Manufacturing value added is also a significant driver at 5%. However, agricultural output plays no significant role in determining peak generation. This may be because the timing of agricultural demand is flexible, as irrigation can take place on a flexible timetable.

As before, the biggest impact comes from the value added from services, followed by per capita income and total GDP. This implies that the services sector drives not only the volume of electricity consumption but also the pattern. The same is true for per capita GDP. As average incomes rise, the population consumes more electricity, which drives up the peak generation during peak hours. Compared to these drivers, the value added from the industrial and manufacturing activities has a smaller positive significant impact. This can be attributed to the fact that manufacturing and other industrial activities can take place in shifts throughout the day, and some of the demand is met by captive power plants. The government has issued licenses of 2600 MW of gas-based and 600 MW of liquid fuel-based captive generation capacity to various industries that have sensitive production processes and cannot tolerate any lapse in electricity supply. These industries therefore provide some of their own electric power, and so do not strongly affect peak generation from the grid.

OVERALL FIT									
Multiple R	0.994894	AIC	-117.825						
R Square	0.988223	AICc	-112.491						
Adjusted R Square	0.985151	BSC	-109.621						
Standard Error	0.119737								
Observations	29								

ANOVA									
	df	SS	MS	F	p-value	Sig	MSE	VIF	Goal
Regression	6	21.67025	3.611708	321.8632	5.42E-21	Yes	0.004193	1	
Residual	23	0.329753	0.014337					3.69684	
Total	29	22							

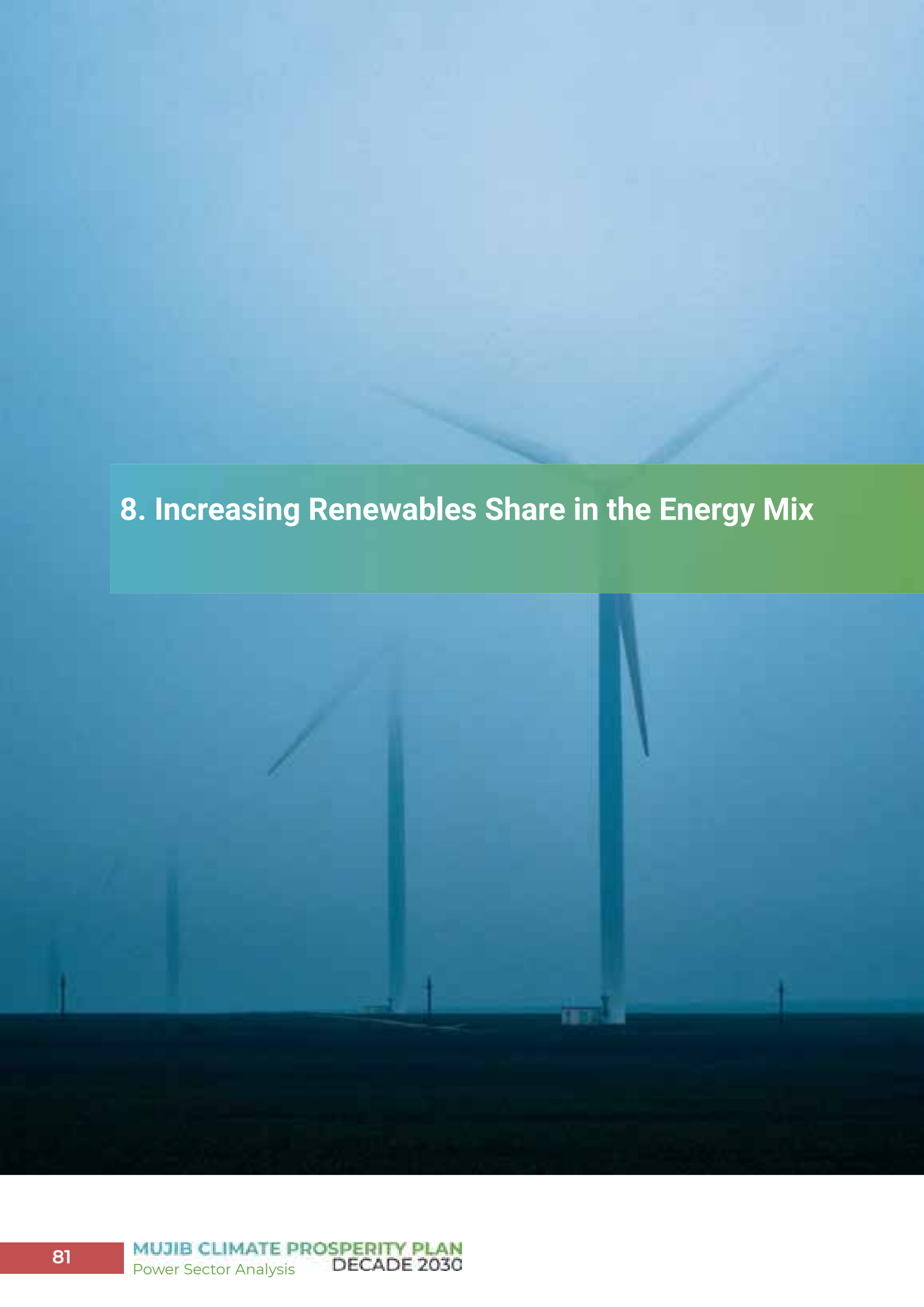
	coef	std err	t	prob> t	[0.025	0.975	[0.025	0.975]	std. dev
Ln GDP (constant 2010 US\$)	0.376398	0.041349	9.102923	4.37E-09	0.29086	0.461935	3.3391	0.586712	0.064453
Ln GDP per capita (constant 2010 US\$)	0.334827	0.051395	6.514773	1.2E-06	0.238508	0.441346	5.158707	0.730644	0.112152
Ln Services (% of GDP)	0.120957	0.046483	2.602062	0.015936	0.024795	0.217118	4.230105	1.377433	0.529362
Ln Industry (including construction) (% of GDP)	0.053063	0.058676	0.904344	0.373188	-0.06832	0.174444	6.723889	0.435653	0.481754
Ln Manufacturing (% of GDP)	0.029168	0.052252	0.558289	0.582696	-0.07692	0.13726	5.332286	0.266939	0.478206
Ln Agriculture, forestry, and fishing (% of GDP)	-0.10651	0.056354	-1.89005	0.071419	-0.22309	0.010065	6.202731	-0.38023	0.158847
Constant								-22.9808	

OVERALL FIT									
Multiple R	0.994657	AIC	-88.9344						
R Square	0.989342	AICc	-80.9344						
Adjusted R Square	0.985345	BSC	-82.3881						
Standard Error	0.118276								
Observations	22								

ANOVA									
	df	SS	MS	F	p-value	Sig	MSE	VIF	Goal
Regression	6	20.77617	3.462696	247.527	7.35E-13	yes	0.002119	1	
Residual	16	0.223827	0.013989					3.69684	
Total	22	21							

	coef	std err	t	prob> t	[0.025	0.975	[0.025	0.975]	std. dev
Ln GDP	0.230796	0.023643	9.761825	3.84E-08	0.180676	0.280916	0.839115	0.297518	0.020478
Ln GDP per capita	0.160442	0.044496	3.605778	0.00237	0.066115	0.254769	2.972118	0.269619	0.054774
Ln Services value	0.254728	0.013096	4.985254	0.000155	0.146409	0.363048	3.919292	0.310425	0.062269
Ln Industry value	0.184636	0.024352	7.581988	1.1E-06	0.133612	0.23626	0.890215	0.196298	0.02589
Ln Manufacturing value	0.107581	0.045566	2.360979	0.031249	0.010985	0.204177	3.116836	0.116021	0.049141
Ln Agriculture value	0.055322	0.075967	0.728245	0.476987	-0.10372	0.216384	8.663995	0.133056	0.182708
Constant								-19.0568	

Table 10: Results of Ridge Regression of Macroeconomic Drivers of Electricity Demand

A large wind turbine is the central focus, its three blades extending towards the top of the frame. The ground is a flat, dark expanse, possibly a field or a beach. The sky is a clear, pale blue. The overall tone is serene and clean, emphasizing renewable energy.

8. Increasing Renewables Share in the Energy Mix

This section discusses maximum possible RE share in the energy mix considering available renewable resources and existing and projected capacity increase from fossil fuel. Information on the addition of fossil fuel-based plants up to 2025 has been taken from the BPDB website; information on additions up to 2030 comes from PSMP 2016.

As of 2020, Bangladesh has installed 490 MWp equivalent solar PV capacity. This is only 2.23% of total installed capacity.

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Utility Scale										
Grid-tied Solar	0.89	0.87	0.85	0.83	0.85	0.83	0.81	0.79	0.77	0.79
Floating Solar	0.90	0.79	0.73	0.70	0.67	0.61	0.57	0.54	0.52	0.50
Rooftop Solar	0.62	0.60	0.59	0.57	0.56	0.55	0.53	0.52	0.51	0.49
Solar Irrigation	1.30	1.28	1.27	1.25	1.24	1.22	1.21	1.19	1.18	1.16
Wind (onshore)	2.10	1.67	1.42	1.26	1.15	1.08	1.04	1.00	0.97	0.94
Wind (offshore)	6.0	4.9	4.6	4.3	4.1	4.0	3.9	3.8	3.7	3.7

Table 11: Solar PV Capacity Installed as of 2020 in Bangladesh from Different Sources
Source: SREDA website²²

The PSMP 2016 assumed a gradual shift toward a daytime peak for electricity demand as Bangladesh industrializes. We used forecasted average peak electricity demand data and estimated daily load curve for 2025 and 2030 from PSMP 2016 to determine average hourly electricity demand for 2025 and 2030. According to PSMP 2016, forecasted average electricity peak demand is 19,874 MW and 27,393 MW for the year 2025 and 2030, respectively. By comparing peak demand and 24-hour normalized load curve, a 24-hour average energy mix has been developed for 2025 and 2030.

For both reference years, two scenarios have been considered. Scenario A considers no penetration of VRE (solar PV and wind) and Scenario B reflects maximum possible VRE penetration. A summary of the assumptions used for each scenario is as follows:

- Yearly retirement and commissioning plans of different types of power plants. Relevant data were collected from BPDB,²³ PSMP-16²⁴
- Solar PV and wind as VRE replacing expensive fuel during daytime
- A minimum plant factor of 50% for coal and gas at any given point
- A plant factor of 90% at any given point for nuclear power plants
- Optimized utilization of gas-based power plants due to their low cost of generation and marginal GHG emission
- Power import plans from neighboring India
- Imported hydropower from Bhutan considered for 2030
- Both offshore and onshore wind power plants considered.

8.1. Electricity Generation Mix 2025

The PSMP 2016 puts peak load for 2025 at 18,600 MW. The energy generation mix in 2025 is graphically represented in Figure 8-1 and Figure 8-2. Figure 8-1 represents Scenario A, with no VRE penetration, while Figure 8-2 reflects Scenario B, i.e., VRE penetration into the grid replacing expensive generation from LNG- and HFO-based power plants, as discussed in Chapter 6. About 4,080 MW installed RE capacity is possible in 2025, where solar PV represents 87% of the share. Onshore wind capacity is estimated at 650 MW due to low wind potential and few projects in the pipeline. While demand is constant for both scenarios, changes in the share of LNG and HFO in total generation due to penetration of RE are shown in Table 12.

Technology	Share in total generation Scenario A (%)	Share in total generation Scenario B (%)
LNG	20.43%	19.15%
HFO	1.18%	0.52%

Table 12: LNG and HFO Share in Total Generation

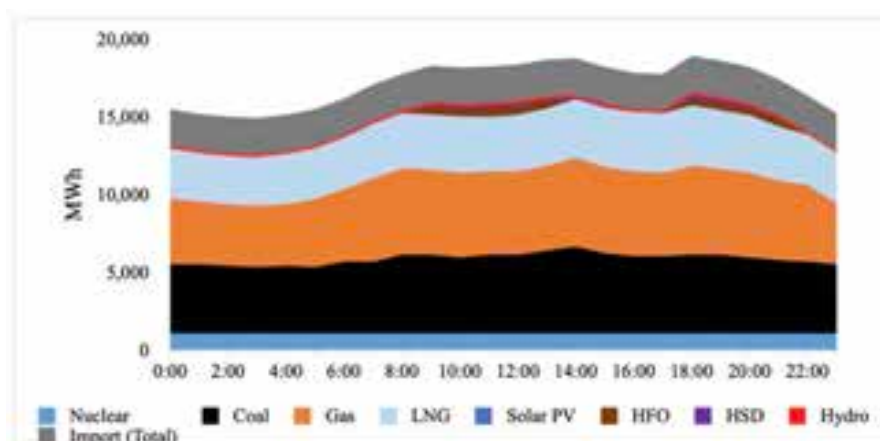


Figure 8-1: Energy Mix-2025 Scenario A (Without VRE)

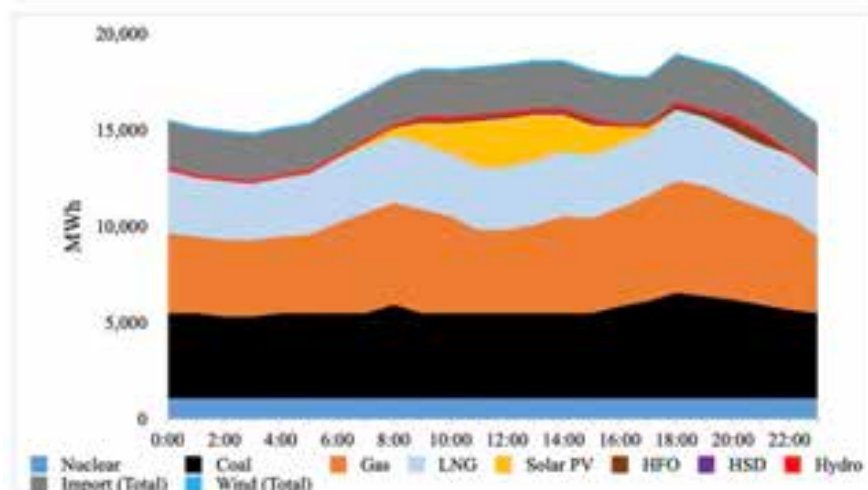


Figure 8-2: Energy Mix-2025 Scenario B (With VRE)



8.2. Electricity Generation Mix 2030

The PSMP 2016 puts peak load in 2030 at 27,393, which is 37.8% higher than that of 2025. Additional nuclear, wind, solar PV, LNG, and imported hydropower would help meet increasing electricity demand. This would allow for solar- and wind-powered generation during daytime to replace generation from costly fossil fuel-based plants like HFO, LNG, and coal, as discussed in Chapter 6. About 10,090 MW installed capacity from RE is possible in 2030, 89.8% of that from solar. An offshore wind capacity of 350 MW and an onshore wind capacity of 750 MW are possible, along with 1,000 MW of hydro power imported from Bhutan. Scenario A and Scenario B for 2030 are shown in Figure 8-3 and Figure 8-4. While demand is kept constant for both scenarios, changes in the share of coal, LNG, and HFO is shown in Table 13.

Technology	Share in Total Generation Scenario A (%)	Share in Total Generation Scenario B (%)
Coal	29.72%	27.64%
LNG	24.19%	16.91%
HFO	0.93%	0.67%

Table 13 : Coal, LNG, and HFO Share in Total Generation

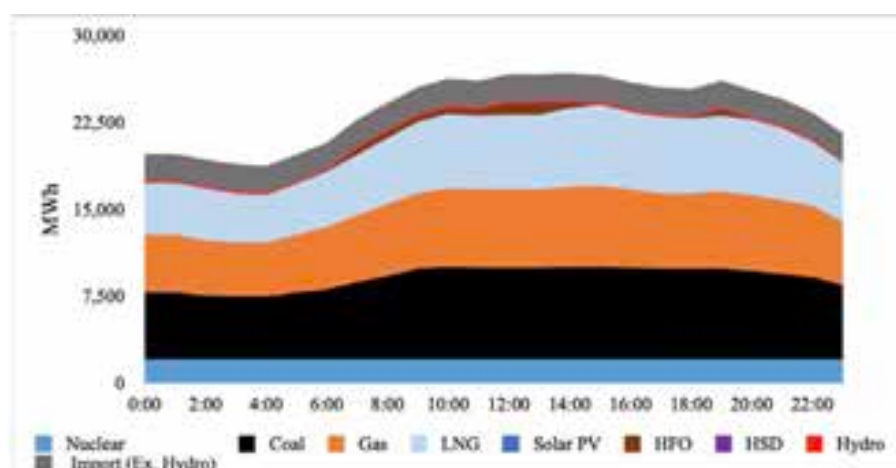


Figure 8-3: Energy Mix 2030 Scenario A (Without VRE)

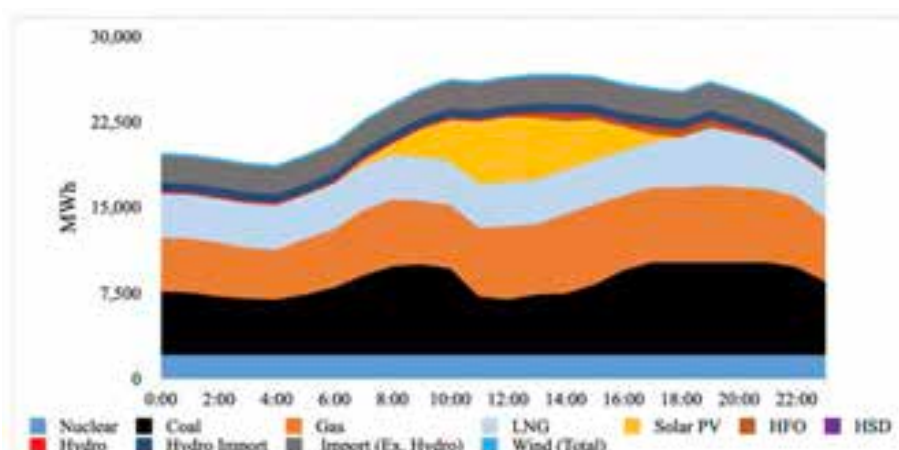


Figure 8-4: Energy Mix 2030 Scenario B (With VRE)

With a daily energy demand of 566,554 MWh and a peak load of 27,393 MW, VRE share adds up to 7.83% of total generation. Share from VRE reaches up to 6,0483 MW at 12.00 PM on a typical day, which is 24.3% of total generation at that point in time. As per Grid Integration Requirements for VRE,²⁵ electricity grids are able to withstand variability caused by VRE up to 10% of installed generation; additional financing would therefore be required to accommodate energy storage systems (ESS) into the grid to withstand the hourly and daily variation that accompanies high-level VRE penetration.

ESS could provide reliability on a MW scale. According to a Bloomberg NEF²⁶ survey the battery storage price decreased more than 50% (Figure 8-5) from 2015 to 2018. Another 50% reduction from current prices is expected by 2024.

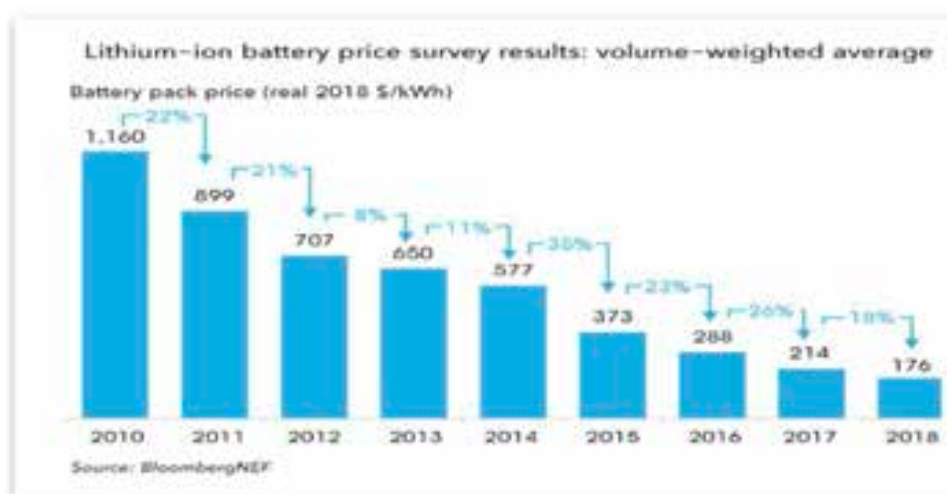


Figure 8-5: Cost Reductions for Lithium-Ion Batteries

Additional ESS requirements raise the cost of solar electricity by 8.4% and wind electricity by 5.93%, lowering their cost-saving potential.

9. Renewable Energy Share in Different Scenarios

As discussed in the previous section, the maximum attainable RE share of the energy mix in 2025 and 2030 seems to be 4,080 MW and 9,090 MW, respectively. In addition, 1,000 MW of imported hydropower could be attained in 2030. Considering these as the maximum attainable capacities, renewable share in the future energy mix 2025 and 2030 have been formulated considering the following three for scenarios:

1. Mujib Climate Prosperity Plan-Maximal Scenario (MCPM-M Scenario)
1. Mujib Climate Prosperity Plan-Realistic Scenario (MCPM-R Scenario)
2. Nationally Determined Contributions Scenario (NDC Scenario)



9.1. General Assumptions

- Bangladesh's most cost-effective RE technology in terms of resource potential is solar PV. The rapidly declining cost of solar PV technologies makes rooftop solar, grid-tied solar, solar parks, and floating solar potentially lucrative electricity solutions. Several solar PV-based projects are already operating successfully following private sector-led business models. As such, most plans for future RE-based power generation focus on solar PV. A portion of electricity generation will also come from wind energy.
- Bangladesh has seen successful deployment of several off-grid solar energy interventions, mainly solar home systems, solar mini-grids, and solar irrigation. With rapid expansion of the grid network there have been fewer opportunities for solar intervention, except in the case of solar irrigation.
- Bangladesh, being an agricultural country, has successfully deployed solar irrigation, following a private sector-led fee-for-service model. Under such a model, the private sector provides irrigation services to farmers at lower rates than are offered for diesel-run pumps, with half the pump cost supported by grant financing. Different agricultural agencies have employed other models based on partial to full grant financing. Solar irrigation pumps depend on subsidies to operate successfully. While such subsidy support has mostly been from development partners so far, the government may provide grants to ensure uninterrupted installation of solar irrigation pumps, replacing diesel-run pumps.

Notably, so far 2,000 solar irrigation pumps with a total capacity of 45 MW have been installed in rural areas and have replaced at least 15,000 diesel-run pumps.

- The prospective areas of solar PV energy deployment are solar park, rooftop solar, floating solar and solar irrigation.
- Bangladesh may also import hydroelectricity from neighboring countries because it is cheap and not variable like solar or wind power.

9.2. Potential VRE Technologies Considered in MCPP

Ground-Mounted Solar IPP

Six ground-mounted solar independent power producer (IPP) projects currently operate in Bangladesh, with a total installed capacity of 88 MW. Twenty-two more solar parks with a cumulative capacity of 980 MW are at various stages of development.²⁷ Ten non-IPP projects with a potential installed capacity of 581 MW are now under development, with financing from both development partners and the government. Several private sector sponsors and project developers with access to finance and land are also interested in implementing solar IPP projects.²⁸

The government has stipulated that solar ground-mounted projects should only be developed on government-owned non-agricultural land or privately owned uncultivable land.²⁹ On this basis approximately 5,000 MW of electricity could be sourced from solar parks by 2030, at a conservative estimate.

At least one 50 MW project could come online in 2021, while the country focuses on economic recovery from the COVID-19 crisis. Land procurement is underway for other projects. Based on the progress already made and industry experience curves, an optimistic estimate has these pipeline projects incorporated into the national grid by 2025. Given the interest of both foreign and local project developers and the government's commitment to using a portion of the reclaimed land under Delta Plan 2100 for solar power generation, about 3500 MW equivalent solar IPP projects are expected to be online by 2030, making total installed capacity more than 5,000 MW.

Solar Rooftop

Installed generation capacity from solar is 45 MW. Generation potential from rooftop solar is unlimited; the best-case estimate is 900 MW of generation by 2025 and 3,300 MW by 2030.

One estimate suggests that Bangladesh Textile Mills Association (BTMA) members and the Bangladesh Garments Manufacturers and Exporters Association (BGMEA) could make available several million square feet of rooftop space for solar generation.³⁰ According to a desk study conducted by TFE Consulting GmbH in 2017, there are about 3,639 large, 6,103 medium, and 15,666 small industries in Bangladesh, and about 3,000 MW could be generated on their vacant roof spaces or unused lands. GIZ Bangladesh estimates that about 400 MW could be generated on public buildings. Unused land or vacant roof spaces in Bangladesh's special economic zones (SEZ) could also be used for solar PV. The 3,400 MW total estimate is conservative; the country could aim far higher. A detailed and systematic government study is required to validate the potential of rooftop solar installations in Bangladesh, which could be made into an investment opportunity through corporate PPAs.

Bangladesh's readymade garment (RMG) business, the country's largest industry and the

second largest apparel exporter in the world, is gradually improving its awareness of environmental sustainability and has demonstrated a commitment to the government's climate targets. BGMEA has committed to reducing the industry's GHG emissions, signing the UN Fashion Industry Charter for Climate Action with the United Nations Framework Convention on Climate Change (UNFCCC) as a supporting organization.³¹ Producers in other industries such as poultry, pharmaceuticals, paper, mill, packaging and cold storage have shown their interest in harnessing this cheaper-than-grid electricity source.

Following the introduction of net metering in 2017, some 63 MW of rooftop solar capacity has been installed. As the country recovers from the COVID-19 pandemic, installed capacity in rooftop solar might dip in 2021 but may also return to rapid growth in 2022. International commitment to combating climate change and resulting pressure from international clients to create green footprints has motivated local industries to explore rooftop solar installations. The adoption of national targets, detailed roadmaps, and increased awareness initiatives may play a vital role in encouraging the sector. It is worth noting that India had installed rooftop solar of 1,896 MWp as of 2019 and intends 40,000 MWp installation by 2022.

Solar Irrigation

The energy requirement for agriculture is mostly for irrigation. The government is trying to fulfil the energy requirement for irrigation through electric, diesel, and solar energy-based pumps. Solar irrigation has gained popularity over the last few years because it is cheaper to operate and less harmful to people's health and the climate than diesel-based pumps. The current installation capacity of solar irrigation is around 44.5 MWp. Several organizations are involved in installing solar irrigation, mostly under IDCOL's solar irrigation program. IDCOL's installation projection considering the current market scenario is provided in the table below:

Year	2021	2022	2023	2024	2025	2026	2027	Total
Projected Installation of solar irrigation pump	500	650	845	1,099	1,428	1,856	1,988	8,366
Projected Installed Capacity (MWp)	20	26	34	44	57	74	80	335

Table 14: Installation Projection of Solar Irrigation Pump

If implemented, the IDCOL program alone could contribute 181 MWp by 2025, making the total installed capacity of solar irrigation 225 MWp, but the success of the program depends on the availability of grant financing and policy support.

The Bangladesh Rural Electrification Board (BREB) aims to install 2,000 solar irrigation pumps with a capacity of around 19.24 MWp. The Department of Agricultural Extension and Bangladesh Agriculture Development Corporation aim to install solar irrigation pumps with cumulative capacities of around 1 MWp and 16 MWp by 2022 and 2023 respectively.

With these initiatives, around 261 MWp cumulative capacity is achievable by 2025 and 540 MWp by 2030. With adequate support and cost reduction, all 1.3 million diesel pumps in Bangladesh could be replaced with solar irrigation pumps, and installed capacity from solar irrigation could be 6,000 MWp. According to a proposed roadmap report commissioned by the

Asian Development Bank, solar PV irrigation pumps could be installed in Bangladesh to replace the diesel pumps currently used, and there is scope to install around 1,000 MW of solar irrigation pumps by 2030 (Jude, Ugarte, Liu, & Mahmud, 2019).

Floating Solar

Floating solar PV minimizes the burden of land requirements. Mongla Port Municipality installed a 10kWp floating solar PV system with a net-metered connection on the surface of its water treatment plant's reservoir in 2019, the first in Bangladesh. This paved the way for many similar systems to be installed and even the development of megawatt-scale floating solar PV plants. Studies are underway for the construction of 10MW floating solar at Mongla and 50 MW at Kaptai.

Wind

A collaboration between the United States Agency for International Development (USAID) and the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) found that, irrespective of constraining factors related to the use of land, the wind general potential in Bangladesh is 30,000 MW where feasible wind speeds of 5.75–7.75 ms⁻¹ are found. However, the country still needs detailed site-specific wind mapping to understand the commercial feasibility of wind energy implementation. The government has already awarded two wind power projects with combined capacities of 90 MW to private-sector sponsors. These are a 30 MW wind power projects at Sonagazi and Feni and a 60 MW wind power project at Cox's Bazar.

Hydroelectricity

Hydropower is not viable within Bangladesh; its only hydropower source is Karnafuli Hydropower Station with a capacity of 230 MW. However by 2041 Bangladesh could import more than 10,000 MW of hydropower from South Asian neighbors, mainly Bhutan, Nepal, and Northeast India.³²

Bhutan and Bangladesh are separated by a narrow strip of Indian territory. As a result, there cannot be a direct transmission link between Bhutan and Bangladesh for delivery of electricity. In 2018, India's power ministry approved its revised Guidelines for Import/Export (Cross Border) of Electricity–2018, enabling Bangladesh to import electricity directly from Nepal and Bhutan using India's transmission lines. In an earlier version of the guideline called Cross-Border Trade of Electricity (2016), section 3.1 said that India would be able to trade electricity with neighboring countries under bilateral agreements, but did not allow neighboring countries to use Indian territory to trade electricity among themselves. The revised guideline says that two separate countries can purchase electricity from each other with India's participation or approval by way of tripartite agreements. This opens an opportunity for Bangladesh to import hydroelectricity from Bhutan. It makes financial sense to include imported hydroelectricity in the energy mix as it is expected to be cheaper than all other options except domestic gas-based generation.

9.3. Scenario 1: Mujib Climate Prosperity Plan-Maximal (MCPP-M)

The installed RE generation in Bangladesh at this moment is approximately 490 MWp. While the country has recently embraced the deflationary price trend of RE and thus aims to enhance clean energy's contribution, achieving an ambitious target in the near term might be challenging without adequate financial and technology transfer support. The successful implementation of the proposed plans will be driven by factors including but not limited to international climate commitment, political motivation, policy interventions, power planning modernization, grid modernization, availability of low-cost financing, technology transfer, a consistent cost deflation trend, private sector involvement, and ease of doing business.

Considering these uncertainties, 80% of the envisaged maximum RE share, along with the imported hydroelectricity as discussed in Chapter 7, has been set as the projected RE generation by 2030. Also, total installed generation capacity will be significantly higher in 2025 than projected in PSMP 2016, which will not leave much room for RE penetration. The generation target for 2030 has thus been set at around 8,080 MW. But should the authorities decide to replace a planned fossil fuel pipeline with more cost-effective RE and storage options, the 2030 RE target could be surpassed.

The share of solar PV, e.g., solar park, rooftop solar, solar irrigation, floating solar, etc., and wind energy in the energy mix is estimated as follows:

	Capacity in MW		Percentage of total RE Capacity	
	2025	2030	2025	2030
Utility Scale Grid-tied Solar	1,400	2,700	43%	32%
Rooftop Solar	1,100	2,600	34%	33%
Solar Irrigation	120	400	4%	5%
Floating Solar	80	300	2%	4%
<i>Installation under Solar</i>	<i>2,700</i>	<i>6,000</i>	<i>83%</i>	<i>74%</i>
<i>Installation under Wind (Onshore)</i>	<i>300</i>	<i>600</i>	<i>10%</i>	<i>8%</i>
<i>Installation under Wind (Offshore)</i>	<i>-</i>	<i>250</i>	<i>-</i>	<i>2%</i>
<i>Installation under Hydro</i>	<i>230</i>	<i>1,230</i>	<i>7</i>	<i>16%</i>
Grand Total	3,230	8,080	100%	100%

Table 15: Mujib Climate Prosperity Plan-Maximal (MCPP-M)

9.4. Scenario 2: Mujib Climate Prosperity Plan-Realistic (MCCP-R) Scenario

Considering that some environmental factors might be unfavorable, a conservative estimate on the contribution from renewables has been developed under the MCCP-R scenario. Under this outlook, the renewables share has been reduced to 44% and 50% of the maximum envisaged renewable generation as mentioned in Chapter 7 under the 2025 and 2030 timeframes, respectively. The targeted generation from RE sources under this scenario has been estimated at 2,620 MW by 2025 and 5,030 MW by 2030.

As such, the share of solar PV e.g., solar park, rooftop solar, solar irrigation, floating solar and wind energy in the energy mix is planned to be as follows:

	Capacity in MW		Percentage of total RE Capacity	
	2025	2030	2025	2030
Utility Scale Grid-tied Solar	1,100	2,000	42%	40%
Rooftop Solar	900	1,800	34%	36%
Solar Irrigation	100	300	4%	5%
Floating Solar	50	200	2%	4%
<i>Installation under Solar</i>	<i>2,150</i>	<i>4,300</i>	<i>82%</i>	<i>85%</i>
<i>Installation under Wind (Onshore)</i>	<i>240</i>	<i>500</i>	<i>9%</i>	<i>10%</i>
<i>Installation under Hydro</i>	<i>230</i>	<i>230</i>	<i>9%</i>	<i>5%</i>
Grand Total	2,620	5,030	100%	100%

Table 16: Mujib Climate Prosperity Plan-Realistic (MCCP-R) Scenario

9.5. Scenario 3: Nationally Determined Contributions Scenario (“NDC Scenario”)

This scenario considers the installed RE capacities targeted in the latest NDC commitment update from Bangladesh. The Government of Bangladesh has committed to reduce GHG emissions in three sectors: power, industry, and transport. The government will reduce GHG emissions by 5% below business-as-usual level by 2030, or by 15% below business-as-usual GHG emissions by 2030 if developed countries provide sufficient and appropriate support. In the updated NDC interim report submitted in December 2020, the Ministry of Environment, Forest and Climate Change stated more specific targets, including the installation of 1,700 MW of utility-scale solar PV power plants and 250 MW from wind sources by 2030.

In line with the targets set under the interim NDC commitment, the share of solar PV, for example solar park, rooftop solar, solar irrigation and wind energy in the energy mix is planned under NDC scenario to be as follows:

	Capacity in MW		Percentage of total RE Capacity	
	2025	2030	2025	2030
Utility Scale Grid-tied Solar	550	900	48%	41%
Rooftop Solar	200	600	17%	28%
Solar Irrigation	80	200	7%	9%
Floating Solar	-	-	-	-
<i>Installation under Solar</i>	<i>830</i>	<i>1,700</i>	<i>72%</i>	<i>78%</i>
<i>Installation under Wind (Onshore)</i>	<i>90</i>	<i>250</i>	<i>8%</i>	<i>11%</i>
<i>Installation under Hydro</i>	<i>230</i>	<i>230</i>	<i>20%</i>	<i>11%</i>
<i>Grand Total</i>	<i>1,150</i>	<i>2,180</i>	<i>100%</i>	<i>100%</i>

Table 17: Interim Nationally Determined Contributions Scenario (NDC Scenario)

All three aforementioned scenarios are presented in the following figure.

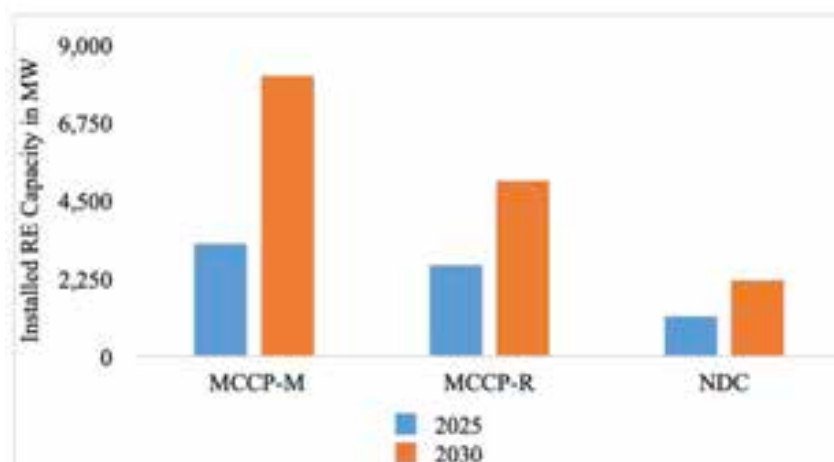


Figure 9-1: Scenario-Wise Installed RE Generation Capacity

Shares in total capacity by 2030 appears to range from 6% in the NDC Scenario to 19% in the MCCP-M Scenario. The shares range from 3% to 10% in the same scenarios in the 2025 energy mix.

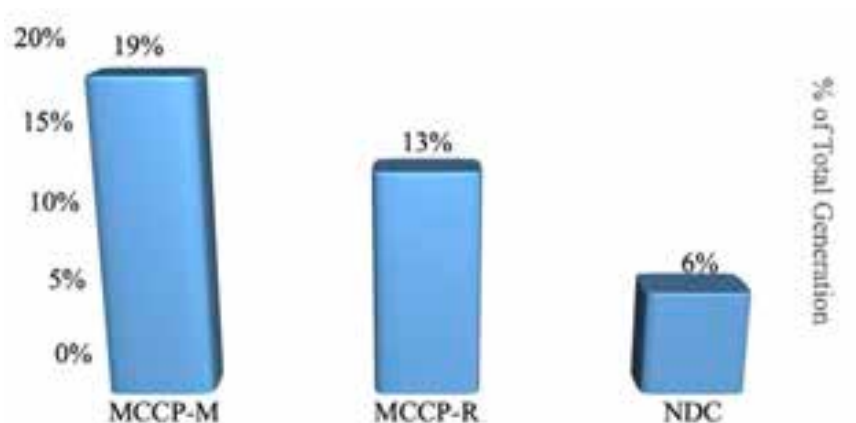


Figure 9-2: RE Share (Generation) in 2030 Energy Mix

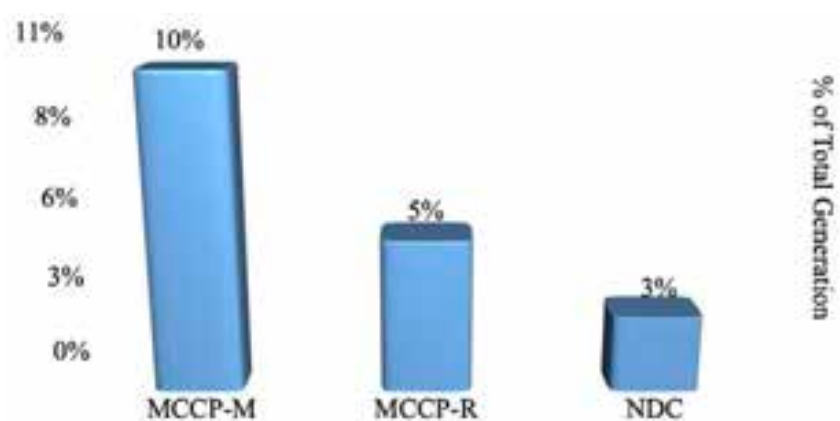


Figure 9-3: RE Share (Generation) in 2025 Energy Mix



9.6. Cost Savings

Below are some aspects of potential cost savings from the addition of VRE plants under various scenarios:

- The PSMP 2016 projected that by 2025 the cost of generation from LNG and HFO will be greater than costs from ground-mounted rooftop solar and wind projects, as can be seen in Chapter 6. Therefore, cost savings have been calculated considering the replacement of LNG and HFO by RE sources.
- The PSMP 2016 projected that by 2030, the cost of generation of coal power along with LNG and HFO will be greater than the costs from ground-mounted and rooftop solar projects. Therefore, cost savings have been calculated considering the replacement of coal, LNG, and HFO by RE sources. Projected load curves from the PSMP 2016 for 2025 and 2030 have also been considered.
- The PSMP 2016 projected 23,000 MW of installed capacity in 2025. However, according to the BPDB's annual report for 2019–2020, installed capacity will be 33,725 MW at that time. In calculating maximum possible RE penetration, projected capacity has been taken from the BPDB while projected load curve has been taken from the PSMP. To take a conservative view of higher installed capacity with a conservative load curve, only 42.97% of generated electricity through VRE will be able to replace HFO- and LNG-based generation in 2025. Remaining electricity will replace other fossil fuel-based generation.
- The PSMP 2016 projected a couple of power plants would be added from 2026 to 2030, and several would be retired. The BPDB website does not have any installation projection beyond 2025. Net capacity of the PSMP-mentioned plants has been added with the 2025 capacity projection, and the total capacity stands at 34,542 MW in 2030.
- In this case 75.29% of generated electricity through VRE (solar and wind) and imported hydroelectricity will be able to replace coal, HFO-, and LNG-based generation in 2030. If ESS with a capacity of 50% of VRE generation at peak time is considered for Scenario 1 and Scenario 2, then the adjusted net savings in 2030 will be BDT5,087 crore and BDT11,180 crore respectively.
- The majority of Bangladesh's solar irrigation pumps operate under IDCOL business model. This requires grant, loan, and equity. Under the MCP, the government could provide grants for solar irrigation using the cost savings provided by greater VRE penetration. The viability of this strategy is apparent in the following figures, which show differences in savings in 2025 and 2030 across different scenarios.

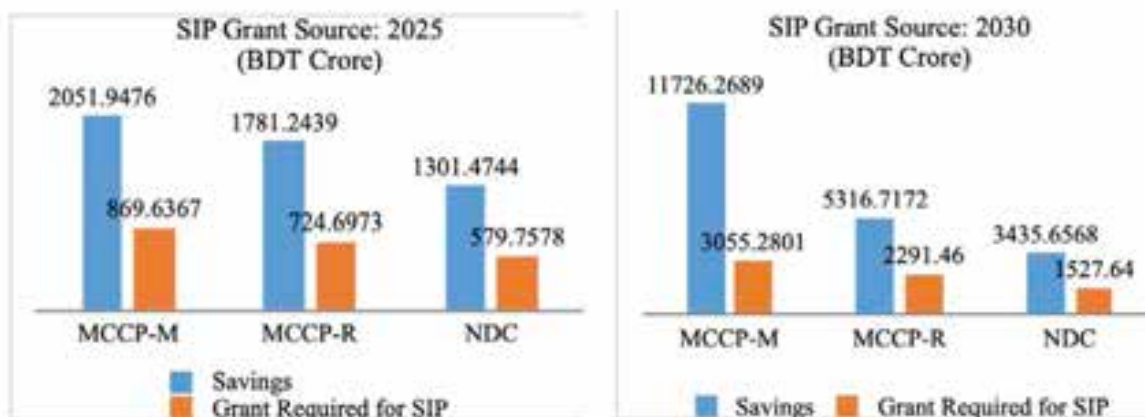


Figure 9-4: Cost Savings and Grant Requirements for Solar Irrigation Pumps

Under these conditions, predicted cost savings from RE penetration under different scenarios are as follows:

Scenario	Yearly Net Savings					
	2025			2030		
	RE Capacity (MW)	Saving (BDT crore)	Saving (USD million)	RE Capacity (MW)	Saving (BDT crore)	Saving (USD million)
Scenario 1: MCCP-M Scenario	3,230	1,228	131	8,080	8,125	774
Scenario 2: MCCP-R Scenario	2,620	1,095	117	5,030	2,796	266
Scenario 3: NDC Scenario	1,150	747	80	2,180	-	-

Exchange rate: 2025: USD 1 = BDT 94; 2030: USD 1 = BDT 105 (projecting rate inflation)

Table 18: Cost Savings under Different Scenarios

Cost savings under different scenarios are also shown in the following chart.

Some factors that may reduce cost savings, such as capacity payments and the effect of plant factor on generation cost, were not included in this calculation.



Figure 9-5: Cost Savings in Different Scenarios



10. Investment Requirements and Implementation Plan



10.1. Investment Requirement

10.1.1 Average Installation Costs of Renewable Interventions

In the proposed scenarios, solar parks, floating solar, solar irrigation, solar rooftop and wind (onshore and offshore) are identified as the prospective RE sources. Investment requirements for implementing the scenarios have been identified, considering current as well as projected installation costs for 2025 and 2030.

(a) Solar Park

The cost components of solar parks can largely be divided into three categories: (a) civil construction, land development, building and infrastructure, mounting structures, etc., (b) equipment and machinery, solar PV modules, inverters, cables, accessories, and (c) miscellaneous installation and transportation costs, preliminary costs, consultancy contingency costs and the like.

The cost of solar panels and inverters is expected to decrease gradually. Based on the prevailing rates in Bangladesh, current PV and inverter prices are estimated at US\$ 21 per Wp and US\$ 8 per Watt, respectively. According to Fraunhofer, PV and inverter prices will be US\$ 15.86 per Wp and US\$ 3.4 per Watt, respectively, by 2050 (Fraunhofer ISE, 2015). Accordingly, the year-to-year average PV price has been derived from this. All other components have been estimated to increase by a nominal 1%. The year-to-year costs per MWp of solar park appear to be as follows:

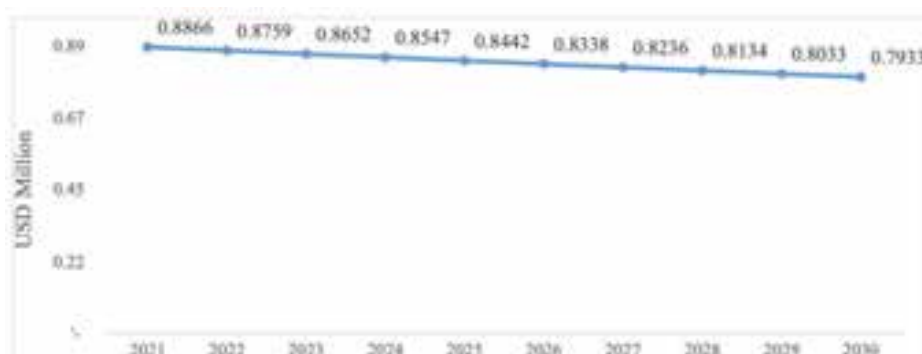


Figure 10-1: Utility Scale Solar PV (Cost per MWp in USD Million)

(b) Floating Solar

In addition to the cost components of a utility-scale solar power project, the cost components of floating solar power plants include floats and moorings. Connecting these plants to the grid is also costly because they are in remote locations.

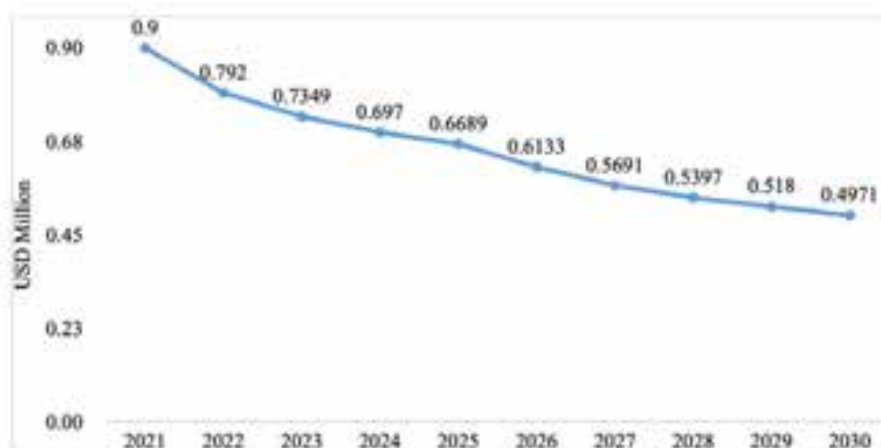


Figure 10-2: Floating Solar PV (Cost per MWp in USD Million)

(c) Rooftop Solar

The cost of rooftop solar has been derived from market price movements observed by IDCOL since 2017. Based on these, a cost trend has been developed following a learning curve model for price calculation, as follows:

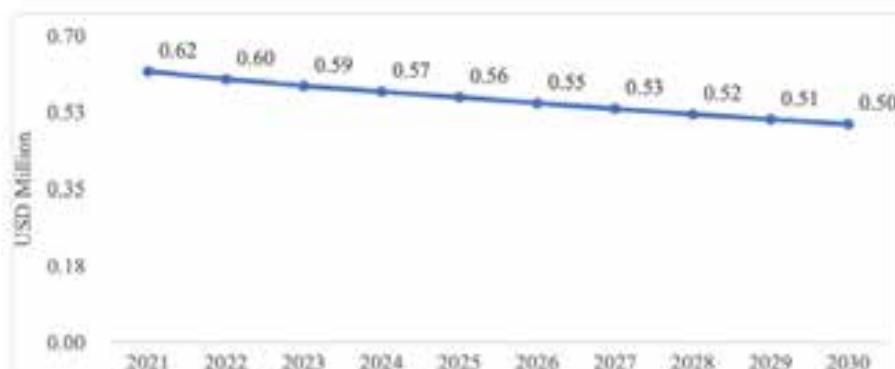


Figure 10-3: Rooftop Solar (Cost per MWp in USD Million)

(d) Solar Irrigation

The cost of pumping systems has fallen 40% since 2010. The cost of a 40-kW pumping system in 2021 is estimated at USD 50,000. Considering the decline in panel price and inflationary increase in other cost components such as pumps, controllers, boring, civil construction, buried pipeline and water tanks, the year-to-year cost of a pumping system is estimated as follows:

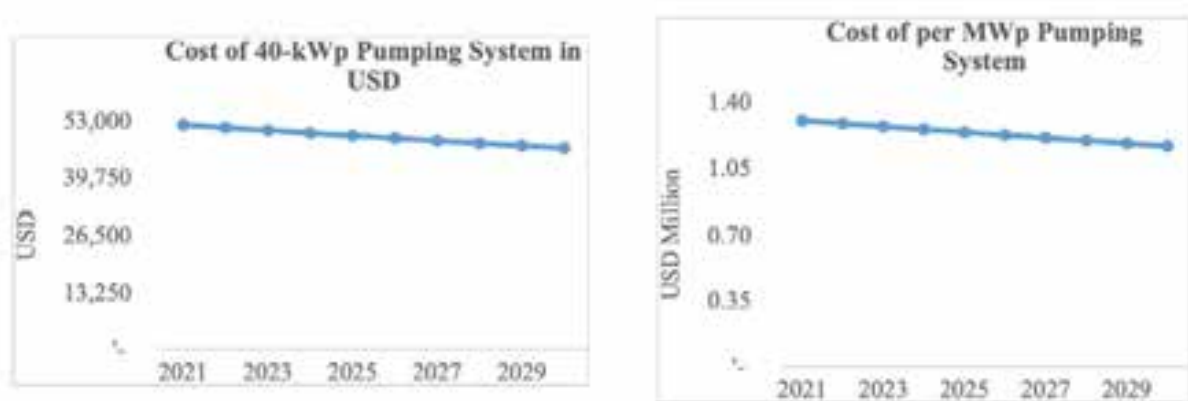


Figure 10-4: Cost of Pumping System

Assuming 40-kWp system size, cost per MWp ranges from USD 1.3 million in 2021 to USD 1.16 million in 2030.

(e) Wind

The cost of wind project installation has been derived from world market price movements. A cost trend has been developed following the earning curve model of price calculation, as follows:

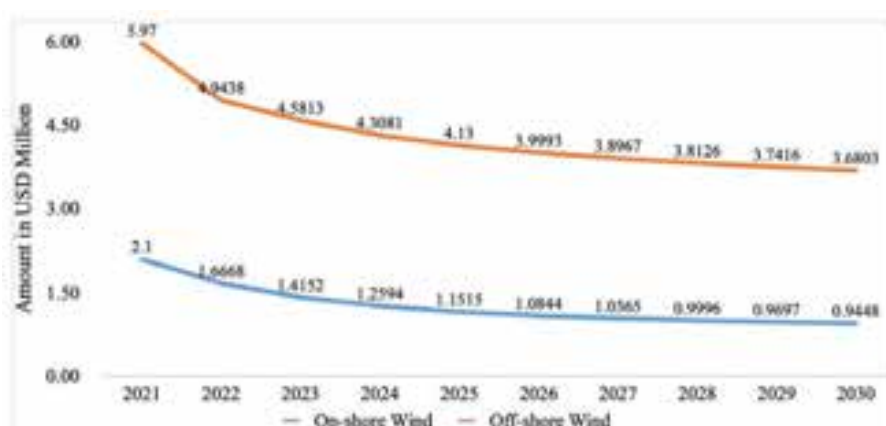


Figure 10-5: Year-Wise Wind Installation Cost per MW

The year-to-year cost per MWp for solar and the cost per MW for wind power in USD million for different renewable sources is as follows:

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Utility Scale										
Grid-tied Solar	0.89	0.87	0.85	0.83	0.85	0.83	0.81	0.79	0.77	0.79
Floating Solar	0.90	0.79	0.73	0.70	0.67	0.61	0.57	0.54	0.52	0.50
Rooftop Solar	0.62	0.60	0.59	0.57	0.56	0.55	0.53	0.52	0.51	0.49
Solar Irrigation	1.30	1.28	1.27	1.25	1.24	1.22	1.21	1.19	1.18	1.16
Wind (onshore)	2.10	1.67	1.42	1.26	1.15	1.08	1.04	1.00	0.97	0.94
Wind (offshore)	6.0	4.9	4.6	4.3	4.1	4.0	3.9	3.8	3.7	3.7

Table 19: Year-to-Year Cost per MWp for Solar and Wind (in USD Million)

Investment requirements for 2025 and 2030 are summarized below:

	Scenario 1: MCP-P-M	Scenario 2: MCCP-R	Scenario 3: NDC
Investment requirement by 2025	26,675	21,193	8,819
Investment requirement by 2030	69,664	44,002	18,720

Table 20: Investment Requirement by 2025 and 2030 (BDT Crore)



Figure 10-6: Investment Requirement by 2025 and 2030 in USD Million

It should be noted that the government does not need to make the aforementioned investment, except for partial grant support in solar irrigation. Rather, the private sector can arrange the necessary funding for the projects if the implementation plan described below is followed.





10.2 Implementation Plan

10.2.1 Solar Rooftop

The rooftop solar project will address the generation of clean energy through installation of solar PV on the roofs of or open space in industrial premises. Any type of industry will be eligible to access the facility. Solar-generated power will partially meet the requirements for grid electricity, which is presently the main source of power. In absence of grid-connected electricity, solar-generated power will mostly replace the diesel generators presently used by the industrial sectors. During periods of non-operation in factories, the generated electricity can be exported to the national grid under the net metering policy. Such projects have two business models:

(a) CapEx Model:

- The roof owner owns rooftop PV assets.
- The roof owner invests required equity and avails financing.
- The roof owner benefits from captive consumption of solar energy and lower electricity bills.
- The roof owner avails technical services from an engineering, procurement, and construction (EPC) contractor.

(b) ESCo/OpEx Model:

- A third-party energy service company (ESCo) leases roofs on which to install systems and sell electricity to the rooftop owners.
- The ESCo owns rooftop PV assets.
- The ESCo injects equity and arranges required financing.
- The rooftop owner only uses electricity and pays for electricity at a pre-agreed tariff.
- The benefit to the roof owner comes from receiving a slightly lower tariff than the grid tariff.

Considering the potential for rooftop solar projects in Bangladesh and to complement the government's objective of sourcing 10% of power generation from renewable sources, many government entities and private sector interests are participating as implementing agencies. Notably, IDCOL has set an installation target of 300 MW of solar rooftop generation by 2025 to facilitate the implementation of such projects.

Smaller-capacity projects are financed through equity investment, but large-scale rooftop solar projects are mostly financed through a combination of equity and loans. Private project companies provide the equity investment while loans are financed through local financial institutions.

The number of major energy financiers is limited in Bangladesh because it is a specialized sector. Notably, IDCOL is the largest financier in this sector with a financing structure of 80%

debt and 20% equity. The World Bank and KfW are the primary financing partners, providing USD 102 million and EUR 70 million respectively. Apart from these funders, commercial banks in Bangladesh can invest in such projects under the central bank's green financing scheme.

10.2.2 Ground-mounted Solar and Wind IPPs

Power generated from utility-scale solar PV and wind power plants will be fed directly into the transmission network of the Power Grid Company of Bangladesh Ltd. (PGCB) and will be purchased by Bangladesh Power Development Board (BPDB) from these projects for a term of 20 years under a power purchase agreement (PPA) with an independent power producer (IPP) on a commercial basis. These projects are awarded on the basis of both solicited and unsolicited proposals.

Sound land allocation is integral to ensuring the implementation of such projects. Although land constraints are a major issue for a densely populated country such as Bangladesh, the project pipeline developed for grid-tied solar projects already has land allocated for these developments. The government has decided to use only non-arable lands for solar, grid-tied, and wind projects. For proposals awarded on unsolicited basis, the project land has to be procured (purchased or leased) by the private sector itself. However, the government may also prepare a project site first and then arrange a competitive process for private sector developers to bid to build and operate a plant under a PPA.

Most of these projects are financed through the combination of equity (20%) and loan investment (80%). The equity investment is ensured by private project companies and the loan financing of such projects is largely from development finance institutions (DFI) such as the Asian Development Bank (ADB), The World Bank (WB), and the International Finance Corporation (IFC). Additionally, non-bank financial institutions such as IDCOL and other national and foreign commercial banks in Bangladesh are currently working on implementing a pipeline of grid-tied and ground-mounted projects for enhancing solar power generation in the private sector.

10.2.3 Solar Irrigation

Solar irrigation pumps require funding of at least 50% of the pump system's cost as grant support or lease finance to be competitive with diesel pumps at the front end. Remaining costs may be met by a combination of equity, concessional loans or lease finance, highlighting how necessary support from the government and development partners is for implementation. Many farmers in Bangladesh have very small plots of land and practice only subsistence farming. Others have more land and operate at an agro-industrial scale. Consequently, two distinct models may be adopted to serve the two different groups. These models are currently being followed by IDCOL, which has financed most of the pumps. The models operate on a fee-for-service or ownership basis.

Under the fee-for-service model, the project sponsor (NGO/microfinance institution/private entity) owns the irrigation pump. Farmers get a pumped water supply for an agreed fee that is significantly lower than prevailing irrigation rates using diesel pumps. The sponsor identifies farmers, selects suppliers, operates the pump, and sells water to farmers. The implementing agency provides grants, soft loans, and technical support to project sponsors. The supplier installs the pump and provides after-sales service.

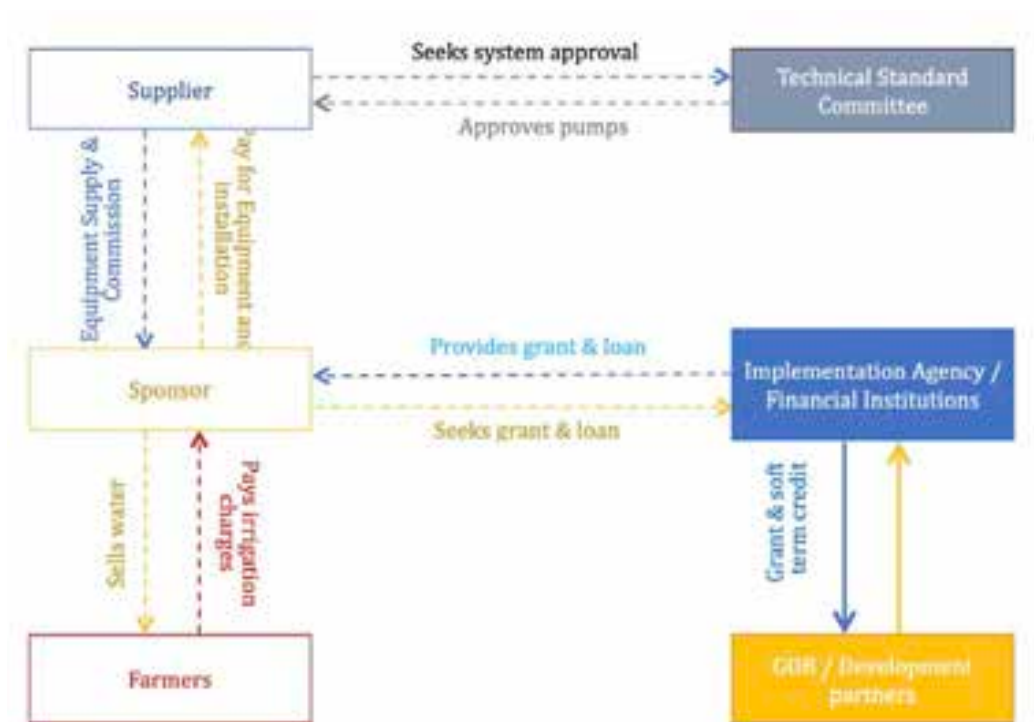


Figure 10-7: Fee-for-Service Model

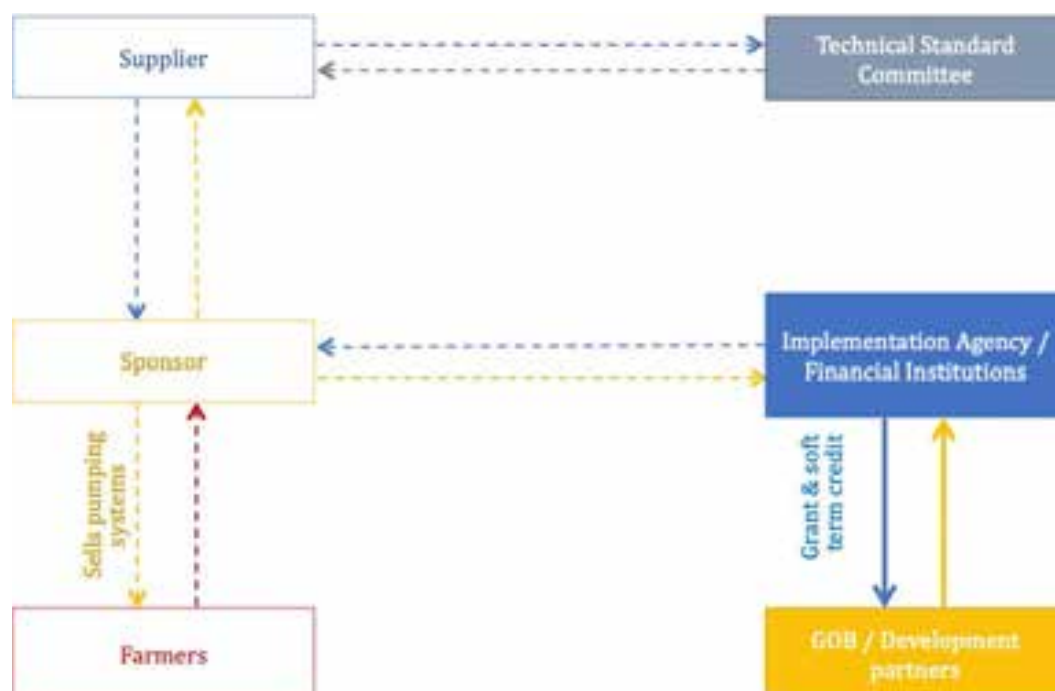


Figure 10-8: Ownership Modality

Most aspects of the ownership model are similar to a fee-for-service operation. The only major change in the nature of the arrangement is that the owner of the system will be a farmer or farmer group. The owner(s) will either create their own irrigation demand and/or serve nearby farmers as well. In this case the farmers will take a loan from the sponsor or the implementing agency while providing the full amount of the equity requirement.

Agencies participating should ensure that they have the right technical capabilities and proper organizational structure for achieving their solar irrigation pump (SIP) systems targets, along with strong technical provisions for ensuring proper operation and maintenance is guaranteed to all SIP systems. This roadmap requires programs to be managed with some level of decentralization, either through local offices, or via designated project developers working under framework conditions.

Moreover, efforts to provide valuable agricultural extension services to sustain or enhance agricultural productivity, in particular very small and small farms, should be ensured by official agencies. Agricultural extension is critical to sustain knowledge-intensive and highly productive farming. Emphasis should be placed on training in integrated farming systems, integrated pest and disease management, and technologies for soil and water conservation.

Various organizations are currently engaged in implementing solar irrigation. Among these is IDCOL which has equipped most of the projects through private sector engagement under a fee-for-service model. Other than IDCOL, organizations such as BMDA, BADCO, DAE, BREB and RDA have been also implementing the intervention using the ownership model of deploying only grant and equity financing structure.

Part of the funding could come from the government's NDC commitment. The government has said it would allocate USD 0.60 billion³⁴ for an "aggressive" scale-up of SIPs for irrigation. The government can also approach the Global Environment Facility (GEF), Green Climate Fund (GCF), or the development partners to arrange grant and concessional support.



11. Number of Jobs by 2025 and 2030

The types and number of jobs that can be generated by the renewable energy industry depends on country-specific factors. The number of jobs created varies according to the type of technology, and the place in the supply chain of the technology that a specific country occupies. According to the International Labour Organization, some specialist jobs in the solar energy sector include project designers, architects, meteorologists, resource site evaluators, environmental consultants, lawyers, developers, facilitators, land development advisors, land use negotiators, and procurement specialists (ILO, 2011). However, the number and composition of jobs changes with the evolution of technology. For example, Bangladesh featured as one of the top countries to generate employment in solar PV in 2016, owing to the proliferation of solar home systems (IRENA, 2017a). This phase in the solar PV industry has matured, and the growth sector of the future is large grid-connected power projects.

In their review of employment generation in the renewable energy sector, Myer and Sommer (2014) have shown that employment generation can be measured in terms of direct jobs, indirect jobs, induced jobs, gross jobs and net jobs. Employment generation calculation methodologies include the employment factor approach, supply chain analysis, and input/output analysis. The review found that the global employment factor in construction and installation was 11 job-years/MW in solar PV, and 0.3 jobs/MW in the operations and maintenance stage. In our analysis, we will consider the employment generation potential created at various stages of large-scale grid connected projects. We will also focus our projections on PV technology, as for the near future this is the sector with the largest proven growth potential in Bangladesh. Although the growth in PV capacity additions will come from ground mounted utility scale PV, solar irrigation, and solar rooftop, for simplicity we will consider all these modes to have similar employment creation potential. In keeping with rigorous definitions of employment generation, we will estimate job creation in terms of person-days and person-days/year. This has the advantage of accounting for some jobs which are temporary at the installation stage, and some other jobs which last for multiple years. It also does not make assumptions about the number of working hours per person.

According to IRENA, the biggest creation of jobs in the solar PV supply chain is in the installation stage and the operations and maintenance (O&M) stage of a project. It estimates that a 50 MW project requires 229,055 person days, where the distribution of the human resource requirement is given in the following Figure 11-1 (IRENA, 2017b). Although the number of people in the O&M stage is not high, it lasts throughout the project lifetime, whereas the other stages are temporary.

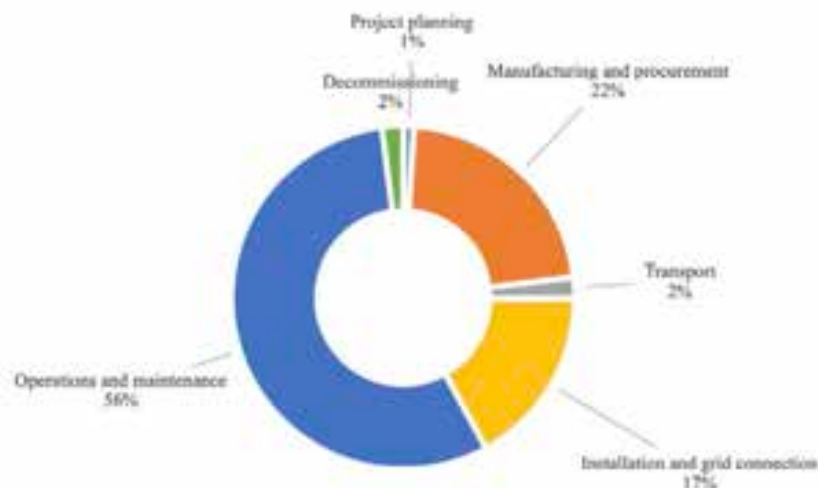


Figure 11-1: Estimated Share (%) of Human Resource Requirement during the Lifetime of a PV Project of 50MW

Within the high employment segment of the supply chain, the installation and grid connection, the biggest employment share occurs in the construction and installation stage, which takes up 90% of the human resource commitment. Figure 11-2 below shows the breakdown of human resources in this stage.

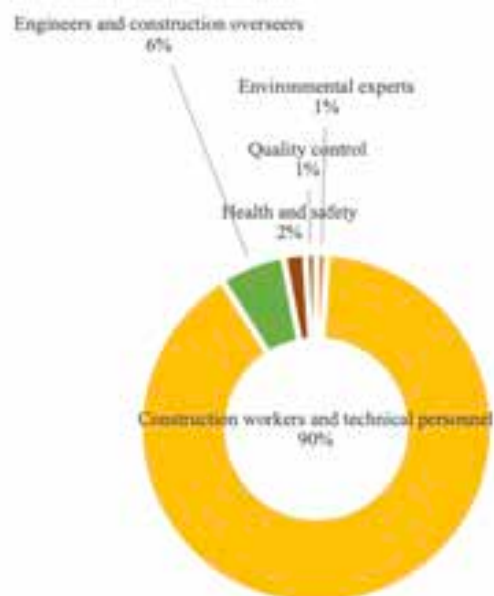


Figure 11-2: Distribution of Human Resources Required to Install and Connect a 50MW Solar PV plant, by Occupation

The next highest employment occurs in the operations and maintenance stage. This is the stage where long-term employment is created within projects, whereas in the previous stages, temporary work was created. For this reason, we express employment creation in this phase in terms of person-days per year.

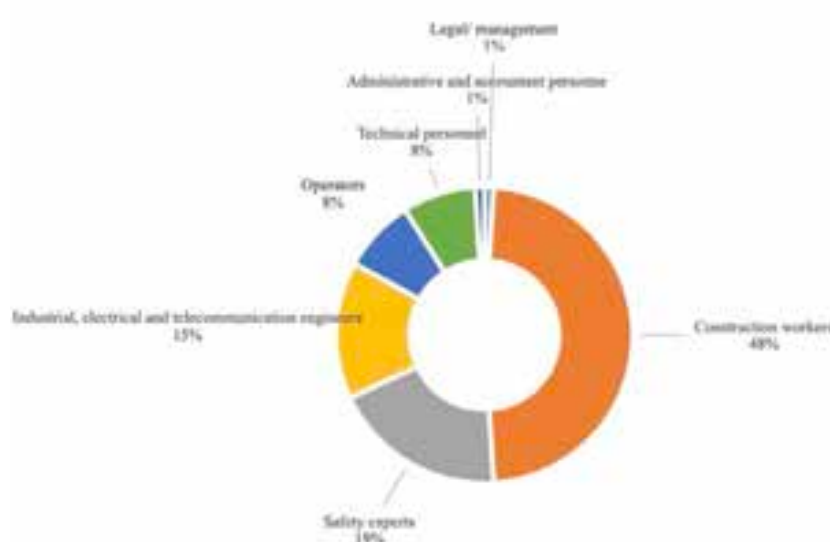


Figure 11-3: Distribution of Human Resources Required to Operate and Maintain a 50 MW Solar PV plant, by Occupation

Based on the above estimates, we can project employment creation in the grid-connected solar PV industry in the following table, according to the installed capacities of the different scenarios.

Scenario	MCCP-M		MCCP-R		NDC	
Year	2025	2030	2025	2030	2025	2030
Capacity (MW)	3,230	8,080	2,620	5,030	1,180	2,180
Temporary jobs	9,784	24,476	7,937	15,237	3,574	6,604
Permanent jobs	3,369	8,428	2,733	5,247	1,231	2,274

Table 21: Summary of Total Job Creation in the Three Scenarios up to 2025 and 2030



12. Reduction in Imported Fossil Fuel and its Effects on Trade Balance, External Trade Account

12.1. Macroeconomic Impact of Fossil Fuel Utilization in Bangladesh

The prices of fossil fuels significantly affect the wealth of importing and exporting countries. When prices rise, producer countries see their currencies appreciate and their current account balances improve, whereas importing countries face the opposite scenario (Krugman, 1983). Oil shocks have been influenced macroeconomic indicators since the 1970s, stemming from wars in oil producing countries, oil cartels, embargoes, and other consequential events. These oil shocks can cause inflation or recession and undermine total factor productivity, consumption, and investment (Barsky & Kilian, 2004).

Demand and supply shocks can affect a country's trade balance, current account, capital gains and net foreign assets, which in turn influence asset valuations there (Kilian, Rebucci, & Spatafora, 2009). As an oil importing country, Bangladesh is sensitive to oil supply and prices. Although it had historically produced fossil gas for local consumption in electricity production, the fossil gas reserves are declining, even as demand increases. Bangladesh will therefore have to rely increasingly on imports unless it invests in renewable energy capability. This section analyzes the historical expenditure on fossil fuel imports in Bangladesh and the effect this has had on trade balance, current account balance, foreign currency reserves, and inflation. This analysis illustrates how these effects can magnify if oil imports increase, and how investing in renewable energy can mitigate such impacts.

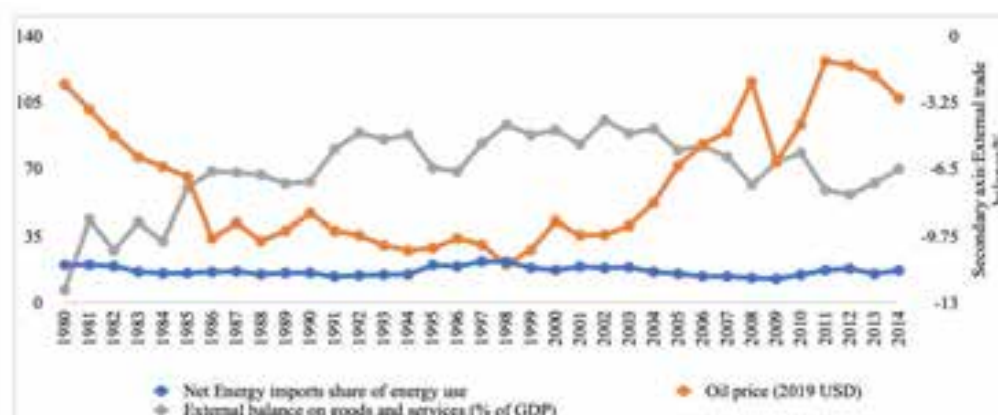


Figure 12-1: Trends of Oil Price and Energy Imports with External Trade Balance



12.2. Impact of Fuel Imports and Oil Price on External Trade Balance

Bangladesh's external trade balance has been steady as a percentage of GDP, but fluctuations in the oil price or the cost of energy imports can disrupt it (Figure 12-1).

In order to assess the effects of fuel imports on the external trade balance, we examine the effect of net energy imports as a share of energy use and the oil price in the external trade balance. We summarize the results of our analysis below:

Net energy imports in themselves do not have a significant impact on the external trade balance, although there is a non-significant negative effect.

Oil price is a highly significant predictor of the external trade balance. A one dollar increase in oil price decreases the external trade balance by 0.05%. This is a relatively small but significant impact.

Impact of Fuel Imports and Oil Price on Annual Inflation Rate

We have analyzed the impact of energy imports and oil prices on inflation. The results of our analysis are summarized below:

- Energy imports are not a significant predictor of inflation in Bangladesh, although they do have a positive, non-significant effect.
- Oil price changes do have a positive and significant impact on inflation. A one dollar increase in oil prices increases inflation by 0.087 percentage points.

Impact of fuel imports and oil prices on the consumer price index (CPI)

The CPI or consumer price index represents the average price of a basket of consumer goods, and tracks changes in the cost of living in a country. For Bangladesh, 2010 is considered the base year for CPI, and the base value is 100. The detailed results are in Table 4 in the appendix. The summary findings are as follows:

-
- Energy imports are a marginally significant predictor of CPI. A 1% increase in energy imports increases the CPI by 0.4 points.
- The oil price is an insignificant predictor of CPI. A one dollar increase in oil prices increases the CPI by 0.058 points.

Impact of Fuel Imports and Oil Price on Total Reserves

In addition to the external trade balance and inflation, energy imports and oil prices also affect the national reserves. Here we present the effect of fossil fuel use on the national reserves.

- Energy imports have a significant and sizable effect on total reserves. Increasing the import

share of energy by 1% decreases the reserve capacity by the equivalent of 0.26 months of imports.

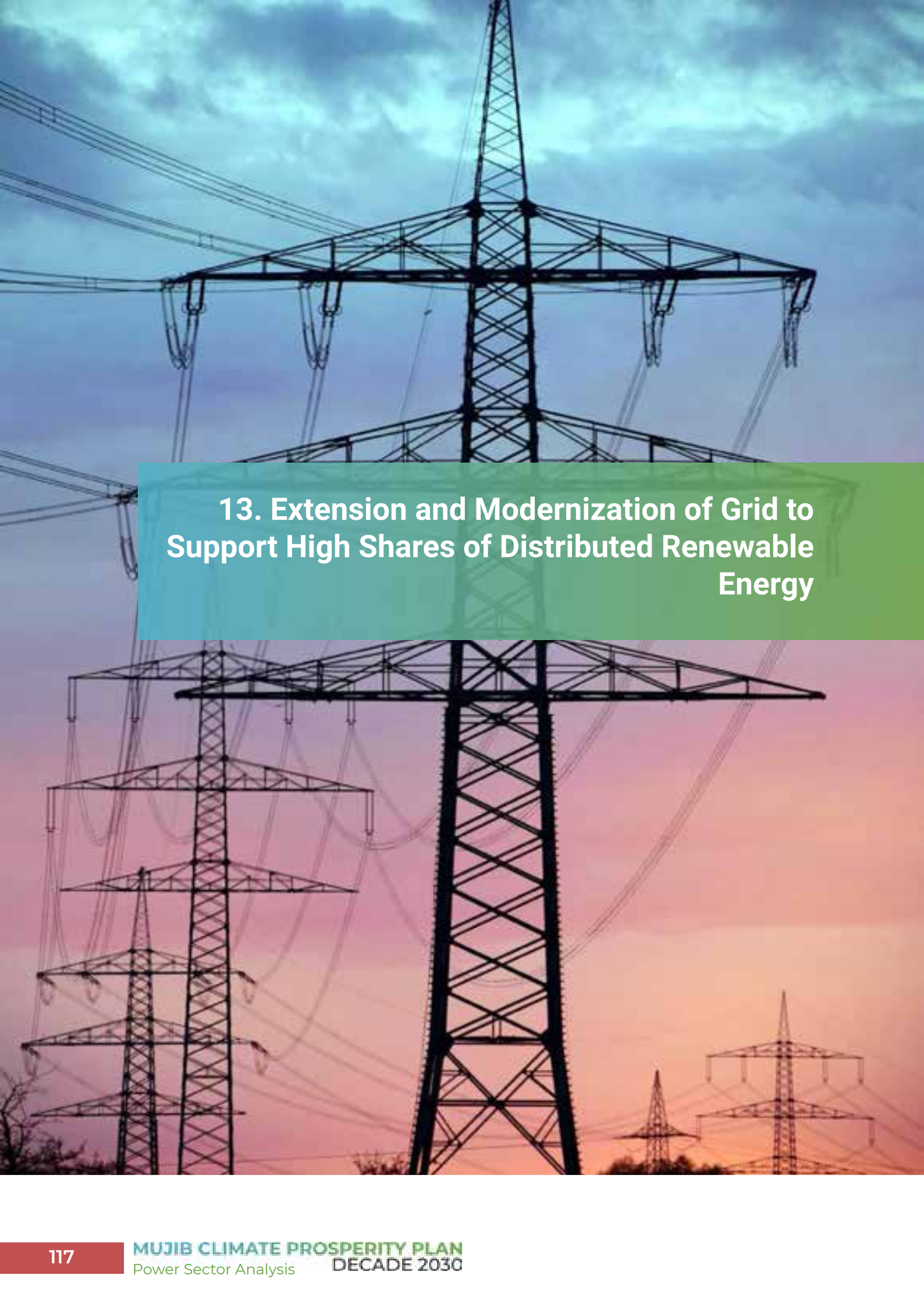
- Oil price increases also have a negative effect on reserves but is not a significant predictor.

Impact of Fuel Imports and Oil Price on the Current Account Balance

Energy imports also can have an impact on the current account balance. We have tested the effect of oil price and energy imports on this, and from the analysis we can gather the following interpretations:

- Net energy imports as a share of energy use have a highly significant impact on the current account balance as a share of GDP. A 1% increase in net energy imports reduces the current account balance by 0.28%.
- Oil prices also have a significant impact. A one dollar increase in the price of oil decreases the GDP share of the current account balance by 0.02%.





13. Extension and Modernization of Grid to Support High Shares of Distributed Renewable Energy

13.1 The Benefits of Extension and Modernization of the Grid

Transmission planning is a key control lever that the Ministry of Power, Energy and Mineral Resources can use to influence the grid's capacity and prioritize domestic renewable energy sources. Mapping the grid and understanding the implications of new technologies is crucial because grid investment shapes future options, and grid investment can also become stranded (or non-performing) if it fails to anticipate new more cost-effective generation strategies. Moreover, using software can improve grid governance in terms of the way in which cost-effective renewable energy and storage is prioritized.

1. High shares of renewable energy	2. Increased installation of storage technology	3. Increased distributed energy resources
<i>Through climate finance investment in . . .</i>		
1. Infrastructure	2. Software (e.g., Advanced Distribution Management System software applications)	3. Training programs that include use of grid modernization software applications, strategies for advanced electricity distribution planning methods and tools, with a focus on emerging grid modernization technologies and deployment of distributed energy resources.
<i>Towards the delivery of . . .</i>		
Flexibility through cost reductions associated with forecast errors and/or reductions in price spikes	Resilience to be able to adapt to changing conditions such as a set of defined hazards	Affordability to not exceed a customer's willingness and ability to pay
Flexibility to be able to respond to economic variabilities and take advantage of new technology development	Sustainability to reduce health and environmental costs	Security to prevent external threats and malicious attacks including reliance on unstable or volatile supply
Reliability to maintain delivery of electricity services, quality of power, and reduced interruption by distribution systems		

Table 22

A modernized grid would aim to increase flexibility to integrate new opportunities in the form of a new ancillary services market (refer to Figure 11-1) for ramping products and fast frequency response by batteries. New market participants could offer ancillary services such as wind turbines providing inertial response, solar PV and utility-scale storage providing voltage support, and distributed energy resources (DERs) providing frequency and voltage control. Moreover, there are more cost-competitive system options for balancing renewable energy on a cost-competitive basis that involve far less risk than potentially stranded fossil fuel plant assets in a time of energy transition.

Ancillary service	Product	Description	Typical response time
Frequency regulation	Primary regulation	The automatic local regulation provided by generating unit speed regulators. This level of regulation sustains frequency levels, preventing large deviations from the scheduled value. Innovations: - Fast frequency response is a new product designed to remunerate the provision of fast response. Batteries are great providers of such services, creating the possibility of additional revenue streams for battery operators/owners. - Wind turbines can provide inertial response through power electronic converters. - Photovoltaic (PV) installations, direct current systems and batteries can also provide synthetic inertial response if the inverter is programmed to do so. However, as inverters are not stuck with characteristics of large spinning masses and have more options to provide system stability, this might not be the best use of them. - If regulation allows, DERs can provide this service.	Sub-seconds to seconds
	Secondary regulation	The automatic regional regulation provided by automatic generation control (AGC), which sends signals from the control centre to certain generators to re-establish the nominal frequency value and restore the primary reserve capacity. • If regulation allows, DERs can provide this service.	5–15 minutes
	Tertiary regulation	The manual regional regulation provided by generating units and controlled by the system operator.	>15 minutes
Non-frequency regulation	Voltage support	The injection of reactive power to maintain system voltage within a prescribed range. Innovations: - Voltage control through reactive power provided by resources connected to the power system through inverters, such as solar photovoltaic and battery storage. - If regulation allows, DERs can provide this service.	Seconds
	Black start	The ability to restart a grid after a blackout.	Minutes
	Innovations: • Ramping products	Fast ramping resources that can respond to large net load variations in a short time. This product properly remunerates the fast ramping capability of generators and incentivises flexibility.	Minutes

Figure 13-1: Types of Modernized Ancillary Services and Associated Products³⁵

Modernizing the grid will integrate cost-effective renewables and improve efficiency in fossil-fueled generation, which will lower demand for gross generation as wastage is reduced. The power sector in Bangladesh has reduced its transmission and distribution losses successfully over a period, but this rate of improvement has slowed, leading to some inefficiencies in the system (Figure 13-2). Improved transmission and distribution loss reduction can lower overall consumption of fuel, ensure better collection of electricity payments from customers, curb pilfering of electricity, and lower administrative costs.

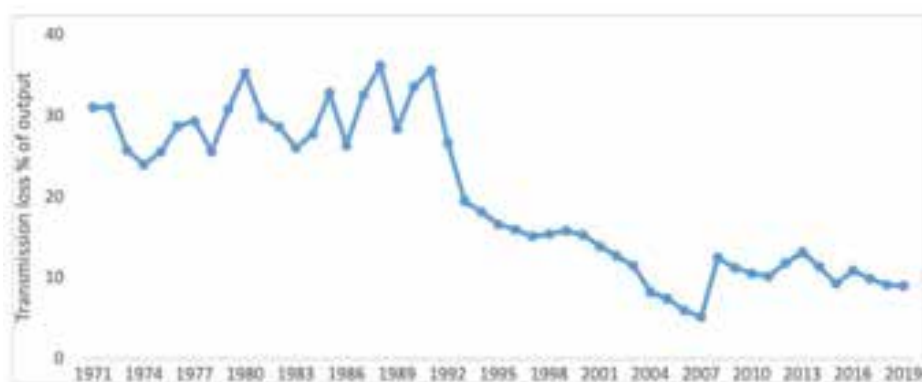


Figure 13-2: Reduction in Transmission and Distribution Loss in Bangladesh (% of Generation)
(Source: World Bank country database and BPDB annual reports 2015-16 to 2019-20)

Grid upgrades will improve flexibility and reduce congestion and curtailment, which in turn will reduce the number of plants needed to secure the grid. It will also reduce reserve requirements and lower prices (IRENA, 2019). Experience from Bangladesh has already shown that weak grid infrastructure can cause loss of generation in existing renewable energy solar photovoltaic (PV) power plants. This occurs due to frequent tripping of the power line demanding several hours of maintenance time during sunlight hours. These grid outages, rather than the efficiency of the solar panels or the level of solar radiation, causes the decline in productivity. Transmission lines in Bangladesh are also vulnerable to damage during periods of heavy rain and storms. Problems with grid and transmission infrastructure have been identified as the leading cause of low productivity in existing PV plants in Bangladesh, which can potentially cause losses for the plants or increase idle capacity payments for the government (Chowdhury & Aziz, 2020).

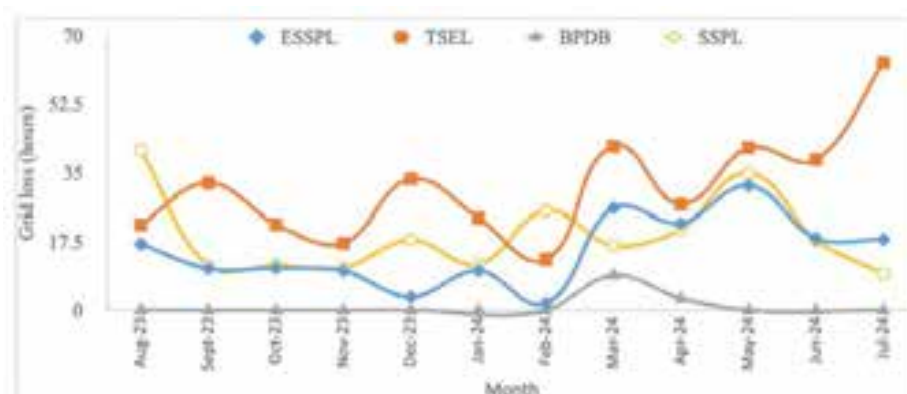


Figure 13-3: Recent Monthly Outage Hours of Grid-tied Ground-mounted Solar PV Projects in Bangladesh (Data collected from the plants by the authors)

A performance evaluation of the first four grid-tied and ground-mounted PV power plants in Bangladesh—Engreen Sharishabari Solar Power Ltd. (ESSPL), Technaf Solar Energy Ltd. (TSEL), BPDB plant at Kaptai and Sympa Solar Power Ltd. (SSPL) —found that the quality and capacity of connecting substations had a massive impact on the productivity of the plant. Figure 13-4 shows that all the plants except the BPDB plant at Kaptai have regular and high hours of outage per month. This is because only the BPDB plant is connected to the Kaptai 11 kV substation, which is directly linked to the Kaptai 132 grid substation by a 20 MVA, 132/11 kV transformer. The substation is only two kilometers away from the solar power plant. Conversely, the TSEL plant at Teknaf, Cox’s Bazaar, feeds its generated power to the BREB Nhila 33/11 kV substation, which is connected to the Cox’s Bazaar 132/33 kV substation by a single circuit 33 kV transmission line of around 70 km. This plant is affected by the frequent low voltage and frequent grid outage due to faults and the high maintenance needs of this long transmission line. The SSPL plant at Tetulia, Panchagarh is connected by the Panchagarh to Tetulia 40 km long 33 kV grid line, which trips and is closed for maintenance for a few minutes to a few hours on most days.

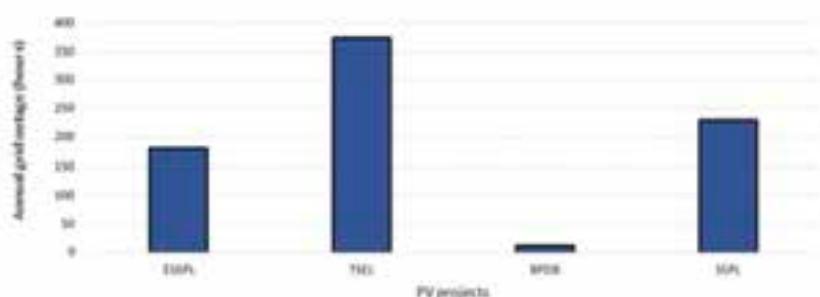


Figure 13-4: Average Monthly Grid Outage Hours per PV Plant from August 2019 to July 2020 (Authors’ calculations)



13.2. Investment Size of Grid Upgrade and Modernization

According to the International Energy Agency, integration of VRE occurs in six different phases. Each phase depends on the degree of VRE penetration into the grid and requires different measures to support system flexibility (IEA, 2020). In phase one, the system has very low levels of VRE inclusion, up to a few percent, and VRE has no immediate impact on power system operation. In phase two, VRE has a minor to moderate impact on system operation, and some minor changes to the operating patterns of the existing system are enough to accommodate this VRE. In phases 3 through 6 there are higher shares of VRE and more investment in flexibility is needed. This requires structural surpluses of VRE generation which causes curtailment. There will also be structural imbalances in energy supply at seasonal and inter-year periods requiring sector coupling.

At present, Bangladesh can be said to be in phase 1. However, in the coming decade, the power system will move on to phase 2 and at most phase 3. In these phases, issues include random fluctuations in power demand, increasing demand after sunrise or rising net load at sunset. These issues can be addressed by short-term frequency control and changes in the supply/demand system regulation. The costs of integration of VRE into the grid include grid infrastructure costs and system operation costs. According to a study by IRENA, at a 10% increase in the share of renewable electricity an increase in reserve capacity of 1.5% to 4% of the installed VRE capacity is needed.

Grid upgrading costs are also estimated to be EUR 0.5-3.0/MWh for a 20-30% electricity share, and grid connection costs can amount to 0-5% of total project cost. The costs due to reduced utilization of plants constitute the highest cost at VRE penetration levels of 30-40% but can be zero or even negative at low levels of VRE penetration (IRENA, 2015). To achieve the Paris Agreement climate targets, the investment in grid upgrades could be equal to the investment in generation capacity up to 2050 (IRENA, 2020b). However, in the case of Bangladesh in the coming decade, we consider the chief additional costs likely for the projected levels of VRE generation to be reserve capacity costs, grid upgrading costs, and grid connection costs. The storage investment discussed in the previous section will provide added grid integration support. The table below shows estimates of projected costs to be incurred for grid integration of VRE for the coming decade.

Installed capacity(MW) in 2030		8,080	5,030	2,180
Generation (MWh)		12,604,800	7,846,800	3,400,800
Projected investment in installed capacity (Million USD)		6,640	4,194	1,784
Grid connection cost (Million USD)	5% of project investment	410	259	110
Grid upgrade cost (Million USD)	up to 3.6 USD per MWh	45	28	12
Profile cost	Negligible for projected levels	NA	NA	NA

Table 23: Cost Components of VRE Grid Integration up to 2030 (Monetary figures are in million USD) (Authors' calculations)



13.3. Investment in Storage

Storage investment is driven by several factors, notably an intent to bring down transmission charges and promote grid resilience. Battery storage can be used to provide firm renewable power. Specifically, a storage system can address the variable nature of solar and wind power, which is not always available when needed, or is produced in quantities that cannot be fully used at a particular time. Globally, primary applications for storage include the integration of renewable energy, ancillary services, micro-grids, telecommunications, and railways. Firming up renewable energy with storage, which is also seen today, can meet peak system need and economically displace and replace peaking plants that burn imported gas. Figure 11-5 illustrates battery storage uses and combinations, as outlined by the US Department of Energy's SHINES program, part of a modernization initiative to improve the resilience, reliability, and security of the power grid.³⁶

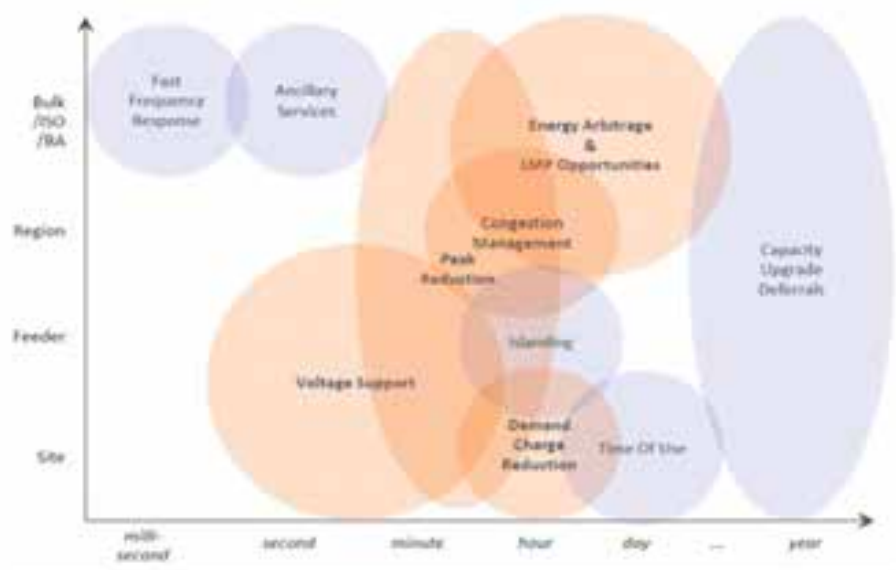
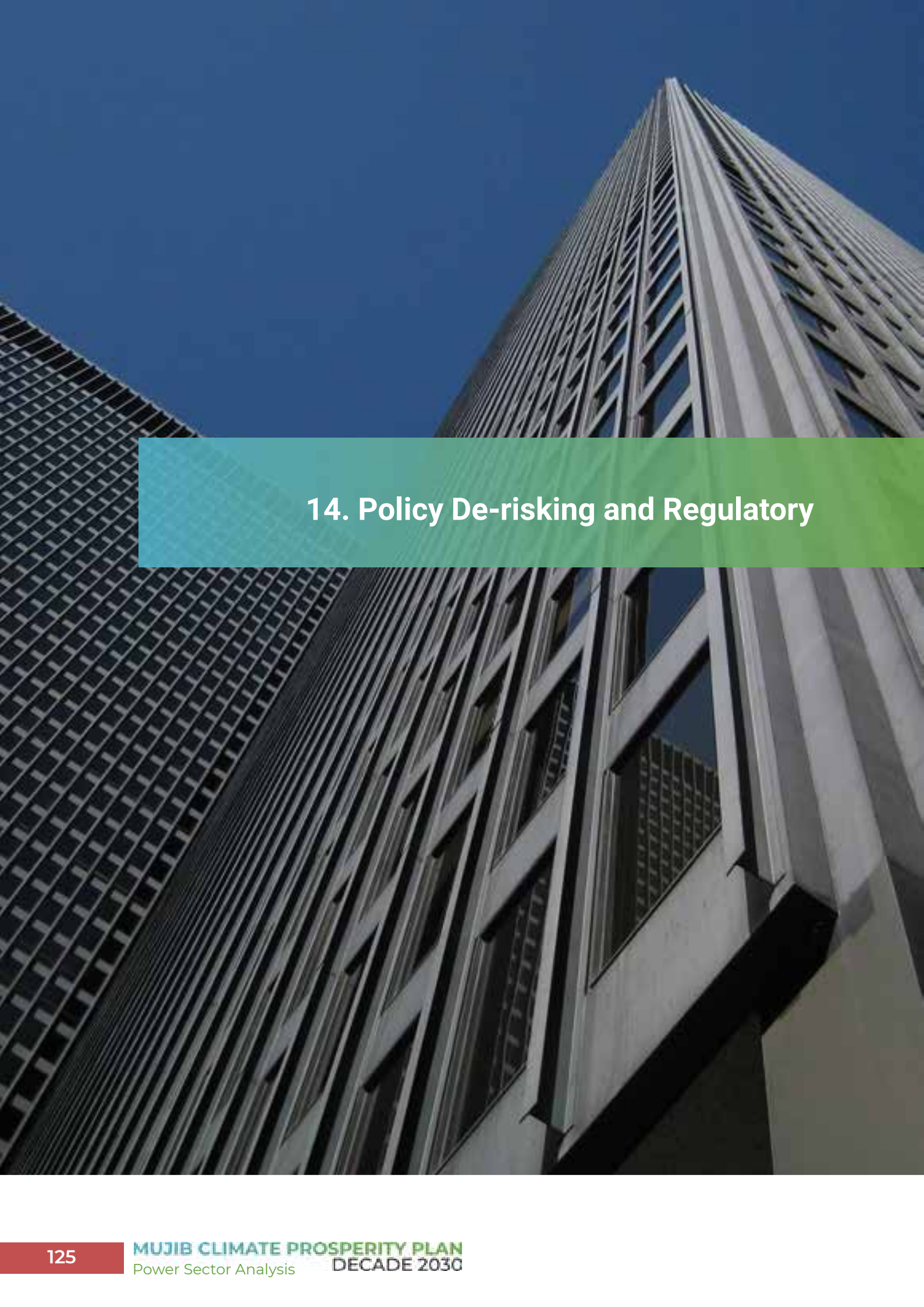


Figure 13-5: Potential Battery Storage Uses and Combinations
(Source: United States DOE's SHINES program)



14. Policy De-risking and Regulatory

14.1. Overview of the De-risking Renewable Energy Investment Methodology

This analysis follows the methodology set out by UNDP, in the report entitled “De-risking Renewable Energy Investment: A Framework to Support Policymakers in Selecting Public Instruments to Promote Renewable Energy Investment in Developing Countries” (Waissbein, Glemarec, Bayraktar, & Schmidt, 2013). In this research, a series of stakeholder meetings is conducted with participants in the Bangladesh power sector, including investors, financiers, and government organizations. Sixteen project developers and four financiers, from both local and multilateral development banks were surveyed. The findings of the survey were used to provide inputs into the de-risking model, which provided the resultant levelized cost of energy 2020 (LCOE) in the business as usual (BAU) scenario and the post de-risking scenario. The BAU assumptions were derived from assumptions in the Power System Master Plan 2016 (Power Division, 2016), and the BPDB annual Report 2019-2020 (BPDB, 2020). The assumptions for the de-risking scenario are based on the Mujib Climate Prosperity Plan Maximal scenario.



14.2. Sampling and Data

The data of the financing cost waterfalls used in the modeling comes from a number of structured, quantitative interviews with solar PV investors and developers. In the interviews, the investors shared their identity and responsibilities in the origination. The interviews and processing of data followed the methodology described in the UNDP report, where each investor scores each risk category according to the probability of risk occurrence and the consequent financial impact.

The investors and developers also assigned a score to the effectiveness of some proposed public and financial instruments to address each risk category. Information about the cost of equity and debt was also collected from the financing organizations. Information about capital structure, loan tenor, and tax rate was obtained from the Power Division, Ministry of Power, Energy and Mineral Resources and IDCOL. Interviewees were briefed about the subject of the interview and provided with a questionnaire. The qualitative aspects of the investment risks were discussed with them, and their feedback was obtained. Interviews and discussions lasted between 30 to 40 minutes. A survey of the German experience was done for an investor because Germany is considered to be the best-in-class country according to the UNDP report. Germany was also analyzed because it has the best score for renewable energy regulatory frameworks, according to Regulatory Indicators for Sustainable Energy (RISE, 2021).



14.3. Assumptions about Risk Modeling

Equity investors in renewable energy typically have greater exposure to development risks. This modeling uses the full set of nine risk categories for equity investors. The ‘permits risk’ and ‘financing risk’ categories are removed for debt investors, assuming that banks will have prerequisites, such as having licenses and equity financing in place, before considering a funding request. Grid transmission risk is also not relevant to debt providers. As such, the modeling uses six risk categories for debt investors. Germany serves as the baseline –the left-most column of the financing cost waterfall. The risk environment stage (Stage 1) differentiates between the answers from equity and from debt investors and assumes the use of solar PV technology.

In order to apply the DREI methodology, some simplifying assumptions were made. This was to keep calculations simple and because of the absence of clear or concrete data on certain values.

- **Variability.** Although solar PV is a variable renewable source, this analysis does not include any extra costs for balancing supply and demand. The overall model assumes that the total share of renewables in the grid will be within limits where balancing will not be a major issue, and significant costs will not be incurred.
- **Transmission lines.** This analysis assumes that transmission infrastructure is available within 10km of the solar PV project site, and significant grid interconnection costs need not be incurred. In practice, some additional capital expenditure may be required in order to accommodate some projects, depending on the final choice of location of the project sites.
- **Baseline costs.** Renewable energy investments are made in the context of an existing or evolving (with new installed capacity coming online) electricity generation mix. Bangladesh’s energy demand is projected to grow, and so the newly installed renewables capacity will compete with existing fossil fuels, and upcoming fossil and nuclear generation. Therefore, the modeling takes a combined baseline approach (50% build margin, 50% operating margin) to estimating the baseline costs, assuming new plants take the form of combined cycle gas turbine (CCGT) technology, coal, HFO, nuclear, and small amounts of HSD. Private-sector financing costs are used in the build margin share. This reflects an assumption that Bangladesh is seeking to attract private sector investment irrespective of the energy technology. The chief difference between the build and operating margins in the baseline scenario is that in the build margin, significant coal capacity is to be added, as well as nuclear. The emission factors are a weighted average of the different fuels and technologies in the energy mix.
- **Unsubsidized baseline fuel costs.** The fuel costs were obtained from the model default in the DREI Excel tool. These fuel costs are unsubsidized. Although the power plants can purchase some fuels at a subsidized rate, the country overall has to pay for the subsidies to the power sector. However, a breakdown of fuel and plant subsidies is outside the scope of

this modeling.

- Installed costs and O&M costs of solar PV. These costs are obtained from data regarding recently completed projects or projects under construction. However, the installation cost of solar PV has been falling steadily in Bangladesh, and the cost of solar rooftop is even lower, as the value of land is excluded from the project cost. However, a conservative estimate of USD800,000/MW of installed capacity is considered, which in reality could be lower for some projects, and is likely to fall further in coming years.



14.4. Cost of Capital Assumptions

While in the sample country case studies of de-risking renewable energy investments for Belarus, Lebanon, Kazakhstan and Tunisia, the authors use the risk-free rate and country risk premium method, in the case of Bangladesh, the existing financing facilities for this type of project are the benchmarks for the cost of equity and debt (Table 24). The cost of capital assumptions for Germany come from interviews with investors in Germany.

Assumption	Value
Cost of debt of best in class country	2%
Cost of equity of best in class country	8%
Cost of debt in Bangladesh	6%
Cost of equity in Bangladesh	15%

Table 24: Cost of Capital Assumptions

14.5. Description of Risk Environment

Data for stage one (risk environment) of the modeling were gathered from interviews of 16 project developers and four financiers, through telephone conversations, and survey forms distributed by email. The interviews took place between January and July 2021. The developers comprise most of the participants in the Bangladesh solar PV market and have experience with projects which are grid connected, ground mounted, and large-scale rooftop systems, as well as off-grid systems. Some of the developers have renewable energy as their core business, while others have installed PV capacity for consumption in another core business, although tied to the grid under the net metering system. As the roadmap for renewables includes all forms of capacity, the developers were also chosen to include different project configurations. Some of the developers are from Bangladesh, while others are international investors with projects in Bangladesh.

The financing cost waterfalls in Figures 14-1 and 14-2 show the analysis of the contribution of investment risks to higher financing costs in Bangladesh. The analysis of the equity and debt investors are shown separately. Definitions of each of the risk categories can be found in the methodology of Waissbein et al (2013). A brief summary of the qualitative feedback that solar PV developers and investors shared in their interviews is provided in Table 25.

The highest impact risk categories were permits risk, power market risk, grid infrastructure risk, and financial sector risk. Low levels of risk originate from social acceptance risk and resource and technology risk. It is assumed that debt investors are not exposed to permits risk and financial sector risk.

Risk category	Impact on financing cost	Explanation
Power market risk	Very high	There is no standard power purchase agreement (PPA). Every PPA has to be customized through comments of the investors, vetted by Power Development Board/ Power Division, Ministry of Law and National Board of Revenue. Currently there are various national targets for the renewables in the policy documents. There is a low level of market liberalization and a high cost of renewables compared to peer group countries, and high subsidies for fossil fuels.

Permits risk	Very high	This is a crucial risk as it makes the timeline of the project unpredictable. Because the due diligence for land is extensive, the number of competitive bidders is low. As a result the evaluation and approval process becomes lengthy. There is low availability of suitable non-agricultural land for solar projects and in addition, land ownership paperwork and transfer are very complicated. (For example when the transfer of legal ownership from forbears has not been done correctly.
Social acceptance risk	Moderate	Inhabitants near the project sites sometimes do not cooperate in giving right of way for electric transmission lines.
Resource and technology risk	High	Civic infrastructure near project sites is often lacking because solar projects are in remote undeveloped areas. Areas suitable for large- scale ground mounted solar projects are usually near riverbanks, which are prone to erosion and flooding. Local EPC and O&M experience is still underdeveloped.
Grid/ transmission risk	High	There is a lack of transmission infrastructure near remote project sites and no grid code to address VRE.
Counterparty risk	Moderate	In Bangladesh, utilities are autonomous public sector, but the payment has to be counter guaranteed by the power authorities.
Financial sector risk	High	There are insufficient concessional funds for renewable energy projects, as the cost of capital is high for such projects. Most banks and financial institutions have little to no experience with renewable energy projects. In addition, there are few local knowledgeable project developers.

Political risk	Moderate	There are no taxes on imports of power generation equipment. Corporate income tax is waived for first 15 years out of 20 years. So far, political instability is not an issue in Bangladesh.
Currency/ macroeconomic risk	Moderate	To date the macroeconomic environment is moderately stable. The electricity tariff is indexed to the US dollar, so it is immune to currency volatility.

Table 25: Qualitative Investor Feedback on Risk Categories for Renewable Energy Investment in Bangladesh

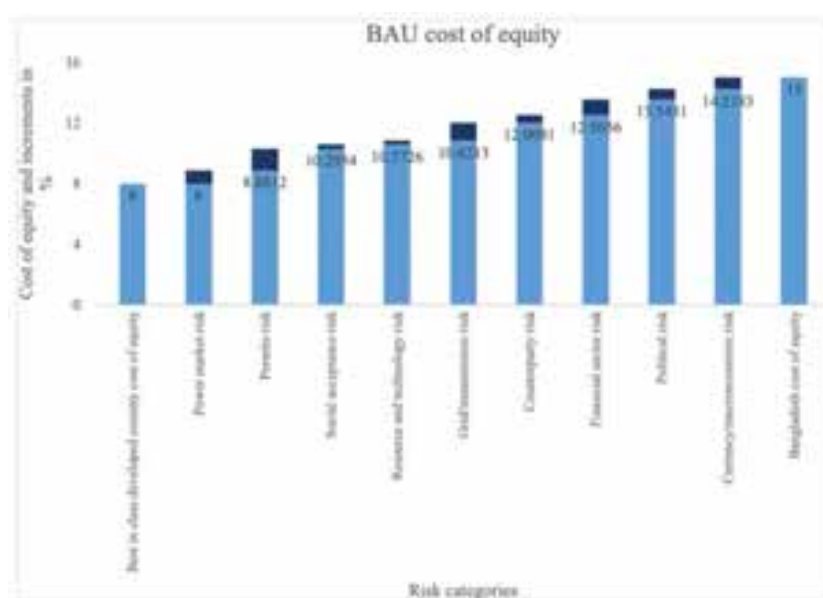


Figure 14-1: Impact of Risk Categories on Financing Costs for Equity Investors for Solar PV Investments in Bangladesh, Business-as-Usual Scenario

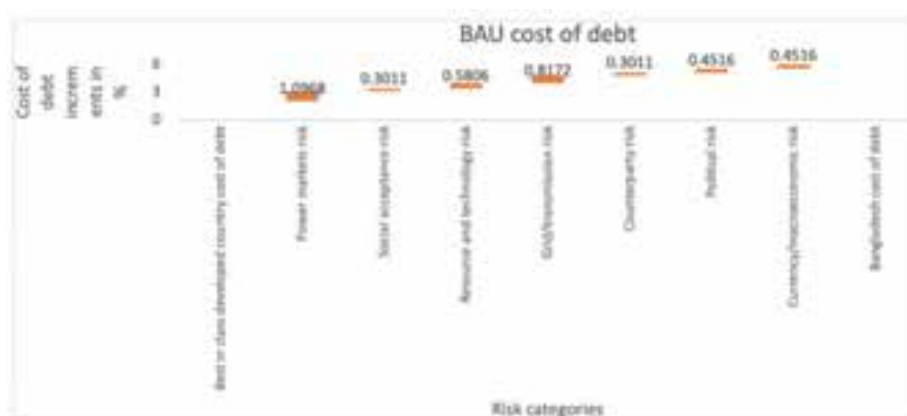


Figure 14-2: Impact of Risk Categories on Financing Costs Debt Investors for Solar PV Investments in Bangladesh, Business-as-Usual Scenario

14.6. Public Instruments Selection

Not all the risks were of a high likelihood, or likely to have a significant financial impact on prospective renewable energy projects, but to get the most effective de-risking, we have chosen to focus on de-risking of the most important risks, which result in the most significant reduction in the cost of capital. These are power market risk, permits risk, grid transmission risk, and financial sector risk. Political and macroeconomic risks can be reduced, but no additional investments may be needed, as some instruments and measures are already in place. The effects of de-risking are shown in Figures 14-3 and 14-4.

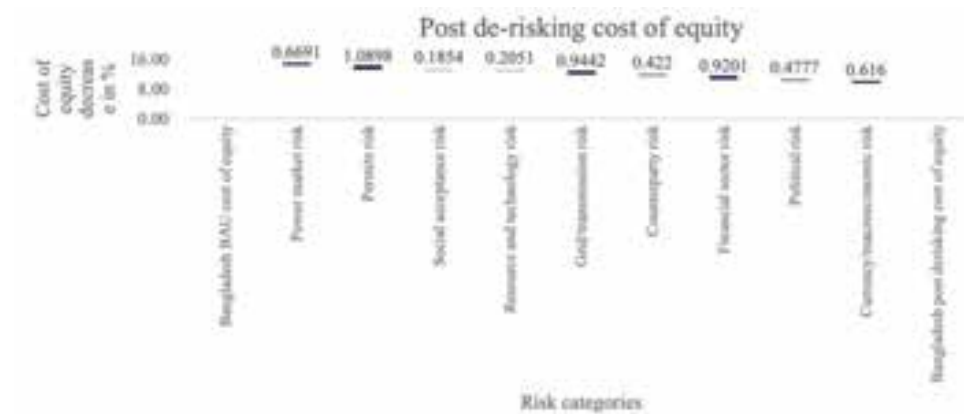


Figure 14-3: Effect of De-risking on Cost of Equity

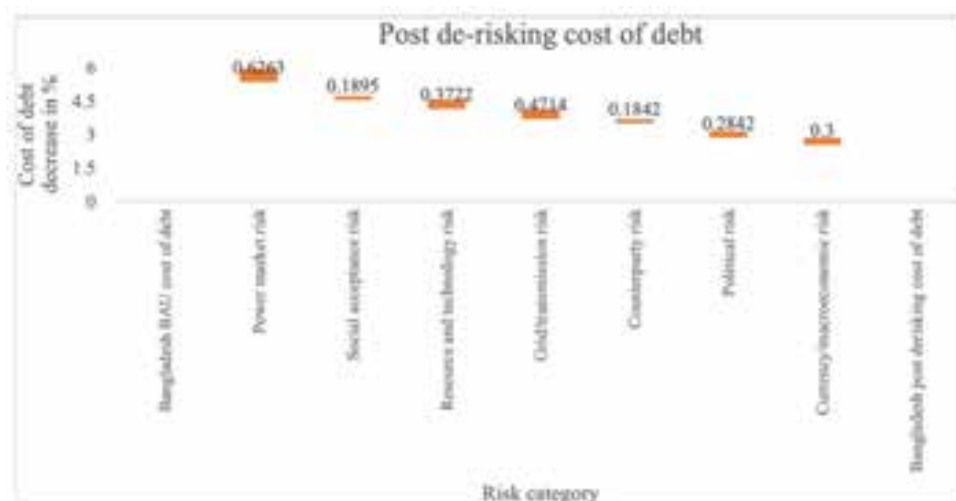


Figure 14-4: Effect of De-risking on Cost of Debt

14.7. Impact of Public Instruments of Financing Costs

The public instrument table is obtained from the methodology laid out in the DREI report by Waissbein et al (2013). For each type of risk, there can be one, two or three types of de-risking instruments. The effectiveness of each instrument was measured from the interviews of the developers and financiers, and the scores of the instruments pertaining to a particular risk were averaged.

Risk category (Equity)	Percentage (score/5)	Effectiveness	Reduced risk percentage
Power market risk	0.787	High	0.669
Permits risk	0.827	High	1.090
Social acceptance risk	0.727	High	0.185
Resource and technology risk	0.778	High	0.205
Grid/transmission risk	0.804	High	0.944
Counterparty risk	0.813	High	0.422
Financial sector risk	0.813	High	0.920
Political risk	0.720	High	0.478
Currency/macroeconomic risk	0.747	High	0.616
Total			5.529

Table 26: Results of Survey on the Risk Reduction Effectiveness of Different Policy and Financial Instruments on Cost of Equity

Risk category	Percentage (score/5)	Effectiveness	Reduced risk percentage
Power market risk	0.82	High	0.626
Social acceptance risk	0.9	High	0.189
Resource and technology risk	0.92	High	0.372
Grid/transmission risk	0.825	High	0.471
Counterparty risk	0.875	High	0.184
Political risk	0.9	High	0.284
Currency/macroeconomic risk	0.95	High	0.3
Total			3.45

Table 27: Results of Survey on the Risk Reduction Effectiveness of Different Policy and Financial Instruments on Cost of Debt

Power market risk	• Make PPAs of international standard (USD 1 million) • Enact firm renewables targets (USD0.5 million)	
Permits risk	• Create one stop permits solution (USD3 million)	
S o c i a l acceptance risk	• Arrange awareness raising campaigns (USD 10 million)	
Resource and technology risk (developer risk)	• Strengthen technology standards and quality control mechanisms (USD3 million) • Local capacity building for design, EPC and O&M (USD 1 million)	
G r i d / transmission risk	• Update grid code to integrate VRE (USD5 million) • Capacity building for the supervision center to organize/control dispatching (USD 3 million)	• Financial products from development banks to provide financing to transmission companies if necessary.
Counterparty risk		• Guarantees or backing for PPA payments by the government or development banks (already exists)
Financial sector risk	• Enact financial sector policy favorable to long term infrastructure payments (USD0.5 million) • Training on project assessment and financial structuring for renewable energy projects (USD0.25 million)	
Political risk	NA	NA
Currency/ macroeconomic risk	NA	NA

Table 28: Cost Estimates of De-risking Instruments (Author's Calculation)

From the survey results, we can see that all the instruments for reducing the associated risk have a high degree of effectiveness. Implementing all of them can result in an overall significant reduction in the cost of capital. However, the selection of the instruments depends on their cost effectiveness. If all the risk reduction measures could be implemented, the total cost of equity could be brought down by 5.529 percentage points. Similarly, the total cost of debt could be decreased by 3.45 percentage points.

Table 27 shows the chosen de-risking instruments and their potential costs. The costs of the de-risking instruments are estimated from the interviews with developers as well as local experts. These types of instruments do not have an exact precedent in Bangladesh, and the benchmark data from exemplary case studies of Lebanon, Kazakhstan, Tunisia, and Belarus are for different populations, with different planned renewable capacities. However, the figures for Bangladesh are estimated from comparable initiatives in the past.



14.8. Baseline Energy Mix Levelized Costs and Emissions

In order to conduct the modeling, the following assumptions are made:

- A combined baseline approach with a 50% build margin (upcoming non-renewable energy in 10 years under construction) and 50% operating margin (existing non-renewable energy to continue for next 10 years) is used as Bangladesh's energy demand, is growing over the long term. And although some of the fossil fuel capacity is old and to be replaced, much of it will operate in the short and medium term. In the near term, new solar PV installations will likely not replace existing generation capacity. The build margin and operating margin ratio is based on information from existing and projected capacity installations in the PSMP 2016 and the BPDB Annual Report 2019-2020.
- The marginal baseline technology is considered to be those technologies that will come in the next 10 years. They include gas, coal, HSD, HFO, and nuclear. The private sector drives investments in these, where the assumptions are based on recent experience.
- For the 50% operating margin share of the baseline, the assumptions are based on the existing energy mix, taken from the BPDB annual report and organizational data. The existing fuel mix includes private and public sector gas plants, the coal plants, the HFO plants, and the HSD plants. All private, public, base load, and peak load plants are included, but due to the lack of data and to simplify the modeling, the existing hydropower plant is not included separately. The captive generation capacities of different industries are excluded.. Off-grid renewable systems are not included because they have a small total capacity compared to total generation capacity, are not likely to expand, and are likely to be integrated into the grid in future.

The modeling assumptions of the operating baseline technologies are given in tables 29, 30, 31, and 32.

Indicator	Hydro	Gas	Coal	HFO	HSD	Solar PV	Import	Total
Installed capacity (MW)(%)	230 (1.13%)	10,979 (53.86%)	1,146 (5.62%)	5,540 (27.18%)	1,290 (6.33%)	38 (0.19%)	1,160 (5.69%)	20,383 (100%)
Annual Generation (GWh)	825 (1.16%)	51,290 (71.82%)	2,968 (4.16%)	9,461 (13.25%)	139 (0.20%)	62 (0.07%)	6,674 (9.34%)	71,419 (100%)

Table 29: Modeling Assumptions for Baseline Energy Technology: Bangladesh Fuel Mix

Installed capacity by plant type (MW) (%)	230 (1.13%)	2966 (14.55%)	851 (4.18)	7330 (35.96%)	7808 (38.31%)	38 (0.19%)	1160 (5.69%)	20,383 (100%)

Table 30: Modeling Assumptions for Baseline Energy Technology: Bangladesh Technology Mix
(Source: BPDB Annual Report 2019-2020)

	Gas (CCGT)	Coal	HFO	HSD	
Initial investment cost (USD/KWet)	USD 800 / KWet (up to 250MW), USD 667 (up to 500 MW) All are combined cycle	USD 1800 /KWet (600MW plant) including cost of coal terminal	USD 1000	USD 1000	Authors investigations
Initial O&M cost excl. fuel (USD/KWet)	Fixed: USD 2.5/ kw/month, variable O&M USD 1.5/ million watt hour	Fixed: USD 3.25/ kw/month, variable USD 2/million watt hour	Fixed: USD 2.5/ kw/month Variable: USD 2/ million watt hour	Fixed: USD 2.5/ kw/month Variable: USD 1.5/million watt hour	BPDB interview
O&M Cost in USD / MW	31000	39500	35000	33000	Authors
O&M Inflation	2%	2%	2%	2%	BPDB interview
Lifespan (years)	25	25	15	15	BPDB interview
System Efficiency	55%	40%	40%	40%	BPDB interview
Capacity Factor	80%	80%	55%	20%	BPDB interview
Emission Factor	0.235 kg-CO ₂ / Million Calory (Page- 11-52)	0.39615 kg-CO ₂ / Million Calory (Domestic) 0.40229 kg-CO ₂ / Million Calory	0.30709 kg-CO ₂ / Million Calory	0.30095 kg-CO ₂ / Million Calory	PSMP
Emission factor in kg/kWh	0.56kg/kWh	1.01kg/kWh	0.783kg/kWh	0.783kg/kWh	Boston Consulting Study
FINANCING ITEM					
Capital structure D/E	70/30	70/30	70/30	70/30	BPDB interview
Cost of Equity	16%	16%	16%	16%	BPDB interview
Loan terms	3%+6 month LIBOR+4.5%	3%+ 6 month LIBOR+4.5%	3%	3%	BPDB interview
Loan tenor	15 years	15 years	15 years	15 years	BPDB interview
Interest on working capital	8%	8%	8%	8%	BPDB interview
Depreciation allocation	Straight line depreciation of 80% of value	Straight line depreciation of 80% of value	Straight line depreciation of 80% of value	Straight line depreciation of 80% of value	BPDB interview

Table 31: Modeling Assumptions for Operating Margin

	Gas	Coal	HFO	HSD	Nuclear	
Share of generation mix	28	30	13	1	11	PSMP 2016
Investment cost (USD/kWd)	USD 800 / kWd (up to 250MW), USD 667 (up to 500 MW). All are combined cycle	USD 1800 / kWd (600MW plant) including cost of coal terminal	USD 1000	USD 1000	USD 5000	BPDB interview
Current O&M cost excl. fuel (USD)	Fixed O&M USD 2.5/kw/month, variable O&M USD 1.5/million watt hour	USD 3.25/kw/month, variable USD 2/million watt hour	Fixed: USD 2.5/kw/month Variable: USD 2/million watt hour	Fixed: USD 2.5/kw/month Variable: USD 1.5/million watt hour	Fixed USD 6.5/kw/month Variable USD 2/million WH (78,500)	BPDB interview
O&M in USD/MW	31000	39500	35000	33000	78500	
O&M Inflation	2%	2%	2%	2%	2%	BPDB interview
Lifespan (years)	25	25	15	15	60 yrs.	BPDB interview
System Efficiency	35%	40%	40%	40%	33%	BPDB interview
Capacity Factor	80%	80%	35%	20%	85%	BPDB interview
Emission Factor	0.56kg/kWh	1.01kg/kWh	0.783kg/kWh	0.783kg/kWh	0	BPDB interview
Capital structure	70/30	70/30	70/30	70/30	Assumed same as others, but Q2G contracts are confidential, and actual figures are not known.	BPDB interview
Cost of Equity	16%	16%	16%	16%		BPDB interview
Cost of debt	3%+6 month LIBOR+4.5%	3%+6 month LIBOR+4.5%	3%	3%		BPDB interview
Depreciation allocation	Straight line depreciation of 80% of value	Straight line depreciation of 80% of value	Straight line depreciation of 80% of value	Straight line depreciation of 80% of value		BPDB interview

Table 32: Modeling Assumptions for Building Baseline Energy Technologies

14.9. Assumptions for Solar PV Investment in Bangladesh

The following assumptions have been made for investment in solar PV in Bangladesh:

- The existing investment environment is considered.
- There is enough land and natural resource/renewable resource in the country to invest in 5 to 10 GW of solar PV plants.
- PV panels and other components are available and reliable.
- Investment will follow a build-own-operate (BOO) business model.
- There is low O&M risk, as PV plants are simple to operate.
- Transmission lines with free capacity and directly connected to the high-voltage grid are relatively close to the project site (within 10 kilometers).
- There is an EPC sub-contractor, qualified for renewable energy, with high penalties for breach of contract (eliminating certain developer risks).
- Investment will follow a project finance structure.

Modeling assumptions for solar PV technology and financing specifications are given in Tables 33 and 34 below.

2030 solar PV installed capacity	8080 MW
Panel technology	Mono silicon or poly silicon
Park size	Solar park and rooftop, grid connected
Core investment costs, including balance of plant costs (civil works, transformers), 2021 Cost	USD 800/kW _{el} for ground mounted, 600 kW _{el} for rooftop, model assumes 700 kW _{el}
Annual O&M costs at start of operation Annual increase	USD 3.077 /million watt hour
Lifetime	20 years
Solar PV capacity factor	17%
Emission Factor	0%
O&M costs	USD 10000/MW

Table 33: Solar PV Technology Specifications Assumptions
(Source: Author's analysis)

	BAU	Post de-risking
Capital structure D/E	75/25	
Cost of equity	15%	
Debt cost	6%	
Loan terms	12.5 yrs (rooftop 10 yrs, ground mounted 15 yrs)	
Depreciation allocation	Straight line	15% (more land is used in solar parks, but no land in rooftop systems)

Table 34: The Modeling Assumptions for Solar PV Terms of Finance
(Source: Author's analysis)



14.10. Levelized Cost

The modeling outputs in terms of LCOEs for solar PV are shown in Figure 14-5. The marginal baseline LCOE, based on private sector investment in fossil fuel technology (50% of the baseline mix) and partial replacement of the existing power plants and upcoming nuclear plants (50% of the baseline mix), is estimated as being USD 10.7 cents per kWh. Solar PV energy is less expensive than the baseline cost in both the business-as-usual and the post-de-risking scenarios. The public de-risking instrument package reduces the LCOE for solar energy from USD 6.2 cents per kWh (business-as-usual scenario) to USD 5.2 cents per kWh (post de-risking scenario). The cost advantage of solar falls from USD 4.5 cents to USD 5.5 cents.

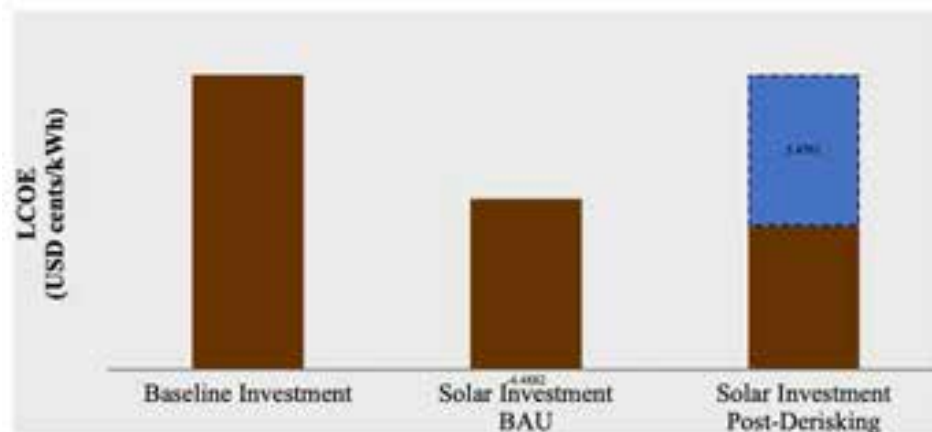


Figure 14-5: LCOE Change of Solar PV due to De-risking, Compared to Baseline

14.11. Evaluation of Performance Metrics

The model's performance metrics, evaluating the impact of de-risking on the envisioned 2030 targets for solar PV investment in Bangladesh, are shown in Figures 14-6, 14-7, 14-8 and 14-9. The investment leverage ratio (Figure 14-6) shows the efficiency of public instruments in attracting investment, comparing the total cost of public instruments with the resulting private-sector investment. As the analysis of the LCOE shows that the LCOE of solar is lower than the baseline mix of fossil fuels, the introduction of de-risking instruments decreases the LCOE of PV, but the benefits to the investment leverage ratio are not there. This is because, if the LCOE of solar PV in the baseline scenario was higher than the fossil fuels, there would be a price premium of the FIT or PPA payments, which would then be eliminated if the LCOE was reduced due to de-risking. However, if the LCOE in the baseline scenario is already lower compared to fossil fuels, there is no price premium saving. Therefore, investment in the de-risking instruments increases the overall costs of investments in renewables and so decreases the investment leverage ratio.

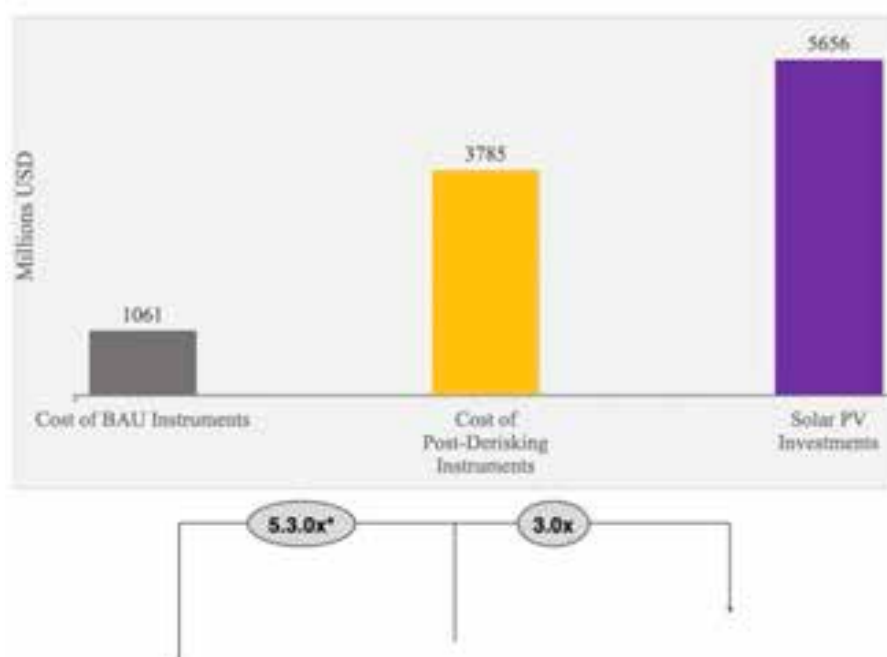


Figure 14-6: Investment Leverage Ratio Effect

The savings ratio takes a social perspective, comparing the cost of de-risking instruments deployed versus the economic savings that accrue to society from deploying the instruments. In the case of Bangladesh, we can see that the savings ratio is 0.7 times (Figure 14-7). However, as the present value of incremental costs of solar PV relative to the baseline is actually negative, considering that the LCOE of solar PV is lower than the baseline fossil fuel mix, the savings are also negative. Moreover, as de-risking lowers the LCOE of solar PV even further, the incremental costs of the post de-risking scenario are even lower. This means that although money is not saved by avoiding the incremental costs of renewables, electricity is produced at an even lower cost, thus increasing the cost advantage of renewables.

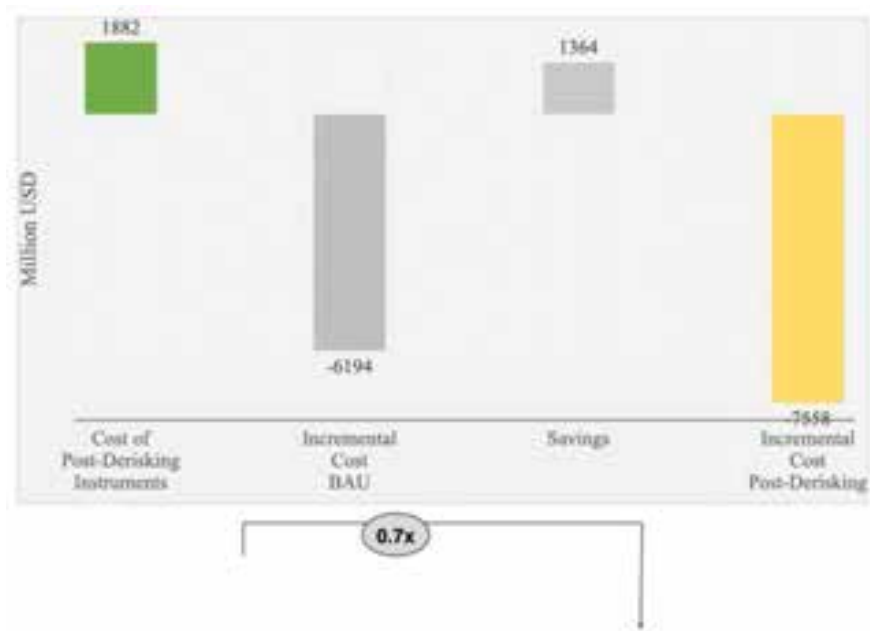


Figure 14-7: Savings Ratio Effect

The affordability metric takes an electricity consumer perspective, comparing the generation cost of solar PV in the post de-risking scenario with the original BAU scenario. In this case, we can see that the LCOE decreases significantly by 16% due to de-risking, and the initial LCOE of 6.2 USD cents becomes 5.2 (Figure 14-8).

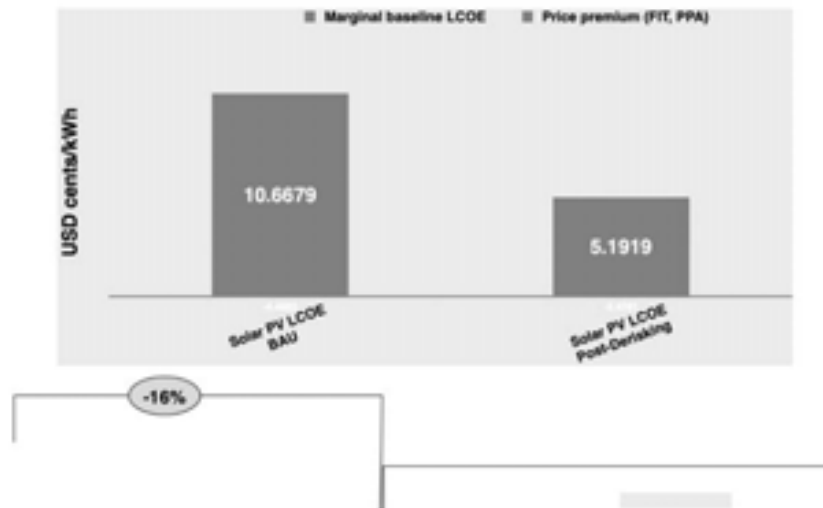


Figure 14-8: Affordability Effect of De-risking

The carbon abatement metric takes a climate change mitigation perspective, considering the carbon abatement potential and comparing the carbon abatement costs (the cost per tonne of CO₂ abated). This can be a useful metric for comparing carbon prices. In this case, as solar PV is already cheaper than fossil fuels in the baseline, the carbon abatement cost is negative (Figure 14-9). This means that carbon emissions are more expensive, and avoiding emissions by switching to renewables is actually the cheaper option. Moreover, as a result of de-risking, the cost of solar PV falls further, making carbon-intensive fossil fuel generation an even more costly option, while avoiding carbon emissions produces an even cheaper outcome.

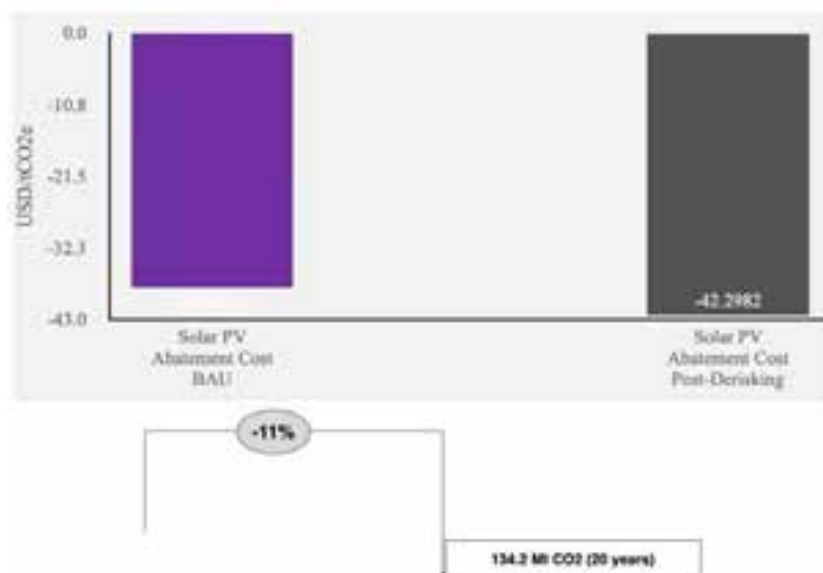


Figure 14-9: Carbon Abatement Effect of De-risking



14.12. Summary

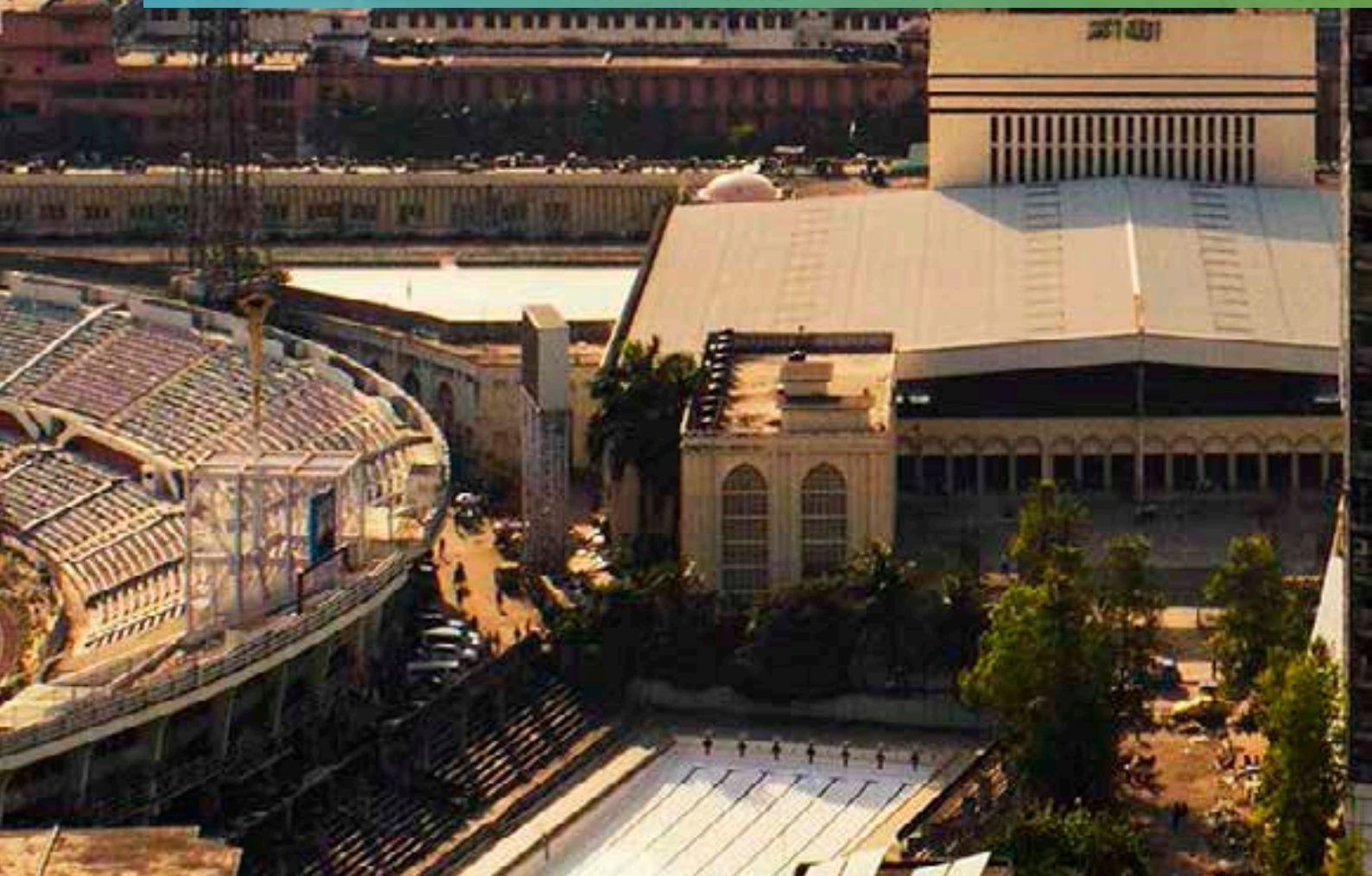
The de-risking analysis for renewables in Bangladesh reflects some of the new realities about the competitiveness of renewables with respect to fossil fuels. In the baseline scenario, solar PV already appears more affordable and cost effective than fossil fuel or nuclear generation. Moreover, if de-risking measures hasten the decline in the cost of capital, this will further lower the cost of solar PV.

If the grid penetration of solar PV or other renewables increases to claim a more significant portion of the energy mix, it will be necessary to invest in storage and other grid integration measures. These costs are outside the scope of this analysis, as they are likely to be incurred towards the end of the planning horizon of 2030. By that time, grid integration costs and technologies are likely to change to have changed., Any potential wind power capacity additions are not considered in this analysis as investment and operations data for wind in Bangladesh is not available. Surveyed existing and prospective investors and developers have experience and opinions on investments in solar PV only.





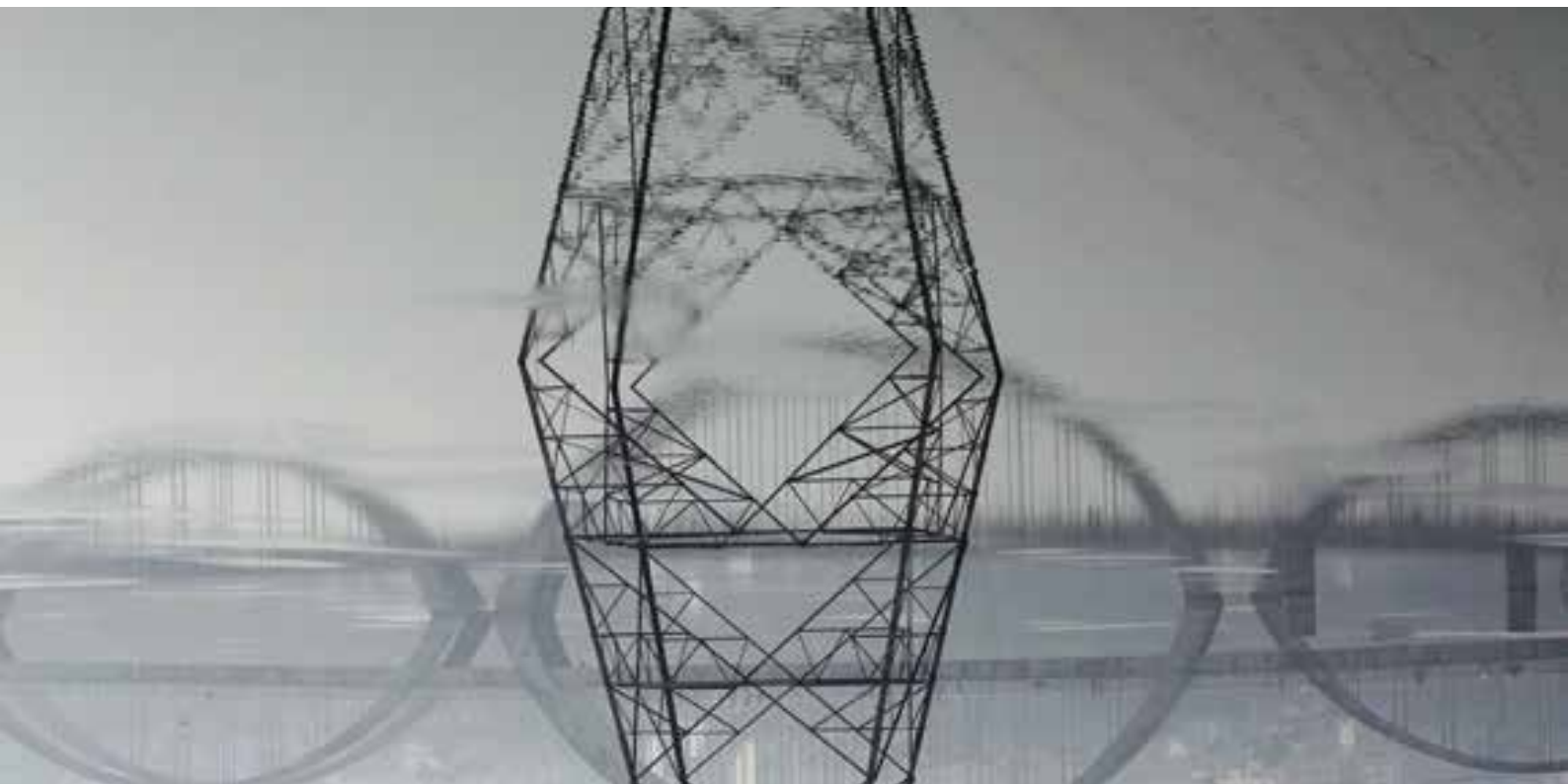
15. Bangladesh Power System Flexibility Assessment





15.1. Background

A flexibility assessment for Bangladesh's power system was conducted using the IRENA Flex Tool software, to determine the power system's readiness to accommodate greater penetration of VRE. This study was done as a part of the research conducted under the Mujib Climate Prosperity Decade Plan (MCPD), with different scenarios for the years 2025 and 2030.



15.2. Methodology

The scenarios to be analyzed were formulated in consultation with the Bangladesh Ministry of Power, Energy and Mineral Resources and existing policy and planning documents. The shares and capacities of renewables under different time periods and scenarios were determined accordingly. The three scenarios examined were the NDC scenario, the MCCP-Realistic scenario, and the MCCP-Maximum scenario. The node-wise capacities and shares of different fossil fuels, nuclear power, and imports in the scenario years of 2025 and 2030 were obtained from the 2016 Power Sector Master Plan (PSMP) and the Annual Report of Bangladesh Power Development Board (BPDB). The demand forecast was obtained from the PSMP, and the total demand was distributed node wise according to PSMP projections. The current hourly demand data for one year, as well as the hourly hydro and import generation data, was obtained from the Power Grid Company of Bangladesh (PGCB (2021), and was divided into the nine nodes, representing the nine grid regions of Bangladesh (Figure 15-1). The hourly demand data was then projected into the years 2025 and 2030 using the demand increase factors derived from PSMP projections. The capacity margins were obtained from PGCB.

Installed Capacity 2025	Dhaka	Chattogram	Cumilla	Mymensingh	Sylhet	Rajshahi	Rangpur	Khulna	Barishal	Total
Coal	635	2424	0	0	0	0	436	1240	4042	8777
Gas	6211.65	1522	1790	622	2043.1	1064	0	1846	1572.18	16670.93
BFO	1715	1264	795	486	0	597	228	370	260	5715
RES	0	0	0	0	0	0	161	0	0	161
Import	0	0	160	0	0	1496	0	1000	0	2656
Nuclear	0	0	0	0	0	2060	0	0	0	2060
Hydro	0	230	0	0	0	0	0	0	0	230
Total	8,561.65	5,440	2,745	1,108	2,043.1	5,217	825	4,456	5,874.18	36,270

Installed Capacity 2030	Dhaka	Chattogram	Cumilla	Mymensingh	Sylhet	Rajshahi	Rangpur	Khulna	Barishal	Total
Coal	635	6114	0	0	0	0	436	1240	4042	12467
Gas	6478.85	4303	2049	820	2018.1	1064	0	2396	2736.18	21865.13
BFO	1416	1106	743	486	0	545	228	370	260	5154
RES	0	0	0	0	0	0	161	0	0	161
Import	0	0	160	0	0	1496	500	1000	0	3156
Nuclear	0	0	0	0	0	2060	0	0	0	2060
Hydro	0	230	0	0	0	0	0	0	0	230
Total	8,529.85	11,753	2,952	1,306	2,018.1	5,165	1,325	5,006	7,038.18	45,093

Table 35: Node-Wise Capacities and Shares of Different Fossil Fuels, Nuclear, and Imports in the Scenario Years of 2025 and 2030



Figure 15-1: Nodes of the Grid in Bangladesh

The data for the solar irradiation and wind speed were obtained from NASA (2021), and were converted into capacity factors. The assumptions of the efficiency, load, installation, operations, and fuel costs came from BPDB annual reports. Other technical parameters were taken from the Flex Tool default values (Table 36). Some penalty parameter assumptions were taken from the default Flex Tool settings.

Unit type	Efficiency	Min load	Efficiency at min load	Ramp up (p.u. per min)	Ramp down (p.u. per min)	O & M cost (M\$/MWh)	Inertia constant (MWh/MW)	Fixed cost (M\$/year)	Investment cost (M\$/kW)	Investment cost (M\$/kW)	Fixed cost (M\$/year)	Start-up cost	Minimum uptime (h)	Minimum downtime (h)	Efficiency charge	Self-discharge loss	Lifetime
ST_coal	0.40	0.40	0.23	0.02	0.02	4.0	5.00	23	1800			2.00	12	12			25
Engine_gas	0.55	0.20	0.43	0.20	0.20	2.0	2.00	24	700			0.50	4				25
CC_oil	0.40	0.00	0.35	0.05	0.05	2.5	3.00	100	1000			1.00	5	5			15
Hydro_RES	1.00			0.20	0.20		3.00	20	0								30
wind	1.00			1.00	1.00			20	1300								30
PV	1.00			1.00	1.00			10	700								30
battery	0.96			1.00	1.00			20		80	1.00				0.96	0.00	15
nuclear	0.33	0.50	0.28	0.05	0.05	7.5		25	5000								60

Table 36: Cost and Technical Assumptions according to Fuel/Technology

Parameter	Unit cost
CO ₂ cost USD/ton	3
Loss of load penalty USD/MWh	2738
Loss of reserves penalty USD/MWh	5477
Lack of inertia penalty USD/MWs	8214
Curtailment penalty USD/MWh	6
Lack of capacity penalty USD/MWh	1370

Table 37: Parameter Assumptions about Penalties and Carbon Cost

The node-wise installed capacities of solar and wind are given in Table 38, for each scenario-year. The capacities for solar are distributed according to land availability, solar resource, demand, and level of industrialization. They include land-based and rooftop installation, solar irrigation, as well as small quantities of floating solar. The distribution of wind power is according to the wind resources and potential sites for wind power projects currently under consideration. It should be noted that hydroelectricity is not included here because Bangladesh does not have significant additional hydro potential and additional hydropower can be imported and is included in imports. It is also treated as a baseload rather than a variable renewable electricity source.

	2025	Dhaka	Chittagong	Cumilla	Rajshahi	Sylhet	Bariisal	Rangpur	Mymensingh	Khulna	Total
NDC 2025	Solar	83	124.5	99.6	99.6	66.4	66.4	107.9	66.4	116.2	830
	Wind	0	50	0	0	0	0	0	0	40	90
MCCP-R 2025	Solar	215	322.5	258	258	172	172	279.5	172	301	2150
	Wind	0	120	70	0	0	0	0	0	50	240
MCCP-M 2025	Solar	270	405	324	324	216	216	351	216	378	2700
	Wind	0	150	100	0	0	0	0	0	50	300
	2030	Dhaka	Chittagong	Cumilla	Rajshahi	Sylhet	Bariisal	Rangpur	Mymensingh	Khulna	Total
NDC 2030	Solar	170	255	204	204	136	136	221	136	238	1700
	Wind	0	150	50	0	0	0	0	0	50	250
MCCP-R 2030	Solar	430	645	516	516	344	344	559	344	602	4300
	Wind	0	250	100	0	0	50	0	0	100	500
MCCP-M 2030	Solar	600	900	720	720	480	480	780	480	840	6000
	Wind	0	500	150	0	0	50	0	0	150	850

Table 38: Node-Wise Installed Capacities of Solar and Wind for Each Scenario-Year

Fuel price data was obtained from the BPDB (2020), and emissions data was obtained from EPA (2021) (Table 39).

The transmission capacities between node pairs are given in table 38 and are obtained from PGCB. The transmission loss between nodes is considered to be 1%, the lifetime of the transmission system is considered 50 years, and investment cost is USD100/kWh.

Figure 15-2 shows the main challenges identified in the preliminary analysis, and the analysis undertaken.

Fuel	Fuel (USD/MWh)	CO2 content (t/MWh)
Coal	55.90	1.00
Natural gas	13.80	0.50
HFO	94.80	0.80
HSD	231.36	1.00

Table 39: Fuel-Wise Cost and CO2 Content

node1	Node2	Capacity (MW)
Chittagong	Cumilla	3000
Cumilla	Sylhet	600
Dhaka	Cumilla	3000
Dhaka	Sylhet	2000
Dhaka	Mymensingh	2500
Dhaka	Khulna	4000
Dhaka	Rajshahi	4800
Khulna	Barisal	4500
Khulna	Rajshahi	2900
Rajshahi	Rangpur	2500
Rajshahi	Mymensingh	400

Table 40: Transmission Capacities between Node Pairs

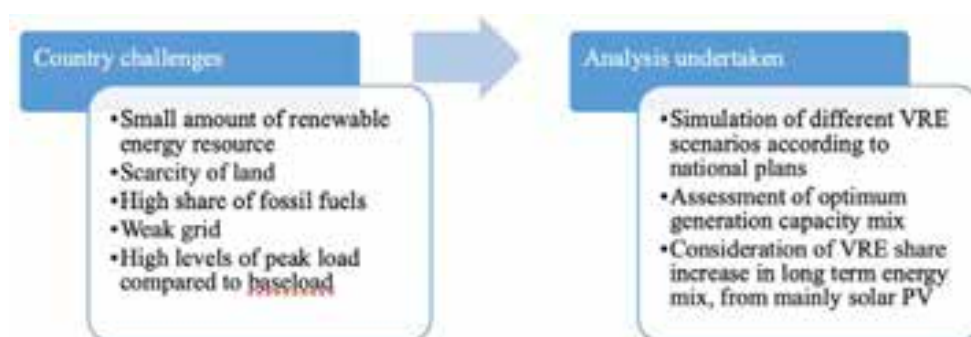


Figure 15-2: Main Challenges of the Power System and Flex Tool Analysis Done

15.3. Results

Prior to running the simulations in Flex Tool, an analysis of the flexibility enablers of Bangladesh's power system was conducted. The results are shown in Table 41.

Flexibility enablers	Definition	Assessment	Strength (High/Medium/Low)
Interconnection capacity vs. average demand	Shows the extent of interconnection capacity with neighboring countries in comparison to the average system demand (average of the yearly time series).	Present import capacity is 1160MW, and present average demand is 9291 MW.	Medium
Generator ramping capabilities	Represents the total ramping capability of the system's dispatchable generation (i.e., non-VRE generation), assuming that all units are online and working at their technical minimum.	Around 35% of present generation capacity are reciprocating engines. As a result, the overall ramp rate is comparatively low.	Low
Matching of demand with VRE generation	Shows the correlation co-efficient between the demand time series and the VRE time series.	Correlation coefficient is 0.002519	Low
Interconnection capacity vs. average demand	Shows the standard deviation of the historical hydro inflows profile and how variable the inflows in the country are.	The standard deviation is 50, with a range of 0 to 200	Low
Interconnection capacity vs. average demand	Expresses how strong the internal grid is, and if there is enough transmission capacity in the system.	Internal grid is strong enough in terms of transmission capacities except in the northwest and northern regions.	Medium
Interconnection capacity vs. average demand	Shows how much storage capacity is available (including hydro reservoirs) in comparison to the total annual demand.	Hydro reservoir storage is 250 MW, present average demand is 9291 MW	Low

Table 41: Flexibility Enablers of the Bangladesh Power System

The results of the Flex Tool simulations are shown in Tables 42 and 43.

	Bangladesh NDC 2025	Bangladesh NDC 2025	Bangladesh NCCP-R 2025	Bangladesh NCCP-M 2025	Bangladesh NCCP-M 2025	Bangladesh NCCP-M 2025
	Base	Invest	Base	Invest	Base	Invest
Status	Optimal	Optimal	Optimal	Optimal	Optimal	Optimal
Optimal objective	3611027047	3611027047	3456660280	3456660280	3397960405	3397960405
Iterations	46	46	44	44	35	35
Solving time (s)	1.002	0.232	0.272	0.278	0.172	0.132
Total cost obj. function (M USD)	3611.03	3611.03	3456.66	3456.66	3397.96	3397.96
Total cost calculated (M USD)	4367.294806	4367.294806	4747.291932	4747.291932	4702.849038	4702.849038
...Operational cost of units (M USD)	4190.793852	4190.193852	4100.739533	4100.739533	4068.511861	4068.511861
...Investment cost of units (M USD)	0	0	0	0	0	0
...Investment cost for transfers (M USD)	0	0	0	0	0	0
...Penalty costs (M USD)	677.1009533	677.1009533	646.5523988	646.5523988	634.3371774	634.3371774
...Carthment payments (M USD)	-6.14E-07	-6.18E-07	-6.26E-06	-6.26E-06	-1.84E-06	-1.84E-06
Time in use in years	0.010958904	0.010958904	0.010958904	0.010958904	0.010958904	0.010958904
Full time series in years	1	1	1	1	1	1
Emissions						
CO2 (Mt)	82.4492	82.4492	79.511	79.511	78.3566	78.3566
General results	etc	etc	etc	etc	etc	etc
VRE share (% of annual demand)	1.687	1.687	4.382	4.382	5.501	5.501
Loss of load (% of annual demand)	0	0	0	0	0	0
→ ramp up constrained (% of annual demand)	0	0	0	0	0	0
Excess load (% of annual demand)	0	0	0	0	0	0

Curtailment (% of VRE gen.)	-1.44E-08	-1.44E-08	-1.44E-07	-1.44E-07	-1.49E-08	-1.49E-08
→ ramp down constrained (% of VRE gen.)	8.11E-09	8.11E-09	3.69E-08	3.69E-08	2.13E-09	2.13E-08
Peak load (MW)	18568.2	18568.2	18568.2	18568.2	18568.2	18568.2
Peak net load (MW)	16287.1	16287.1	16288.5	16288.5	16177.1	16177.1
Flexibility losses	also	also	also	also	also	also
Loss of load (max MW)	0	0	0	0	0	0
Excess load (max MW)	0	0	0	0	0	0
Reserve inadequacy (max MW)	0	0	0	0	0	0
Insufficient inertia (TW/a)	0	0	0	0	0	0
Curtailment (max MW)	0.000610199	0.000610199	0.00247522	0.00247522	0.00168441	0.00168441
Curtailment (TW/a)	-1.85E-07	-1.85E-07	7.10E-07	7.10E-07	-1.07E-07	-1.07E-07
Model leakage (TW/a)	0	0	0	0	0	0
Capacity inadequacy (max MW)	1111.73	1111.73	1017.32	1017.32	1006.24	1006.24
Spill (TW/a)	0	0	0	0	0	0
Energy balance	also	also	also	also	also	also
Demand (TW/a)	-112.32	-112.32	-112.32	-112.32	-112.32	-112.32
Consumers (TW/a)	0	0	0	0	0	0
Loss of load (TW/a)	0	0	0	0	0	0
Excess load (TW/a)	0	0	0	0	0	0
Generation, fuel based (TW/a)	90.4413	90.4413	87.4036	87.4036	86.3452	86.3452
Generation, VRE inc. river hydro (TW/a)	1.89461	1.89461	4.92197	4.92197	6.17818	6.17818
Discharge, inc. reserv. hydro (TW/a)	0.770824	0.770824	0.770824	0.770824	0.770824	0.770824
Charge (TW/a)	0	0	0	0	0	0
Convert (TW/a)	0	0	0	0	0	0
Import (TW/a)	19.3904	19.3904	19.3904	19.3904	19.3904	19.3904
Transfer losses (TW/a)	-0.177536	-0.177536	-0.167	-0.167	-0.164828	-0.164828
Costs	also	also	also	also	also	also
Cost operations (M USD)	2945.29	2945.29	2839.64	2839.64	2800.71	2800.71
Cost investments (M USD)	0	0	0	0	0	0
Fixed annual costs (M USD)	1267.8	1267.8	1267.8	1267.8	1267.8	1267.8
Cost loss of load (M USD)	0	0	0	0	0	0
Cost excess load (M USD)	0	0	0	0	0	0
Cost curtailment (M USD)	-6.18E-07	-6.18E-07	4.26E-06	4.26E-06	-1.84E-06	-1.84E-06
Cost of insufficient reserves (M USD)	0	0	0	0	0	0
Cost of insufficient inertia (M USD)	0	0	0	0	0	0
Cost of insufficient capacity (M USD)	677.101	677.101	646.532	646.532	634.337	634.337
Total (M USD)	4967.29	4967.29	4767.29	4767.29	4702.83	4702.83

Table 42: Flex tool Results Comparison of the Three Scenarios for 2025

	Bangladesh NDC 2035	Bangladesh NDC 2035	Bangladesh MCCP-M 2035	Bangladesh MCCP-M 2035	Bangladesh MCCP-M 2035	Bangladesh MCCP-M 2035
	Base	Invest	Base	Invest	Base	Invest
Status	Optimal	Optimal	Optimal	Optimal	Optimal	Optimal
Optimal objective	487918811	3610325067	4372958310	3456680280	4367734114	4367734114
Iterations	21	21	23	23	22	22
Solving time (s)	0.292	0.692	0.242	0.252	0.182	0.222
Total cost obj. function (M USD)	4879.31	4879.31	4372.96	4372.96	4367.72	4367.72
Total cost calculated (M USD)	5309.972373	8309.972373	3648.16599	3648.36359	7999.950791	7999.950791
...Operational cost of units (M USD)	3979.03913	3979.03913	3774.641438	3774.641438	5695.212496	5695.212496
...Investment cost of units (M USD)	0	0	0	0	0	0
...Investment cost for transfers (M USD)	0	0	0	0	0	0
...Penalty costs (M USD)	2330.913218	2330.913218	2273.524421	2273.524421	2204.738295	2204.738295
...Curtailment payments (M USD)	-2.31E-07	-2.31E-07	0.006490337	0.006490337	9.885666666	9.885666666
Time in use in years	0.010938904	0.010938904	0.010938904	0.010938904	0.010938904	0.010938904
Full time series in years	1	1	1	1	1	1

Exclusion						
CO2 (Mt)	118.408	118.408	112.816	112.816	110.05	110.05
General results	elec	elec	Elec	Elec	elec	elec
YRE share (% of annual demand)	5.557	5.557	6.226	6.226	7.82	7.82
Loss of load (% of annual demand)	0	0	0	0	0	0
=> ramp up constrained	0	0	0	0	0	0
Excess load (% of annual demand)	0	0	0	0	0	0
Curtailed (% of YRE gen.)	-8.60E-07	-8.60E-07	0.01106	0.01106	12.33	12.33
=> ramp down constrained (% of YRE gen.)	2.60E-08	2.60E-08	1.64E-08	1.64E-08	0.007969	0.007969
Peak load (MW)	23968.6	23968.6	23968.6	23968.6	23968.6	23968.6
Peak net load (MW)	23603.6	23603.6	23498.8	23498.8	23414	23414
Flexibility issues	elec	elec	Elec	Elec	elec	elec
Loss of load (max MW)	0	0	0	0	0	0
Excess load (max MW)	0	0	0	0	0	0
Reserve inadequacy (max MW)	0	0	0	0	0	0
Inadequate inertia (TWh/a)	0	0	0	0	0	0
Curtailed (max MW)	0.00175506	0.00175506	10.5644	10.5644	1623.64	1623.64
Curtailed (TWh/a)	-3.86E-08	-3.86E-08	0.00108172	0.00108172	1.51428	1.51428
Model leakage (TWh/a)	0	0	0	0	0	0
Capacity inadequacy (max MW)	1791.34	1791.34	1711.2	1711.2	1861.41	1861.41
Spill (TWh/a)	0	0	0	0	0	0
Energy balance	elec	elec	Elec	Elec	elec	elec
Demand (TWh)	-157.085	-157.085	-157.085	-157.085	-157.085	-157.085
Consumers (TWh)	0	0	0	0	0	0
Loss of load (TWh)	0	0	0	0	0	0
Excess load (TWh)	0	0	0	0	0	0
Generation, fuel based (TWh)	133.114	133.168	127.334	127.334	124.823	124.823
Generation, YRE inc. river hydro (TWh)	4.01672	4.01672	4.78063	4.78063	12.2842	12.2842
Discharge, inc. reserve, hydro (TWh)	0.770824	0.770824	0.770824	0.770824	0.770824	0.770824
Charge (TWh)	0	0	0	0	0	0
Convent (TWh)	0	0	0	0	0	0
Import (TWh)	19.3904	19.3904	19.3904	19.3904	19.3904	19.3904
Transfer issues (TWh)	-0.206634	-0.206634	-0.190911	-0.190911	-0.183373	-0.183373
Costs	elec	elec	Elec	Elec	elec	elec
Cost operations (M USD)	4972.53	4972.43	4338.12	4338.12	4236.69	4236.69
Cost investments (M USD)	0	0	0	0	0	0
Fixed annual costs (M USD)	1406.52	1406.52	1436.52	1436.52	1458.12	1458.12
Cost loss of load (M USD)	0	0	0	0	0	0
Cost excess load (M USD)	0	0	0	0	0	0
Cost curtailment (M USD)	-2.51E-07	-2.11E-07	0.00649034	0.00649034	9.08506	9.08506
Cost of insufficient reserves (M USD)	0	0	0	0	0	0
Cost of insufficient inertia (M USD)	0	0	0	0	0	0
Cost of insufficient capacity (M USD)	2236.91	2236.91	2273.52	2273.62	2294.74	2294.74
Total (M USD)	8316	8316	8038	8038	7900	7900

Table 43: Flex tool Results Comparison of the Three Scenarios for 2030

The flexibility indicators assessed by the IRENA Flex Tool are summarized in Table 44.

Indicator	NJC 2025	NJC 2030	NJC P-R 2019	NJC P-R 2040	NJC P-R 2025	NJC P-R 2040
Curtailed	Peak: 0.00963 MW Total: -1.87E-07 TWh	Peak: 0.001755 MW Total: -3.86 E-08 TWh	Peak: 0.00245 MW Total: 7.10E-07 TWh	Peak: 10.5644 MW Total: 0.0011 TWh	Peak: 1623.64 MW Total: -3.67E-07 TWh	Peak: 1623.64 MW Total: 1.5143 TWh
Loss of load	0	0	0	0	0	0
Spillage	0	0	0	0	0	0
Reserve inadequacy	0	0	0	0	0	0

Table 44: Flexibility Indicator Comparison of the Three Scenarios for 2030



15.4. Discussion

Solver results: All simulations have run with an optimum result, and therefore can be considered valid. Figures 15-4 to 15-23 are given for reference.

General results: In all the scenarios of 2025 (Table 42), the share of VRE in the electricity mix is the highest in the MCCP-M scenario. There is no loss of load or excess load in any of the 2025 or 2030 scenarios, and the curtailment is a minuscule share of total VRE generation. **The highest cost in 2025 is for the NDC scenario, and the least cost is in the MCCP-M scenario.**

In the scenarios of 2030 (Table 43), the highest share of VRE is again in the MCCP-M case. However, the share of VRE in electricity generation does not increase as sharply from the MCCP-R to the MCCP-M case. In 2030, the curtailment levels are minute for the NDC and the MCCP-R scenarios but becomes noticeable in the MCCP-M case. **Again, like 2025, the highest cost in 2030 is for the NDC scenario, and the least cost is in the MCCP-M scenario.**

Cost results: The highest cost both in 2025 and 2030 are for the NDC scenarios, and the least cost is in the MCCP-M scenarios. However, the cost decrease is not a high share of total cost in this time period (Table 42). The same pattern in cost reduction is seen in 2030, but here the cost reduction is more significant between the NDC and MCCP-R scenario, and less between the MCCP-R and MCCP-M scenario.

Flexibility issues: In the 2025 scenarios, there is no loss of load, excess load, reserve inadequacy, insufficient inertia, model leakage or spill, and a minute amount of curtailment of VRE. There is a small amount of capacity inadequacy (between 1115 and 1005 MW). The same pattern can be seen in the 2030 scenarios, with slightly higher capacity inadequacies (between 1791 and 1661 MW).

If we look at the comparisons of net load and demand in all the scenario years, (Figure 15-4 to Figure 15-15), we can see that the distance between the demand curve and the net load curve remains uniform along the horizontal axis, indicating that the VRE generation matches the demand well. However, the ramp duration curves in all the scenarios show that there is no gap between the net load ramp and the demand ramp, indicating the possibility of flexibility issues.

Node and unit-wise flexibility analysis: The VRE curtailment occurs mostly in Khulna, Barishal, and Rajshahi in the 2025 scenarios (Figure 15-16). In 2030, the same nodes are involved in curtailment, but there is a small share of curtailment in Sylhet (Figure 15-17).

Figures 15-18 and 15-19 show which units provide the reserves in each of the nodes. In Dhaka, Cumilla, Rangpur and Mymensingh, HFO oil provides the reserves in all scenarios. In Chittagong, it is HFO followed by hydro and gas. Similarly, in Rajshahi, Barishal, and Khulna, HFO oil is the top provider of reserve, followed by gas. This is not an ideal situation, as HFO should be phased out in the long run and replaced with superior options, such as gas, storage, or other energy carriers. Reserves are produced in Rangpur, Mymensingh, and Khulna only in

the NDC scenarios in 2025, but in all scenarios in 2030.

Contribution of fossil fuel and VRE: Figure 15-20 shows the unit-wise generation necessary to meet demand in the three scenarios for 2025. Here we can see that the share of solar in the mix increases noticeably in the MCCP-R scenario, and more in the MCCP-M scenario. The same pattern is observed in 2030 scenario comparison in Figure 15-21, where the effect is even more pronounced. We can see a minute contribution from wind energy. In the MCCP-M scenario, there is a small amount of curtailment. The contribution of HFO is imperceptible in 2025 and is a small share in 2030.

Node- and unit-wise utilization analysis: Gas has the highest rates of utilization in all the nodes except Barisal, where coal is the highest, and Rajshahi, where nuclear is the highest. HFO has the lowest rates of utilization, even though it provides the most reserves (Figures 15-22 and 15-23). The rate of utilization of PV is low in Barisal and Khulna in 2025, but it increases in Barisal in 2030, while remaining low in Khulna. Wind utilization is comparable to PV utilization. The rates of utilization in a particular year are similar in all the scenarios.

Figure 15-3 shows how curtailment varies with the share of electricity generated from VRE. This curtailment only starts when the VRE share is above 6% and occurs in the highest VRE penetration scenario of MCCP-M 2030.

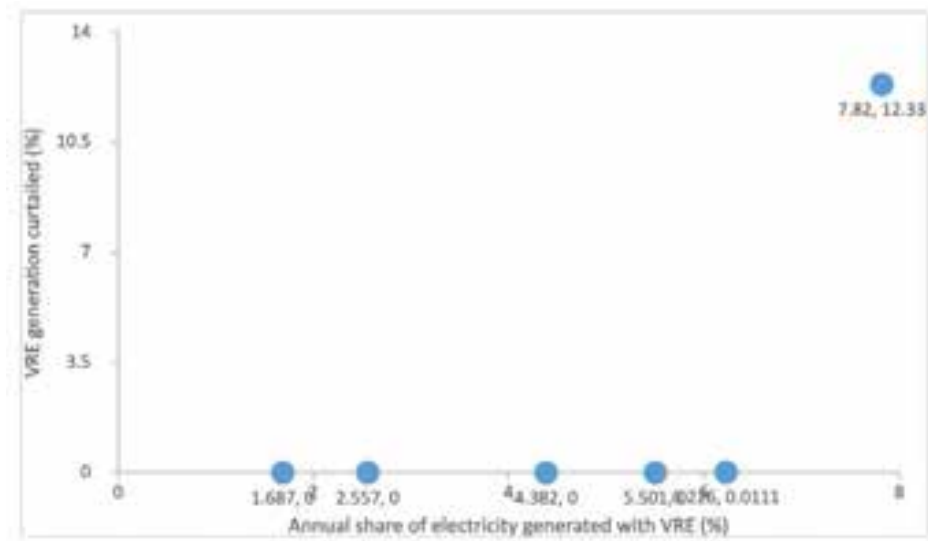


Figure 15-3: VRE Curtailment at Different Levels of VRE Penetration

Although the curtailment starts at relatively low levels of VRE penetration, it is not a significant issue in the scenarios analyzed under the Mujib Climate Prosperity Plan. In the longer term, however, curtailment should be decreased by increasing the share of storage and adapting the fossil fuel units to be compatible with high levels of VRE. On the other hand, the generation capacity of the Bangladesh power sector will be approximately 150 times than the peak demand in 2030. So, there will be a huge reserve margin by that time.

15.5. Conclusion

According to the Flex Tool analysis, the least-cost option is the MCCP-M option for 2025 and 2030. The system does not have significant flexibility issues under the scenarios analyzed. The analysis does not recommend additional investments in storage and transmission. Therefore, based on the results of the analysis, additional solar and wind capacity can be incorporated into the power system.

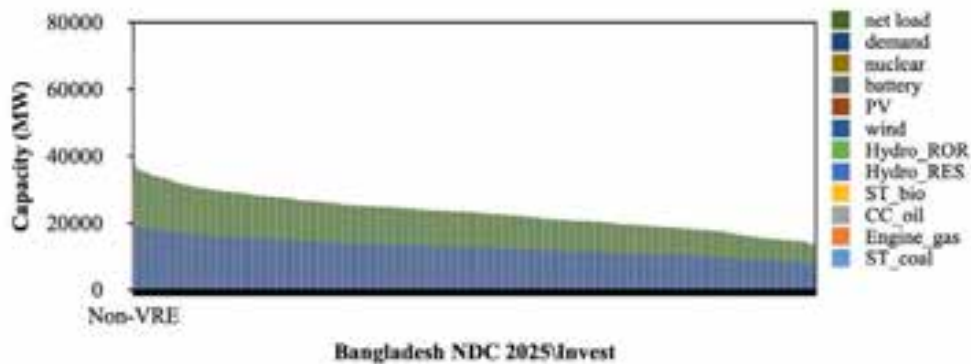


Figure 15-4: NDC 2025 Scenario Duration Curve for Energy Demand and Net Load (Lines) together with Unit Capacities (Leftmost Column for Conventional Capacity and Rightmost for VRE and Storage)

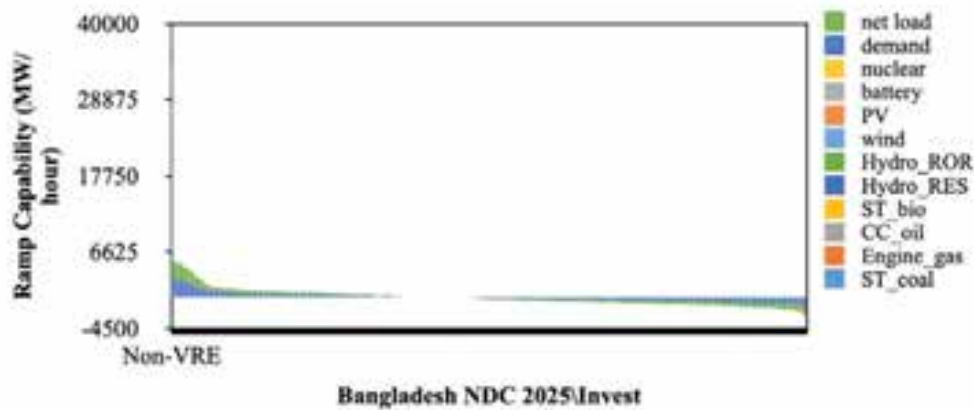


Figure 15-5: NDC 2025 Scenario Ramp Duration Curve for Demand and Net Load (Change Between Two Time Periods) as well as Upward Ramping Capabilities of Units (Leftmost Column for Conventional Capacity and Rightmost for VRE and Storage)

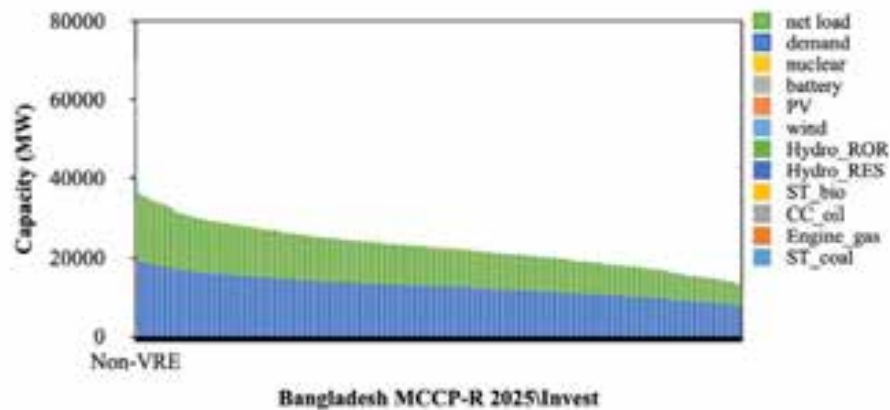


Figure 15-6: MCCA-R 2025 Scenario Duration Curve for Energy Demand and Net Load (Lines) together with Unit Capacities
(Leftmost Column for Conventional Capacity and Rightmost for VRE and Storage)

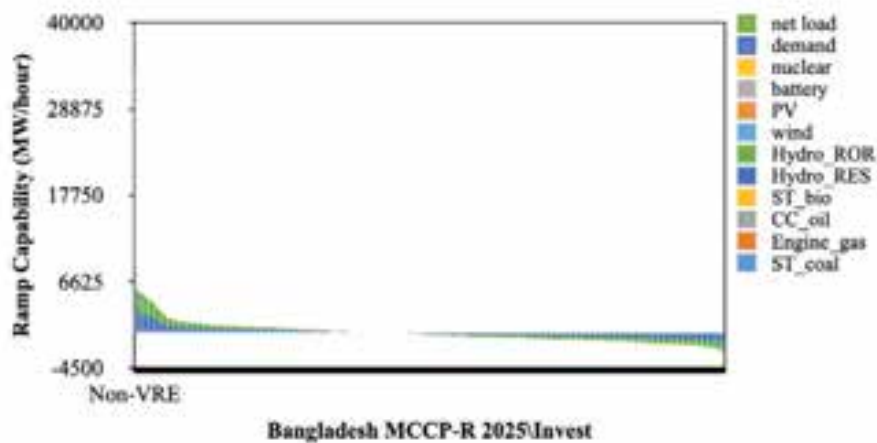


Figure 15-7: MCCA-R 2025 Scenario Ramp Duration Curve for Demand and Net Load (Change Between Two Time Periods) as well as Upward Ramping Capabilities of Units
(Leftmost Column for Conventional Capacity and Rightmost for VRE and Storage)

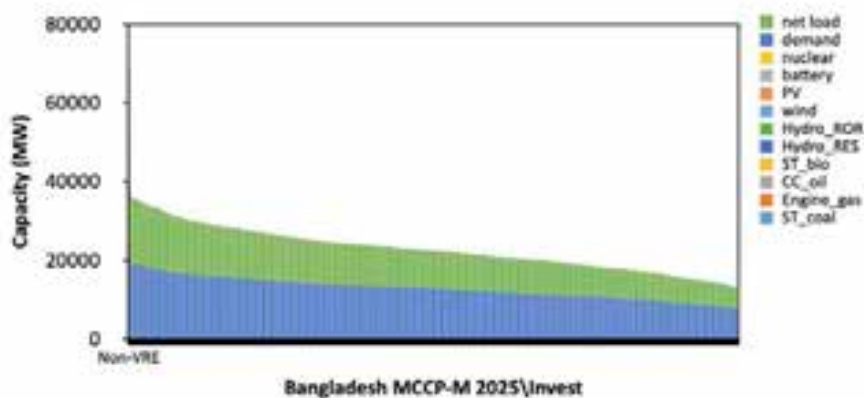


Figure 15-8: MCCA-M 2025 Scenario Duration Curve for Energy Demand and Net Load (Lines) together with Unit Capacities
(Leftmost Column for Conventional Capacity and Rightmost for VRE and Storage)

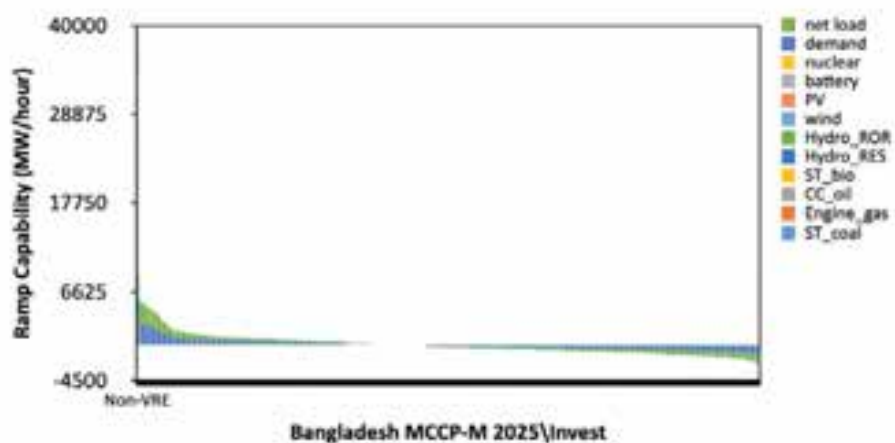


Figure 15-9: MCCC-R 2025 Scenario Ramp Duration Curve for Demand and Net Load (Change Between Two Time Periods) as well as Upward Ramping Capabilities of Units (Leftmost Column for Conventional Capacity and Rightmost for VRE and Storage)

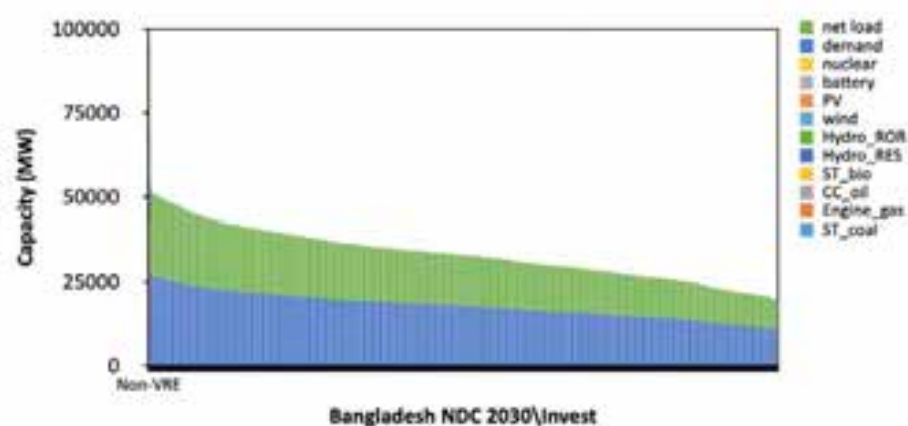


Figure 15-10: NDC 2030 Scenario Duration Curve for Energy Demand and Net Load (Lines) together with Unit Capacities (Leftmost Column for Conventional Capacity and Rightmost for VRE and Storage)

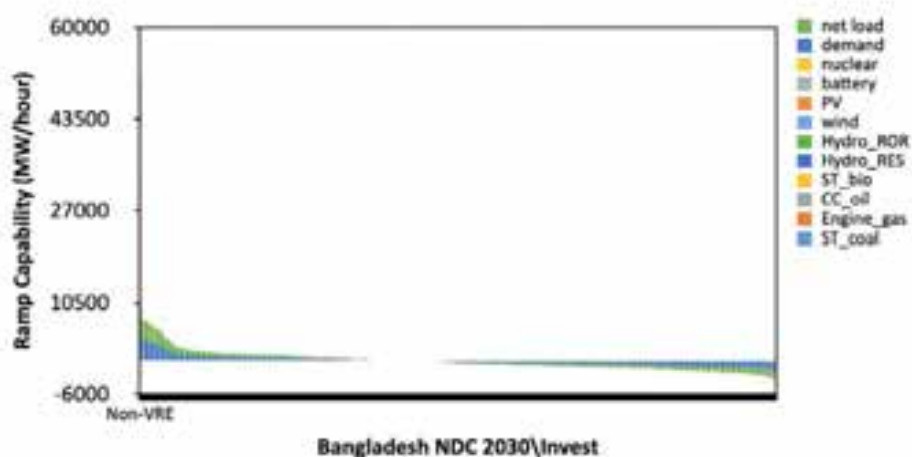


Figure 15-11: NDC 2030 Scenario Ramp Duration Curve for Demand and Net Load (Change Between Two Time Periods) as well as Upward Ramping Capabilities of Units (Leftmost Column for Conventional Capacity and Rightmost for VRE and Storage)

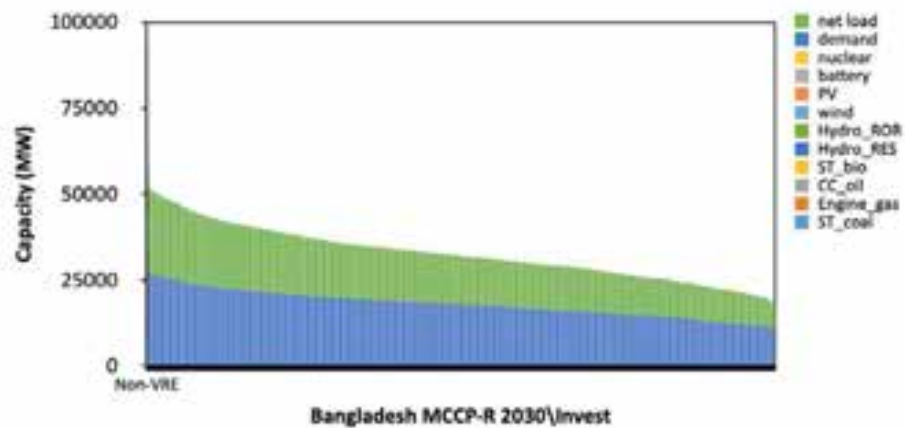


Figure 15-12: MCPP-R 2030 Scenario Duration Curve for Energy Demand and Net Load (Lines) together with Unit Capacities
(Leftmost Column for Conventional Capacity and Rightmost for VRE and Storage)

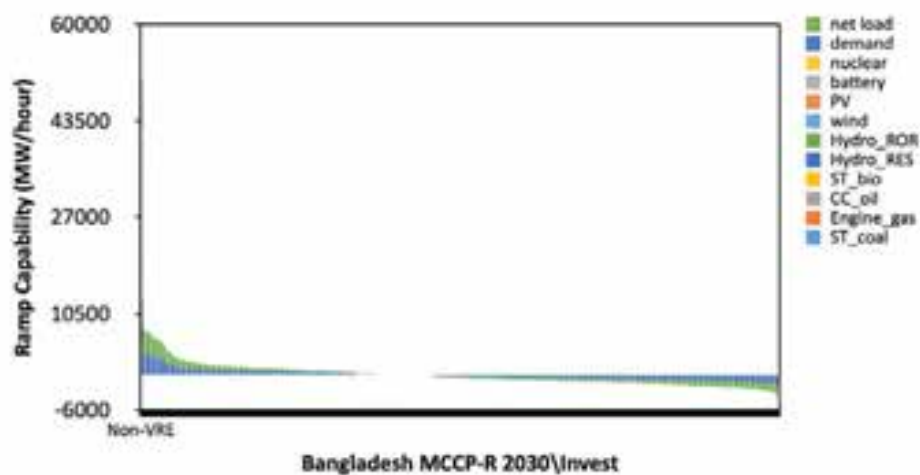


Figure 15-13: MCPP-R 2030 Scenario Ramp Duration Curve for Demand and Net Load (Change Between Two Time Periods) as well as Upward Ramping Capabilities of Units
(Leftmost Column for Conventional Capacity and Rightmost for VRE and Storage)

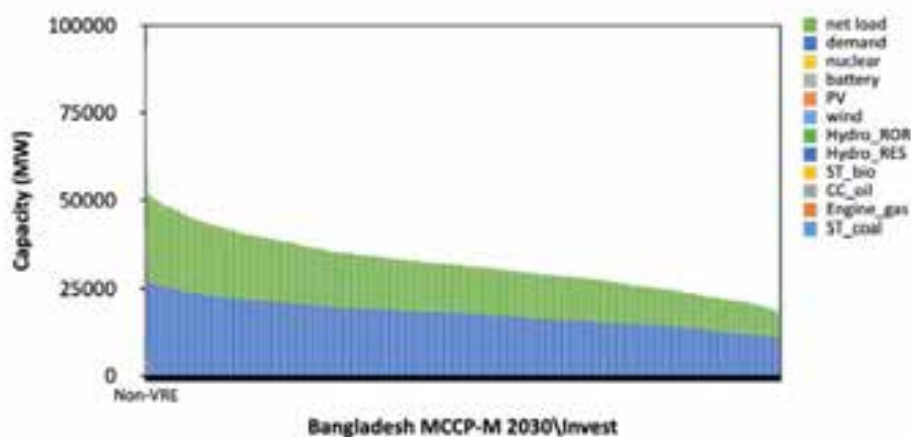


Figure 15-14: MCPP-M 2030 Scenario Duration Curve for Energy Demand and Net Load (Lines) Together with Unit Capacities
(Leftmost Column for Conventional Capacity and Rightmost for VRE and Storage)

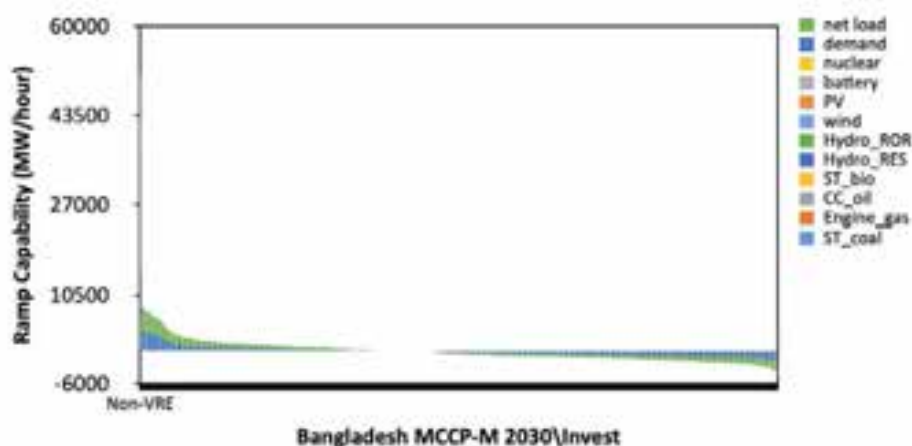


Figure 15-15: MCPP-M 2030 Scenario Ramp Duration Curve for Demand and Net Load (Change Between Two Time Periods) as well as Upward Ramping Capabilities of Units (Leftmost Column for Conventional Capacity and Rightmost for VRE and Storage)

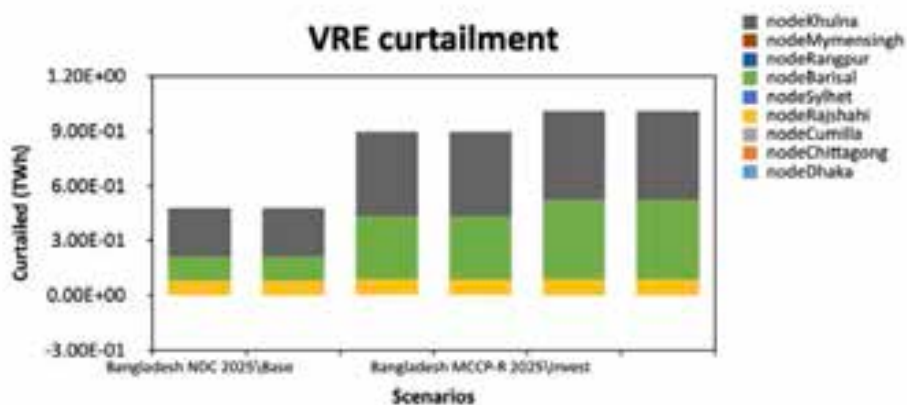


Figure 15-16: VRE Curtailment According to Node in 2025

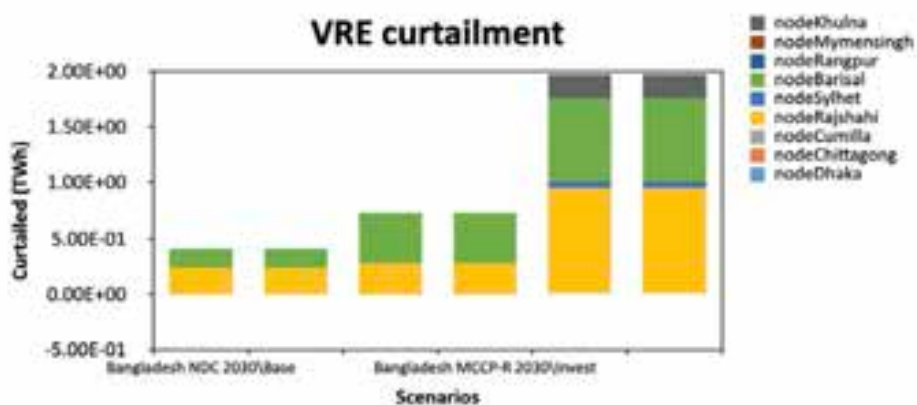


Figure 15-17: VRE Curtailment According to Node in 2030

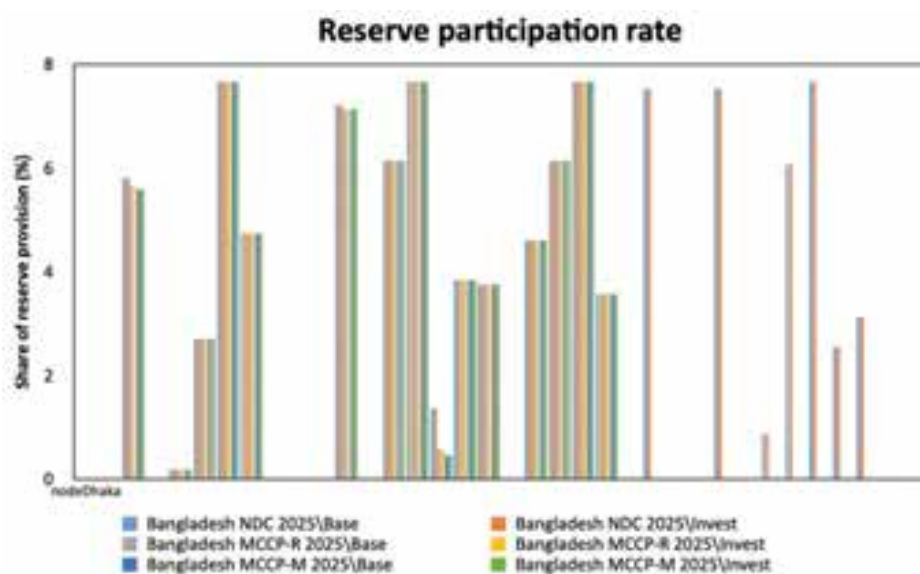


Figure 15-18: Units Producing Reserves in the System, According to Nodes in 2025

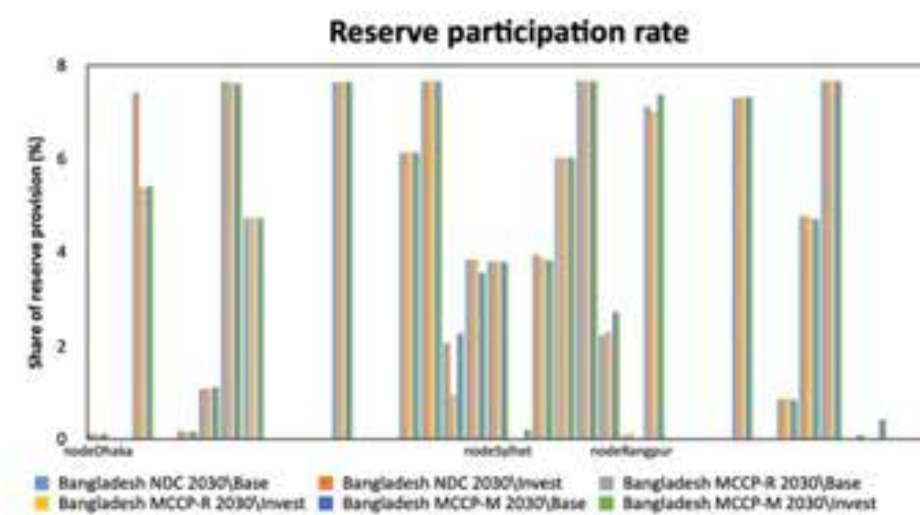


Figure 15-19: Units Producing Reserves in the System, According to Nodes in 2030

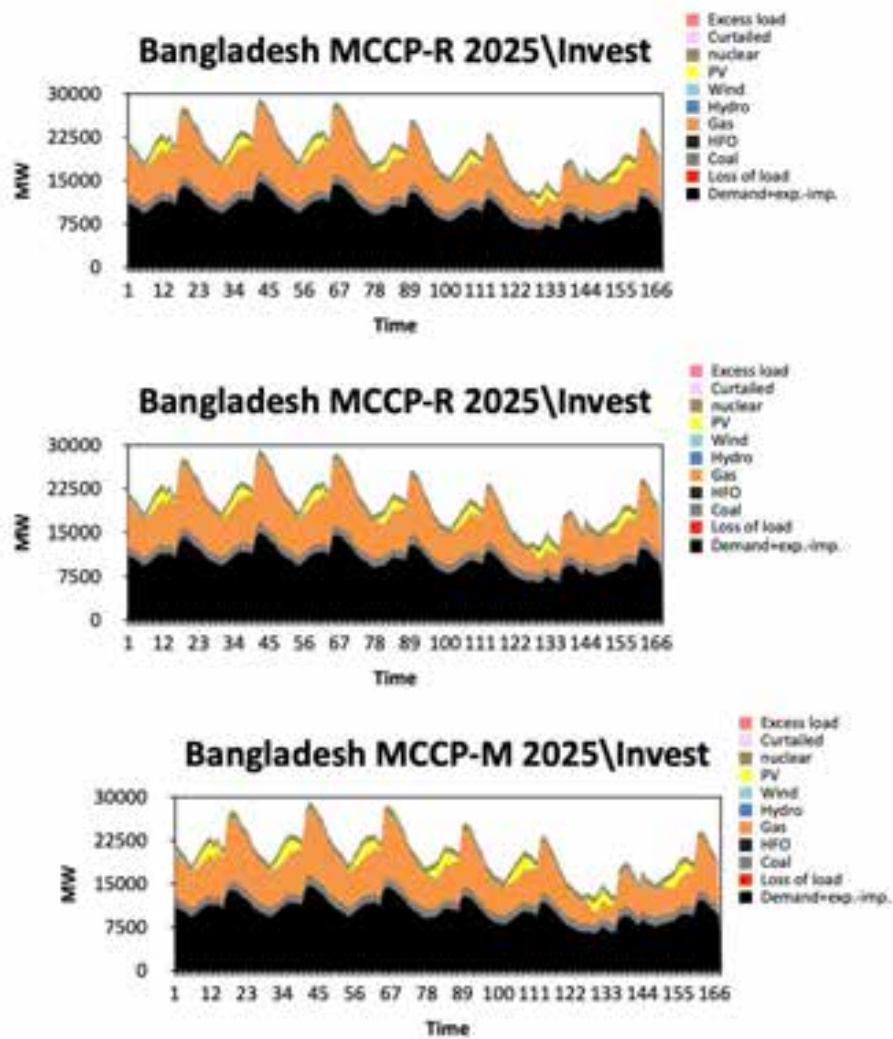


Figure 15-20: Unit-Wise Generation to Meet Demand in the Three Scenarios in 2025

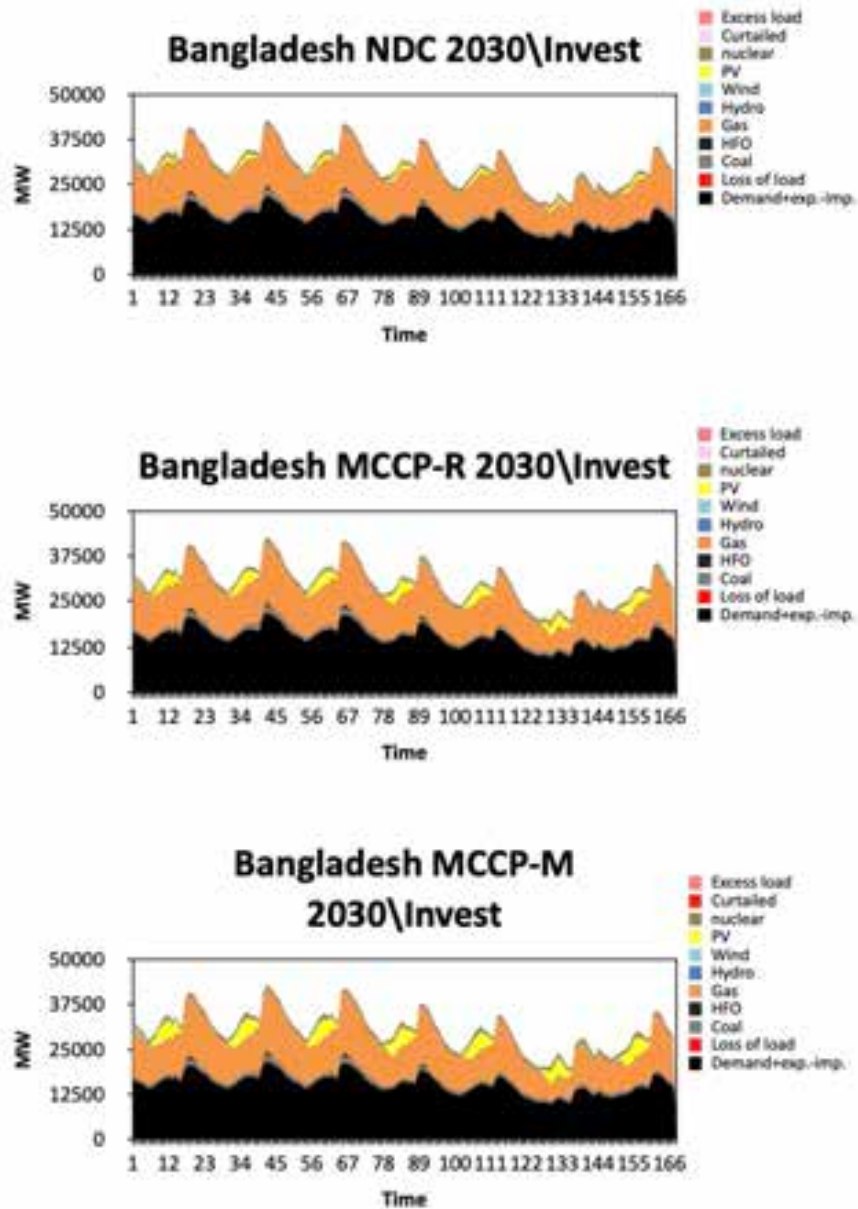


Figure 15-21: Unit-Wise Generation to Meet Demand in the Three Scenarios in 2030

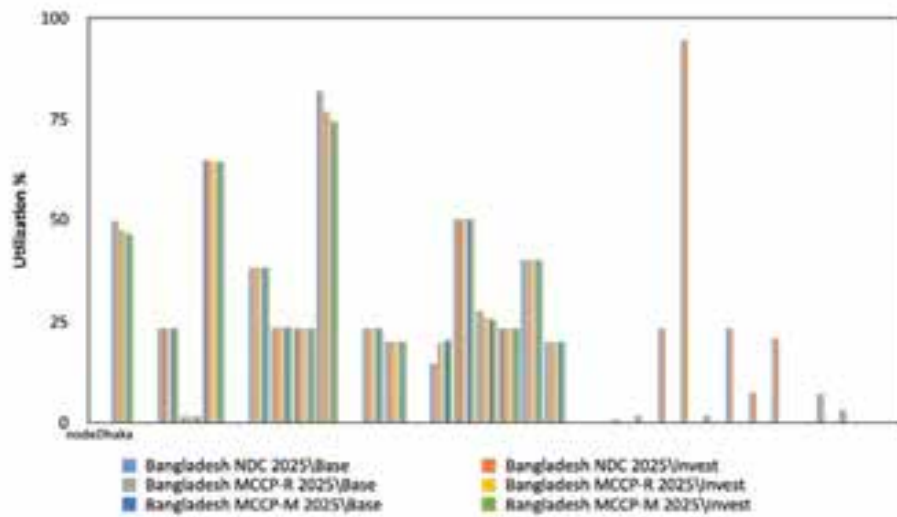


Figure 15-22: Node-Wise Utilization Rate of Units in 2025

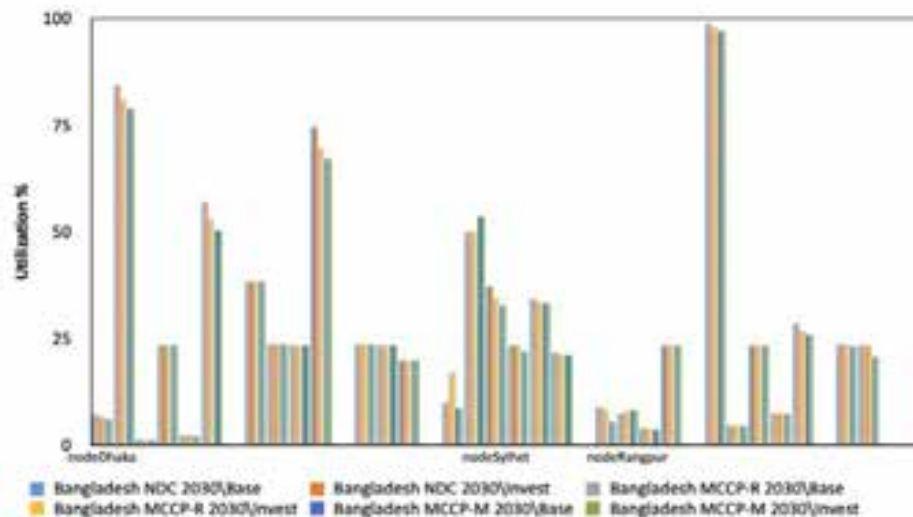
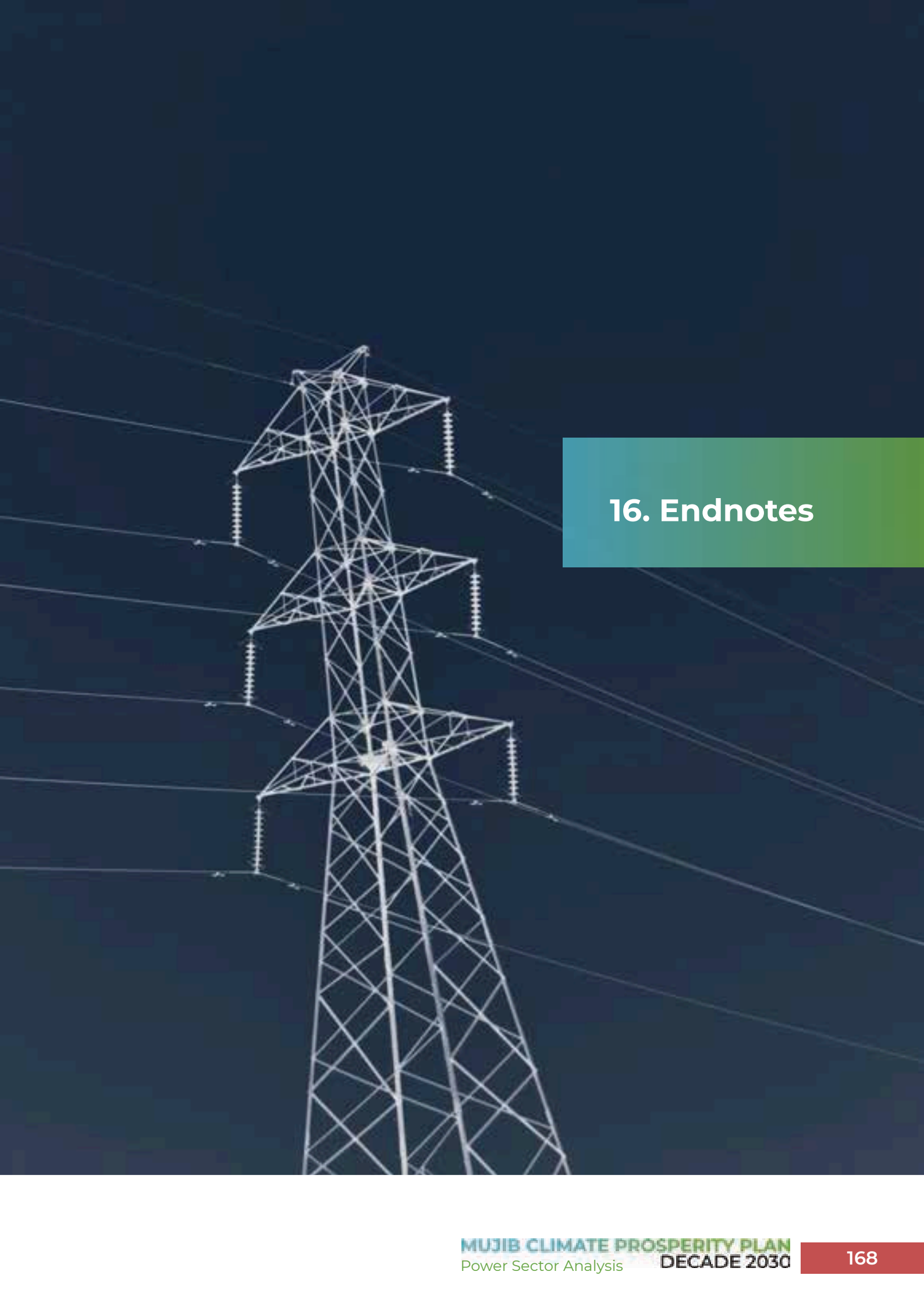


Figure 15-23: Node-Wise Utilization Rate of Units in 2030



16. Endnotes

- ¹ 8th Five Year Plan July 2020 to June 2025, December 2020
- ² Minor discrepancy in the data can be attributed to a lack of data availability.
- ³ <https://www.imf.org/en/Publications/CR/Issues/2019/09/17/Bangladesh-2019-Article-IV-Consultation-Press-Release-Staff-Report-and-Statement-by-the-48682>
- ⁴ <https://www.imf.org/en/Publications/CR/Issues/2019/09/17/Bangladesh-2019-Article-IV-Consultation-Press-Release-Staff-Report-and-Statement-by-the-48682>
- ⁵ <https://chinadialogue.net/en/energy/bangladesh-may-ditch-planned-coal-power/>
- ⁶ <https://thefinancialexpress.com.bd/trade/chinese-loans-govt-to-drop-coal-plant-project-1584684501>
- ⁷ https://irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_Costs_2019_EN.pdf?la=en&hash=BFAAB4DD2A14EDA7329946F9C3BDA9CD806C1A8A#:~:text=Offshore%20wind%20and%20CSP%20projects,USD%200.075%2FkWh%20for%202021.&text=The%20cost%20of%20electricity%20from,82%25%20between%202010%20and%202019.
- ⁸ <https://thefinancialexpress.com.bd/national/introducing-floating-solar-pv-technology-in-bangladesh-1589818193>
- ⁹ <https://www.daily-sun.com/post/456358/Government-plans-to-install-floating-solar-panels>
- ¹⁰ <https://www.pv-magazine.com/2019/11/28/asian-development-bank-hails-bangladeshs-floating-pv-potential/>
- ¹¹ https://ieefa.org/wp-content/uploads/2020/06/Is-Combined-Floating-Solar-and-Hydro-the-Energy-Solution-for-ASEAN_July-2020.pdf
- ¹² <https://www.rechargenews.com/transition/fossil-fuels-given-3-1-trillion-subsidies-at-staggering-twenty-times-level-of-renewables/2-1-868319>
- ¹³ <https://www.irena.org/newsroom/pressreleases/2020/Jun/Renewables-Increasingly-Beat-Even-Cheapest-Coal-Competitors-on-Cost>
- ¹⁴ According to Bangladesh Bank data, depreciation of Bangladesh Taka against US Dollar in last 6 years is 1.41% p.a.
- ¹⁵ <https://www.indexmundi.com/commodities/?commodity=natural-gas&months=60>
- ¹⁶ <https://www.iea.org/data-and-statistics/charts/lng-import-prices-in-selected-countries-2010-2019>
- ¹⁷ <https://tbsnews.net/bangladesh/cost-unit-electricity-rooppur-be-tk-450-yeafesh-osman-123034>
- ¹⁸ According to Fraunhofer, PV and inverter price will be US\$ 15.86 per Wp and US\$ 3.4 per Watt by 2050. Accordingly, year-to-year average PV price has been derived.
- ¹⁹ <https://www.iea.org/reports/projected-costs-of-generating-electricity-2020>
- ²⁰ <https://www.irena.org/costs/Power-Generation-Costs/Wind-Power#:~:text=Offshore%20wind%2C%20with%20deployment%20of,Denmark%20was%20USD%200.087%2FkWh>
- ²¹ <https://www.irena.org/publications/2020/Jun/Renewable-Power-Costs-in-2019>
- ²² <http://www.renewableenergy.gov.bd/index.php?id=8> (as per status of 20th April 2021)
- ²³ Annual Report, 2019-2020, Bangladesh Power Development Board
- ²⁴ Power System Master Plan-2016, Bangladesh Power Development Board and JICA
- ²⁵ Grid Integration Requirements for Variable RE, ESMAP-2019
- ²⁶ <https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/>
- ²⁷ Solar Park | National Database of RE, SREDA
- ²⁸ Source: IDCOL
- ²⁹ Investment Plan for Bangladesh Under Scaling Up RE Program in Low Income Countries
- ³⁰ <https://www.thefinancialexpress.com.bd/views/views/grid-connected-renewable-energy-use-on-the-rise-in-the->

country-1606575383

³¹ https://www.bgmea.com.bd/page/Sustainability_Environment

³² IEA, "The Power of Transformation - Wind, Sun and the Economics of Flexible Power Systems", 2014; PSMP 2016.

³³ <https://www.agora-energiawende.de/en/publications/current-and-future-cost-of-photovoltaics/>

³⁴ Intended Nationally Determined Contributions 2015 (INDC)

³⁵ (https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Feb/IRENA_Innovative_ancillary_services_2019.pdf?la=en&hash=F3D83E86922DEED7AA3DE3091F3E49460C9EC1A0)

³⁶ https://ieefa.org/wp-content/uploads/2020/02/Paying-Less-for-More-Auctions-in-the-Philippines_February-2020.pdf



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