Draft

National Solar Energy Roadmap, 2021 - 2041

Submitted to

Chairman, Sustainable and Renewable Energy Development Authority (SREDA)
Power Division, Ministry of Power, Energy and Mineral Resources
Government of Bangladesh
&
National Project Director
Sustainable Renewable Energy Power Generation (SREPGen)
United Nations Development Programme (UNDP)

Date of Submission

14 December, 2020

Consultant

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Abbreviations and Acronyms

AC	Alternating Current
AMI	Automatic Metering Infrastructure
BAU	Business as Usual
BCCSAP	Bangladesh Climate Change Strategy and Action Plan
BDS	Bangladesh Standards
BERC	Bangladesh Energy Regulatory Commission
BEZA	Bangladesh Economic Zones Authority
BNEF	Bloomberg New Energy Finance
BoS	Balance-of-System
BRTA	Bangladesh Road Transport Authority
CDMP	Comprehensive Disaster Management Programme
CoD	Commercial Operation Date
COP	Conference of Parties
CPP	Captive Power Plant
CSP	concentrated solar power
DC	Direct Current
DPHE	Department of Public Health Engineering
FY	Fiscal Year
FYP	Five-Year Plan
EE	Energy Efficiency
EE&C	Energy Efficiency and Conservation
EPZ	Export Processing Zone
EZ	Economic Zone
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GOB	Government of Bangladesh
GW	gigawatt
GWh	gigawatt-hour
GW_p	gigawatt peak
FIT	Feed-in-Tariff
IEA	International Energy Agency
IDCOL	Infrastructure Development Company Limited
INDC	Intended Nationally Determined Contribution
IPP	Independent Power Producer
kW	kilowatt
kWh	kilowatt hour
kWh_e	kilowatt hour electricity
kW_p	kilowatt peak
kWh_{th}	kilowatt hour thermal energy
LCOE	Levelised Cost of Electricity
LGED	Local Government Engineering Department
LOI	Letter of Intent

LULUCF	Land Use, Land Use Change and Forestry
MOEF	Ministry of Environment and Forests
MPEMR	Ministry of Power, Energy and Mineral Resources
MSW	Municipal Solid Waste
$MtCO_{2e}$	million-ton equivalent of CO_2
MW	megawatt
MWh	megawatt-hour
MW	megawatt
MW_p	megawatt peak
NDLC	National Load Dispatching Center
NEM	Net Energy Metering
NREL	National Renewable Energy Laboratory
PCM	Phase Change Materials
PGCB	Power Grid Company of Bangladesh
PPA	Power Purchase Agreement
PPP	Public Private Partnership
PSMP	Power Sector Master Plan
PV	photovoltaic
ORPP	Quick Rental Power Plant
RE	Renewable Energy
REB	Rural Electrification Board
REC	Renewable Energy Certificate
RPS	Renewable Portfolio Standards
ROO	Rehabilitate, Own and Operate
ROT	Rehabilitate, Operate and Transfer
RPO	Renewable Energy Purchase Obligations
SCADA	Supervisory Control and Data Acquisition
SHS	Solar Home System
SIP	Solar Irrigation Pump
SMG	Solar Mini-grid
SPP	Small Power Plant
SREDA	Sustainable and Renewable Energy Development Authority
SREPGen	Development of Sustainable Renewable Energy Power Generation
UNEP	United Nations Environment Program
USD	United States Dollar
VAT	Value Added Tax
VNM	Virtual Net Metering
VRE	Variable Renewable Energy
W_p	watt peak

Executive Summary

Bangladesh is one of the world's most rapidly growing developing economies with extreme vulnerability to climate change. Both of these crucial aspects necessitate the inclusion of sustainable and renewable energy sources into the country's long-term development plans. An unambiguous vision backed by well-developed strategies are essential for the development of any sector, and renewable energy, especially the solar photovoltaic sector, is no exception to this. With active support from its various stakeholders, the Government of Bangladesh has already taken a few measures in this regard. However, the spectrum of potential benefits of clean and renewable energy technologies is yet to be fully appreciated and attained.

The report on *National Solar Energy Roadmap, 2021 - 2041* is an attempt realized under the framework of the 'Development of Sustainable Renewable Energy Power Generation (SREPGen)' project. This document will assist the framing of a long-term vision for the nation and to set achievable capacity targets for the country's solar energy sector; furthermore, it will also support outlining the broader strategies required to achieve those targets. After presenting three implementation scenarios, the Roadmap advocates in favor of these cases, backs one particular selection, and delineates a few general as well as specific and time-bound measures that will be necessary to achieve that target by the year 2041.

The document is structured into nine chapters. The introductory chapter sets the premise by briefly explains the sectorial background of Bangladesh including a short overview of RE energy potential and the relevant policy context. Chapter 2 presents a review of the global context of RE implementation with special emphasize on solar PV technology. It also touches on the future projection of growing energy demand and supply scenario by considering technological advancement. A brief review of strategies of a few countries and legislations that have declared high RE target is presented in this chapter as well. Chapter 3 describes the most recent component-wise status of solar PV energy implementation in Bangladesh. In Chapter 5, the national policy context is detailed followed by a few important insights that are very much relevant for the current undertaking. Chapter 5 proposes the component- and decade-wise solar PV capacity targets to be achieved in Bangladesh by the year 2041. Three possible scenarios are presented and the high deployment case along with appropriate rationale is endorsed for implementation. Chapter 6 suggests the general actions that can be undertaken to meet the targets as proposed in the previous chapter. The actions are presented in order of decades, and are also thematically categorized. Chapter 7 elaborates the specific actions for each component of the solar PV sector. Apart from presenting the limitations of the current undertaking, Chapter 8 also discusses the implementation challenges and the possible way outs. The concluding chapter summarizes the specifics of the Roadmap and offers several significant remarks for the policymakers.

One of the most important parts of the Roadmap (Chapter 5) presents and discussed three possible solar PV deployment scenarios: the base or BAU case, the medium, and the high case scenarios. While the BAU case is partially based on the PSMP 2016, the development of the mid and high case has been greatly influenced by the prospect of future resource availability, such as land, policy incentives, etc. The three cases project the solar PV installed capacity to be 6, 20, and 30 GW respectively by the year 2041. The Roadmap recommends that Government of Bangladesh (GOB) should consider opting for the high deployment case. It is to be emphasized that the realization of the high case will be, however, subject to a few important conditions. For instance, the realization of the *Bangladesh Delta Plan 2100* within the specified timeframe is imperative, and the reclaimed and accrued land allocation decision will also have the defining role. Equally important, if not more, would be the role of numerous stakeholders, since any energy transition is an essential cross-societal process.

However, the Roadmap proposes several doable actions or specific measures that should be undertaken in order to meet the targets proposed in Chapter 4. These actions are based on five broad themes. The most important suggestions are: (a) revise policy documents and set new renewable energy target, especially a solar energy target; (b) formulate policies and implement smart grid to tackle high shares of VRE; (c) introduce policies for large-scale storage system (grid) for peak shifting, shaving of load and VRE generation smoothing; (d) upgrade existing grid infrastructure, especially the transmission network to evacuate uninterrupted and high quality grid power according to the grid code for safe injection of generated power from solar plants; (e) develop capacity in terms of both institutional and human resources; (f) ensure availability of long term and concessionary financing through commercial financial institutes for RE; (g) mandate net metering for new industrial and commercial electric connections; (h) develop solar power hubs (by the Government) along with facilities of power evacuation infrastructure (transmission lines); and (i) include RE and EE&C based curriculum in the secondary level of education.

1 Introduction

1.1 Background

Both developing and developed nations across the globe have already started putting in varied and extensive efforts to adapt and to mitigate the adverse effects of climate change. Simultaneously, the necessity of availing universal access to sustainable and environment friendly sources of energy has been well established as a precondition for socio-economic development, particularly among the developing nations. Understandably, the widespread deployment and utilization of renewable energy (RE) has received its due focus and importance in the global arena of sustainability and climate change. In this context, the case of Bangladesh (a rapidly developing state and one of the most vulnerable countries to climate change) over the last decade is a worthy mention.

Even though the nation-state Bangladesh got its independence in 1971, the electricity utilization in the region started since 7 December 1901 at Ahsan Manzil, residence of the Nawab of Dhaka. Later power house was set up in Dhanmondi, and the journey of commercial distribution started back in 1930. In 1959, the Water and Power Development Authority (WAPDA) was created to take over the electricity generation system from the private sector. After the independence of Bangladesh in 1972, the government created the Bangladesh Power Development Board (BPDB) by separating it from WAPDA. The BPDB started its journey with only 547 MW installed capacity and the net electricity generation was 683 GWh (FY1971-1972).

After slow and steady progress for the two following decades, the sector underwent serious reforms. The post-reform condition of the sector changed dramatically leaving a noticeable mark on both the installed capacity and total net generation.

Figure 1.1 and Figure 1.2 shows the historical trend of cumulative total installed power and net generation of Bangladesh power sector (excluding captive power) until FY2019-2020. Bangladesh has seen remarkable growth in power sector since 2010.

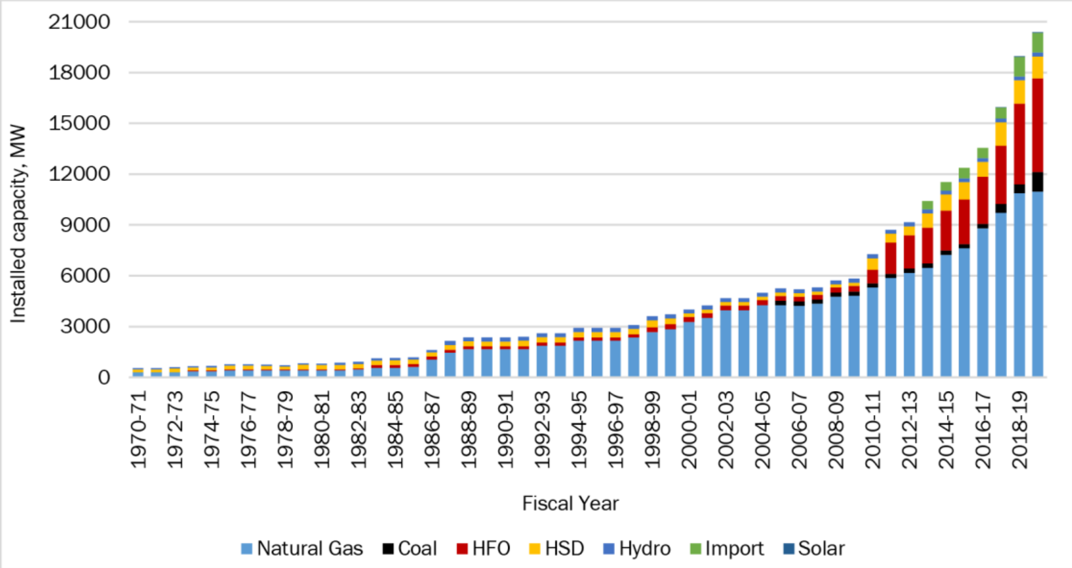


Figure 1.1: Historical Trend of Installed Power Generation Capacity of Bangladesh.

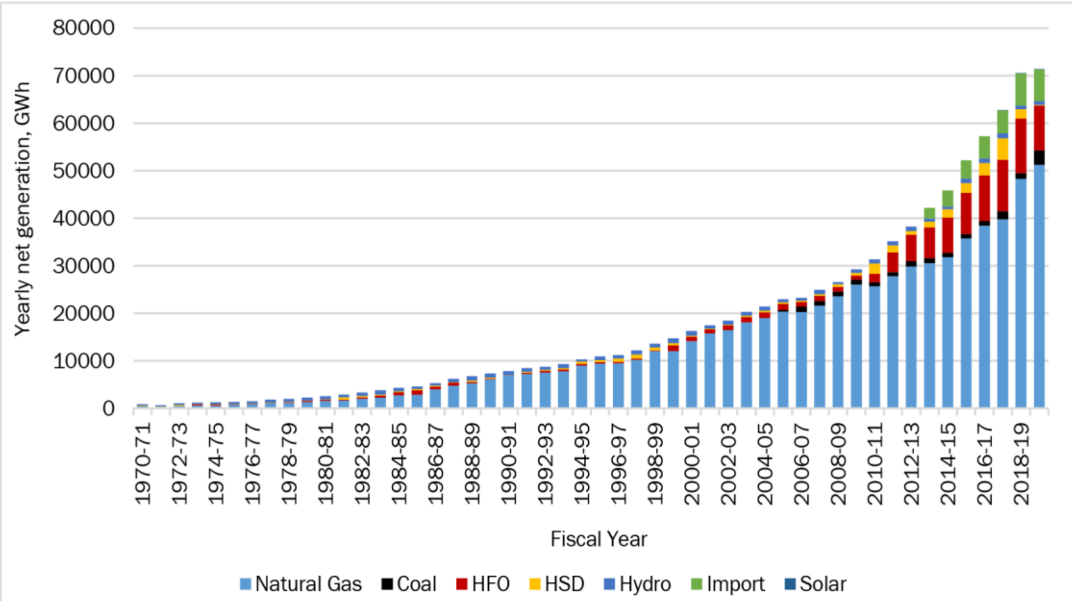


Figure 1.2: Historical Trend of Net Energy Generation in Bangladesh.

It is also worthwhile to look at the fuel mix trend of the country separately. Figure 1.3 Figure 1.4 show the historical trend of national fuel mix for installed capacity and net energy generation. It is visible from the figure that until 2010, domestic natural gas was the dominant fuel followed by oil. But the mix started to alter since 2010 with increasing percentage of liquid fuel (HFO and HSD). In FY2013-2014, another important addition took place that is the imported energy from neighbouring country (India). Country added its first ever solar PV project into the grid in 2017. The country is also preparing to launch its first nuclear power plant.

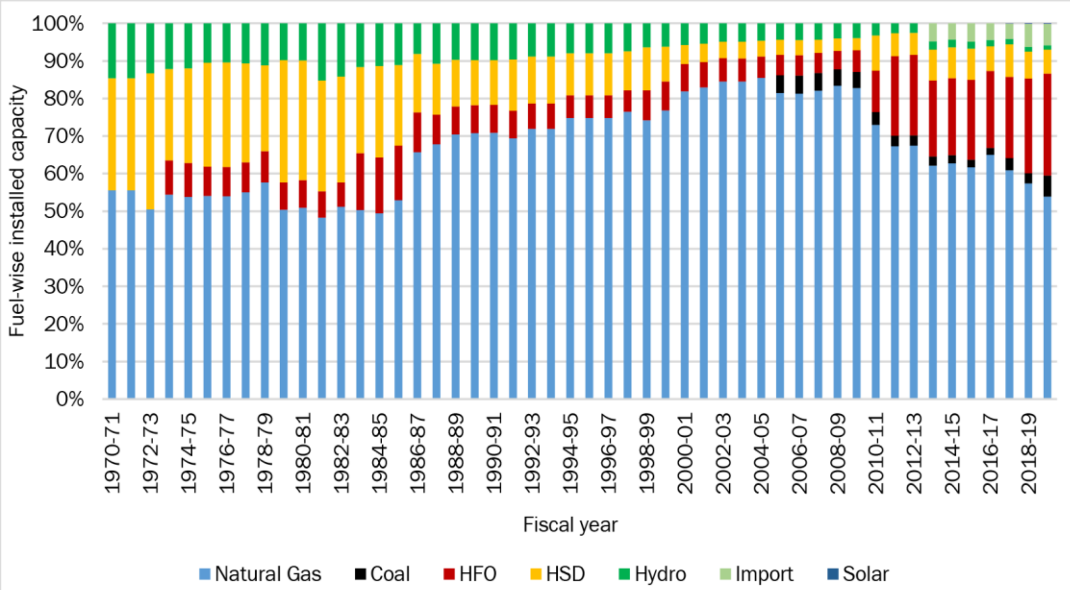


Figure 1.3: Historical Trend of Fuel-wise Installed Capacity.

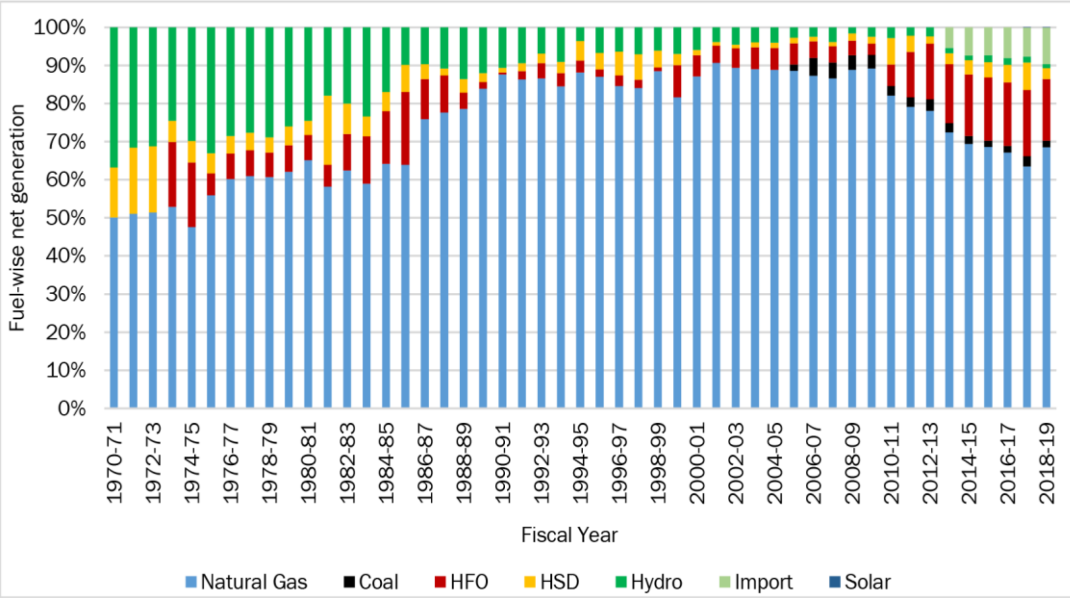


Figure 1.4: Historical Trend of Fuel-wise Net Energy Generation.

The Government of Bangladesh has taken up number of initiatives to enhance the penetration of Renewable Energy. One such initiative is the preparation of Renewable Energy policy that mandates at least 10% of the total generation to be generated from RE sources. The intention is not only to reduce the greenhouse gas emissions, but also to ensure energy security for the nation. In order to promote RE resources and to achieve the RE target in the total generation mix, the GOB has taken 500 MW Solar Programs in 2012. In this program, the private sector has been identified as one of the vital partners. Special emphasis has been given on RE development programs by allowing unsolicited private projects under the "Power & Energy Fast Supply Enhancement (Special Provision)

Act, 2010". Besides this 500 MW solar program, the government initiated programs like the Solar Home System (SHS), solar mini-grid, solar rooftop, solar irrigation, etc. with an aim to scale up the contribution of renewable energy in the country. But the present progress of RE development program is not satisfactory.

In addition to the sectorial needs, the development of RE sources is also very important to meet the national and international goals and targets. After successfully achieving the targets of Millennium Development Goals (MDG), Bangladesh is now committed towards the Sustainable Development Goals (SDG) of the United Nations. The Goal 7 relates to energy, where "substantially increase the share of renewable energy in the global energy mix" is one of the major targets. The Intended Nationally Determined Contributions (INDC) are reductions in greenhouse gas emissions under the United Nations Framework Convention on Climate Change (UNFCCC). All the member countries of UNFCCC were asked to publish their INDCs at the United Nations Climate Change Conference. Bangladesh has made a commitment in its NDC to reduce GHG emissions unconditionally 5% by 2030 in the power, transport and industry sectors and a conditional 15% reduction in GHG emissions by 2030. Besides these, the national plan and programs such as, the Bangladesh Climate Change Strategy and Action Plan (BCCSAP), Power System Master Plan 2016 (PSMP), the Five-Year Plans, etc. have highlighted and focused on the development of RE resources.

Recognizing the need for promoting RE, the GOB has established Sustainable & Renewable Development Authority (SREDA) with the objectives to promote, develop & co-ordinate RE activities and to ensure energy security & sustainability. SREDA has already conducted potential assessment on solar, wind, bio-mass, municipal waste etc. Recently, they have formulated the *Net Metering Guidelines* for solar rooftop systems. The organisation is also trying to identify and solve the barriers for the development of RE resources. Nevertheless, the share of RE in the total power generation is much less than the policy target to achieve 10% of the total generation. Among the other RE resources, solar PV is the most potential and proven technology in Bangladesh. Hence, SREDA has taken initiative for the preparation of "Solar Energy Road Map" to achieve the goals of SDG, NDC and to meet the targets of REP, PSMP, FYPs, BCCSAP, etc.

All these efforts indicate that fuel mix diversification has become a clear priority in order to ensure future energy security since the prospect of domestic fossil fuel resource development started to appear increasingly dim, especially that of domestic natural gas supply. However, opting for other forms of fossil fuels, such as coal, will certainly pose severe environmental threats and raise serious questions about the country's commitment towards a sustainable future. On the other hand, the increased reliance on imported fuel and direct power has its own set of multidimensional drawbacks.

Therefore, for Bangladesh, one of the most effective ways to simultaneously address environment, economy and energy security concerns would be the widespread deployment of renewable energy technologies closely coupled with smart grid and large-scale storage facilities in the long-run. In this regard, preparation of a "National Solar Energy Road Map, 2021–2041" is essential.

Combating climate change with renewables

National plan and policy related documents articulate the Government of Bangladesh's (GOB) intention to contribute to adaptation and mitigation measures in alignment with the global endeavor. According to the NDC report, under the Business As Usual (BAU) scenario greenhouse gas (GHG) emission from the power, transport and industrial sectors shall account for "69% of the total emissions by 2030 (excluding Land Use, Land Use Change and Forestry or LULUCF)," resulting in 234 $MtCO_2e$ (an increase of 264% with respect to the level in 2011) [1]. The emission reduction contribution intended by the GOB is stated in the following **Table 1.1**.

Table 1.1: Nationally Determined Contributions – Mitigation **[1]**.

Unconditional Contribution	Assuming no additional international support	Bangladesh will reduce its GHG emissions in the power, transport, and industry sectors by 12 $MtCO_2e$ by 2030 or *5% below BAU* emissions for those sectors.
Conditional contribution	Assuming additional international support	Bangladesh will reduce its GHG emissions in the power, transport, and industry sectors by 36 $MtCO_2e$ by 2030 or *15% below BAU* emissions for those sectors.

Reasonably enough, all the above-mentioned documents thus also emphasize the importance of RE technologies due to their low emission features. The BCCSAP has declared 'Renewable Energy Development' to be its fourth program under the fifth theme titled 'Mitigation and Low Carbon Development'. The stated objective of the program is 'maximizing the use of RE sources to lower GHG emission and ensuring energy security' [2].

Sustaining economic growth with renewables

Energy access is a very crucial element towards achieving sustained economic growth as it relates to other important developmental challenges like poverty, gender inequality, rural development, food security, health and education services, etc. It is, in fact, one of the indicators of SGD progress assessment. But access to energy has both quantitative and qualitative aspects. Also, energy is required by a multitude of locales, such as household applications, productive and community purposes. Specially, the productive uses of energy—ranging from agriculture to small and medium enterprises, industries, etc.—directly relate to the economic productivity of the country.

Very recently, Bangladesh has satisfied the conditions of attaining the status of "lower middle-income" economy and articulated its vision to become a developed economy by 2041 [3]. The draft *8th Five-Year Plan* (FYP) of the Government has set the country's average GDP growth target to be 8.37% during the five-year period (FY2020-2021 to FY2024-2025) [4]. To achieve this, not only the existing electricity generation capacity should be significantly increased in order to meet the growing demand, but the energy access frontier must be expanded to include the entire population. The issue of universal energy access has already appeared in the vision statement of the Power Division of GOB. It envisions to provide quality electricity for all citizens by 2021 “through integrated development of power generation, transmission and distribution network” [5].

Renewable energy sources can play important roles in sustaining the current economic growth or, on a broader sense, drive the country towards sustainability. In recent years RE sources, especially the solar PV solutions, have been instrumental in pushing the energy access frontier around the world. Bangladesh’s Solar Home System Programme has earned global reputation in this regard. But as mentioned earlier, the energy access is not a binary phenomenon anymore. It is the quality of energy access, and not merely the quantity, that is more crucially related to the economic developments. The majority of productive applications require higher quality (or grid-quality electricity) measured in terms of the amount and time of supply, reliability, voltage, emissions, affordability, etc. However, it may not be always economically and technically feasible to extend the national grid to cover the entire population. Even in such cases RE technologies are proving themselves to be extremely valuable, and sometimes indispensable.

At this point it is worthwhile to take a brief look into the potential of various RE sources in Bangladesh.

1.1.1 Overview of RE Potential in Bangladesh

Bangladesh is bestowed with a few forms of renewable energy sources, the most promising of which is the solar energy. The country receives moderate level of solar radiation on daily basis (GHI ≈ 4.5 kWh/m^2), which can be converted into reasonable sources of energy via either the thermal or the photovoltaic route. The thermal route, however, is still quite capital- and technology-intensive and also require direct or bean sunlight for its operation. On the other hand, the photovoltaic route is increasingly proving itself to be technically and economically viable. A geographical distribution of photovoltaic power potential is shown in the **Figure 1.5**.

The data shown in the figure represents long-term average between the years 1999 to 2018. The map reveals that the south-eastern part of the country (including the Kaptai lake area) holds higher potential when compared to the rest of the country. It is also interesting and very crucial to note that the southern coastal belt, especially the Meghna estuary region has quite sizeable photovoltaic power potential. For large-scale solar PV capacity deployment, the most suitable spots or locations are likely to be found in these regions.

The next most promising source of RE in Bangladesh is the bioenergy that includes biomass and biogas. Biomass itself covers a wide range of materials starting from firewood, agricultural crops to 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 easily stored and transported. Many studies have attempted to assess the biomass potential available in Bangladesh. But the inherently non-homogenous nature makes the estimation of potential a complex and difficult task. However, in order to provide a sense of proportion, one study can be cited that 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 [6].

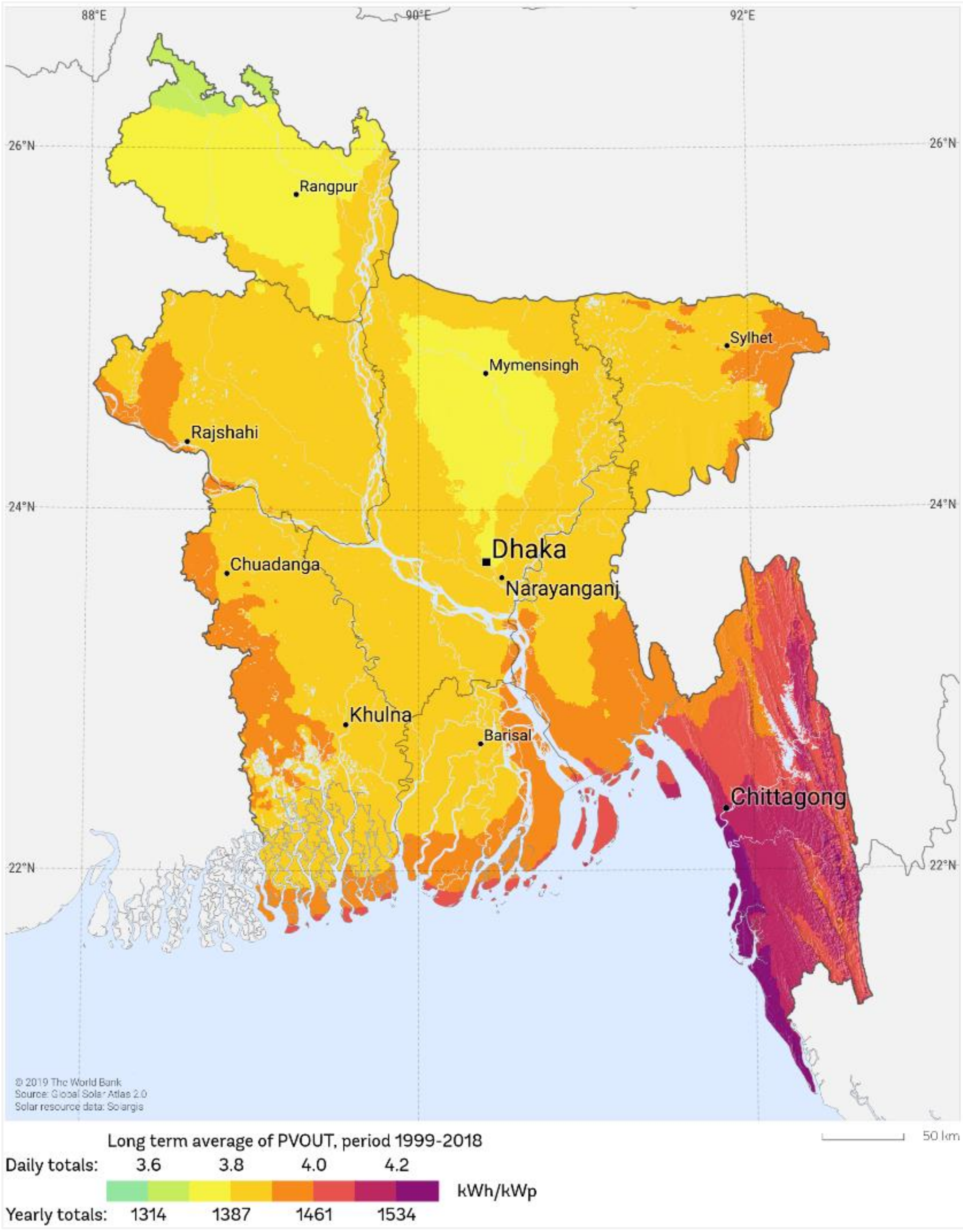


Figure 1.5: Photovoltaic Power Potential in Bangladesh (Source: ESMAP).

The utilization of biomass as a reliable source of power and fuel poses many challenges. For instance, production of some of the biomass feedstock depends on the season and time of the year. Use of forest and agricultural biomass may even lead to concerns related to deforestation and food security. Another important concern is the non-homogeneity of biomass composition, which become acute in case of municipal solid waste (MSW). Such wastes typically include wet food waste, textiles, glasses, plastics, metals, paper, wood, etc. requiring an additional step to separate glasses, metals, and other various valuable components in the energy extraction process. Unfortunately, in Bangladesh, adequate waste management and recycling practices are still not enforced, and waste composition data is available only for 6 major municipal corporations. The uncertainty of biomass generation from MSW can be easily demonstrated by citing two journals. While one paper report generation of nearly 19.8 million tons of biomass from MSW in the FY2011-2012 [7], the other one report the value to be around 13.8 million tons in FY2012-2013 [6].

The third most important RE source in Bangladesh is wind energy. But the resource still largely remained inadequately explored. The most recent attempt has been a study conducted by the Power Division, Ministry of Power, Energy and Mineral Resources (MPEMR), Bangladesh through NREL with support from the USAID. 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 km^2 of land with a gross wind potential of over 30,000 MW” [8]. But the study emphasized that the estimate to be still unrealistic since it does not filter out unsuitable land (already developed, environmentally sensitive, etc.). The report concludes that site specific detailed feasibility study will be needed for project formulation and to respond to more specific question related to competitiveness of wind power in the local energy market.

However, this has been a really important first step in the wind resource history of the country. Within the framework of this project, a web tool for wind resource assessment has been developed and launched. **Figure 1.6** shows both on- and off-shore wind resource (in terms of wind speed) distribution in Bangladesh at 4 different altitudes. From the figure, it is visible that the southern part of Bangladesh (coastal region) has higher wind potential. The wind power potential increases as the hub height increases. But higher hub height in coastal region is challenging to realize for Bangladesh considering the cyclone prone coastal region.

Among other types of RE sources are hydro and geothermal. Despite being a riverine country, the hydropower potential of Bangladesh is greatly limited by the geographical as well as geopolitical realities. Power Cell conducted a hydropower potential assessment study in the South-East part of Bangladesh through the consulting firm M/s. Stream Tech Inc., USA. The study result showed very limited mini- and micro-hydro potentials on the Sangu, Matamuhuri, and Bakkhali rivers that need detailed feasibility assessments. As for geothermal energy, there are indeed 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 technical or even theoretical potential of geothermal energy is still far from realization [6].

Therefore, it is only reasonable to state that among all types of RE sources, solar energy, especially solar PV technology is the most relevant and promising one for Bangladesh. It has experienced a remarkable growth trend globally in the last few years as well. The global weighted average Levelized Cost of Electricity (LCOE) of large-scale solar PV plants has significantly dropped, while the market has grown and investment has increased. The overall prospect is most optimistic for solar PV technology in the world as well as in Bangladesh.

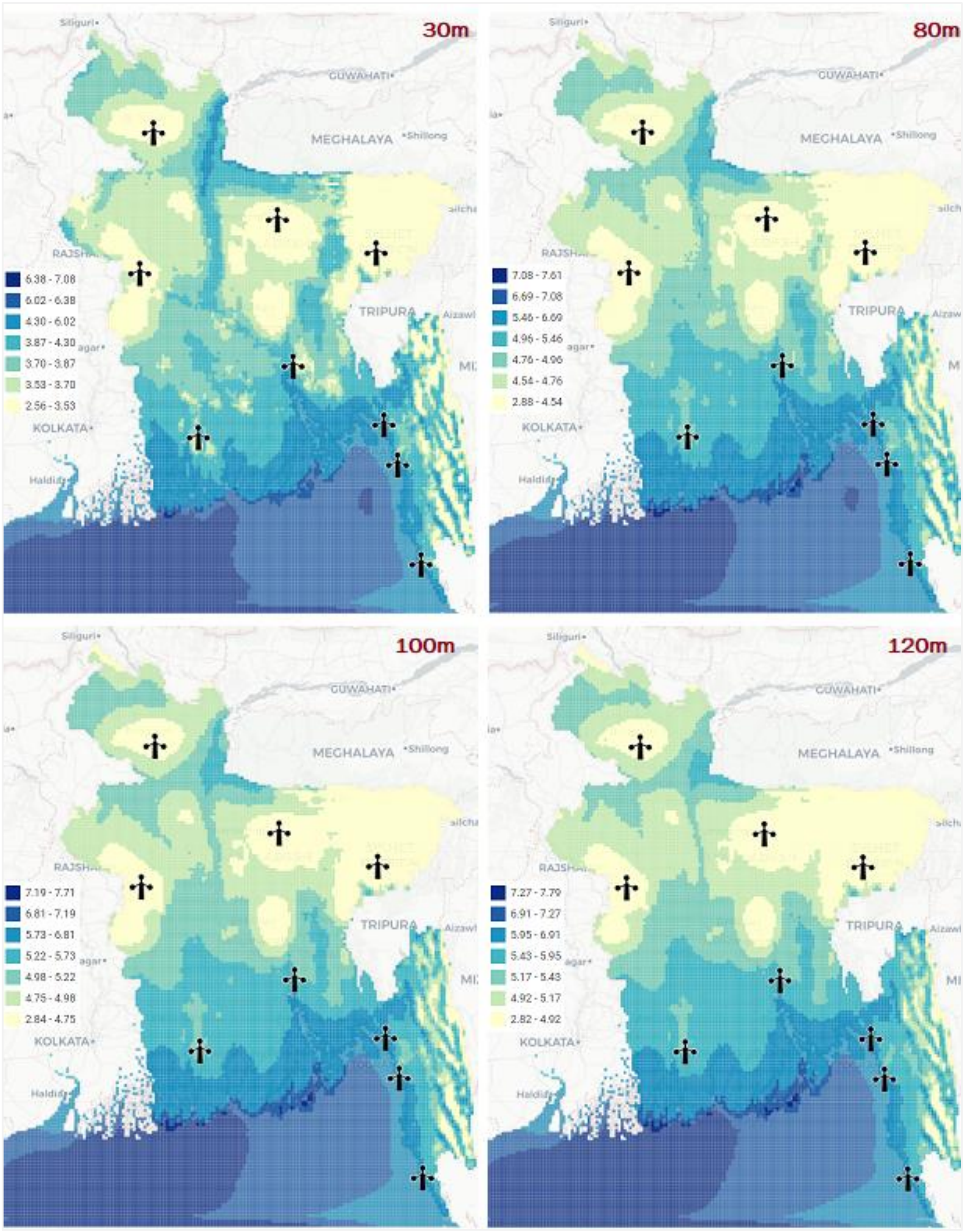


Figure 1.6: Wind Speed Distribution over Bangladesh at 30m, 80m, 100m, and 120m (Source: RE Data Explorer, NREL, USAID).

1.1.2 Policy Context of RE Utilization in Bangladesh

The Power Division of GOB has already started investing notable resources in expanding the national grid and developing the RE based off-grid electrification sector. It has developed and launched the *Renewable Energy Policy* in the year 2008 with multiple important objectives [9]. This policy document mandates that 10% of the total *power demand* by 2020 should be sourced from various RE sources. In absolute terms, this means that at least 2,000 MW has to be generated from RE sources by 2020. Very recently, the Power Division has also launched the *Net Metering Guidelines-2018* [10], and RE based options have been included in the 'Bangladesh National Building Code' for some time now. All these efforts manifest the Government's sincere commitment towards propagating RE usage and building a sustainable future for Bangladesh.

Establishment of SREDA and dissemination of solar PV in Bangladesh

The *Renewable Energy Policy* of 2008 has laid the foundation of Sustainable and Renewable Energy Development Authority (SREDA) with a broader aim to increase and promote the utilization of RE in the local domain. Apart from launching programs such as the *Guidelines for the Implementation of Solar Power Development Program-2013*, *500 MW Solar Program 2013*, and developing *Energy Efficiency and Conservation Master Plan up to 2030*, SREDA has set a Roadmap for the renewable energy sector development up to the year 2020, which is provided in **Table 1.2**.

As of July 2020, the installed capacity of RE has reached up to 650 MW including 230 MW of hydropower [11]. Most of the recent capacity addition is from standalone solar systems, generally referred to as Solar Home Systems (SHSs). There are 5.8 million cumulative installations of SHSs in predominantly off-grid areas of Bangladesh, making it the largest off-grid RE program in the world. Despite huge potential, grid-connected electricity consumers are yet to reap the benefits of solar energy. Every on-grid household and commercial or industrial consumer can utilize solar energy—the most dispersed form of energy—to generate electricity by installing solar PV panels on their own rooftops. They can become electricity producers, meet their electricity demand partly or fully by themselves and can even sell excess electricity produced to the distribution according to the scope of the Net Metering Guidelines.

Table 1.2: Sector-wise Renewable Energy Roadmap Set by SREDA.

#	Program	2017	2020
1.	Solar Park	3 MW	700 MW
2.	Solar Home System	205 MW	252 MW
3.	Solar Mini-grid/Micro-grid/Nano-grid	2.69 MW	7 MW
4.	Solar Irrigation	14 MW	46 MW
5.	Rooftop Solar Program- Net Metering	0 MW	600 MW

#	Program	2017	2020
6.	Rooftop Solar Program- Others (including new connection)	30 MW	50 MW
7.	Solar Drinking Water System	1.6 MW	6 MW
8.	Solar Powered Telecom Tower	8 MW	15 MW
9.	Solar Street Light	2.3 MW	5 MW
10.	Hydro Power Plant	230 MW	230 MW
11.	Wind	2.9 MW	30 MW
12.	Biomass (Biogas, Biomass, Waste) to Electricity	0.5 MW	20 MW
13.	Others (Vehicle, Aquaculture, Boat, Pico system)	1 MW	10 MW
	Total	**501 MW**	**1971 MW**

With the end of the 7th FYP fast approaching, it is only reasonable to reflect upon the passing decade of RE development in the country, assess the status of the set targets and, if required, and devise new targets for the coming decades. In doing so, a practical, financially feasible and technologically robust roadmap shall provide the necessary direction to the stakeholders. In such a context, the present task under the framework of SREDA's project the 'Development of Sustainable Renewable Energy Power Generation (SREPGen)' aims to develop a solar energy roadmap for the time period 2021 to 2041.

1.2 Objectives of the Roadmap

The broader objective of the SREPGen project is to reduce the annual growth rate of GHG emissions from fossil fuel-based electricity generation systems by utilizing Bangladesh's RE resource for electricity. Through this project, support will be provided to SREDA to achieve a considerable share of RE in the country's energy mix by promoting its widespread use. In doing so, the present document is prepared with the specific aim of assisting SREDA to develop a solar energy roadmap from 2021 to 2041.

The roadmap will propose the prospective future solar power generation scenario of the country that is developed based on a general global outlook of the sector, analysis of current impending barriers faced by the national RE sector, examples of neighboring countries, technological advancements, etc. The roadmap aims to identify and recommend potential financing sources and market enhancement ways, policy requirements and technological ways forward. It will translate these goals in to doable actions. The main objectives of the Solar Energy Roadmap are:

a) Increase share of RE in the total energy mix;
b) Ensure energy security and sustainability;
c) Attract private investment in RE projects;
d) Achieve global and national RE generation targets; and
e) reduce the rate of GHG emissions.

The detailed scope of the work presented in Appendix A: Scope of the Roadmap.

2 Global Status of Energy and Solar Energy Applications

The world has observed remarkable growth in modern RE-based technologies over the last decade. In fact, the year 2017 in particular has experienced the largest ever increase in renewable power capacity as a consequence of decreasing costs, increasing investments and noticeable advances in enabling technologies. This chapter of the Roadmap aims to set the premise for setting future targets and devising the way forward for Bangladesh by first exploring and analyzing the global solar PV landscape.

2.1 Global Energy Consumption and Supply Trend

In the last couple of years, the world has seen a sustained rise in the global primary energy consumption, especially in power consumption. According to the *BP Statistical Review of World Energy* reports, the annual change in global primary energy consumption in 2017 and 2018 have been +2.2% and +2.9% respectively. **Figure 2.1** below depicts the annual change in global primary energy consumption from 2000 until 2018. In fact, the consumption growth rate of 2018 has been recorded as the fastest since 2010, while the 3.7 % power demand increase has been labelled as one of the strongest growths in the last 20 years [12, 13].

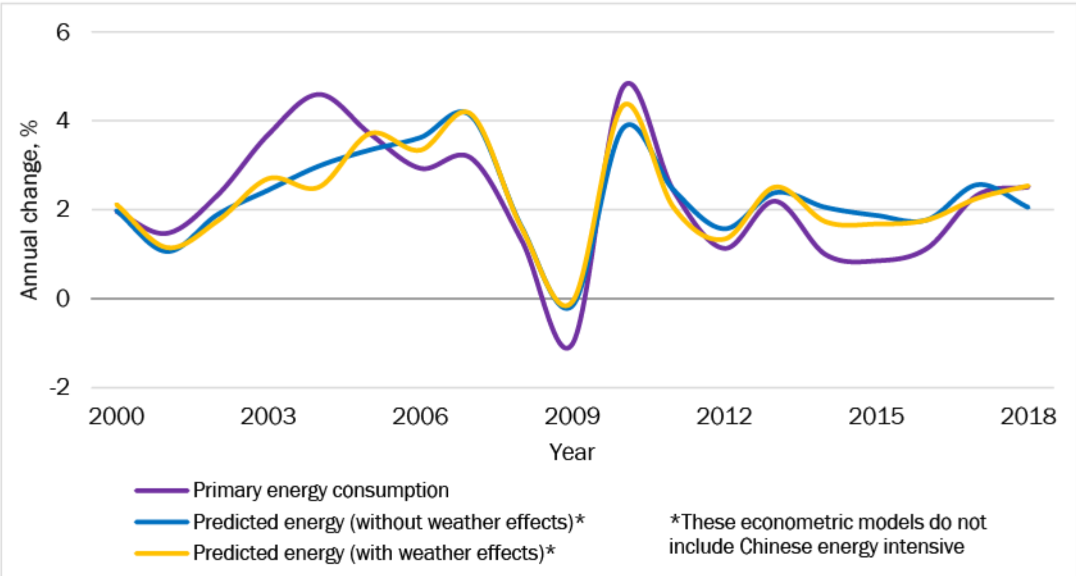


Figure 2.1: Global Primary Energy Consumption Growth Trend up to 2018 **[12].**

But the energy consumption growth rate has slightly decelerated in 2019. According to *BP Statistical Review of World Energy 2020*, the growth rate has been +1.3% in 2019, owing much of it to the widespread use of renewables and natural gas. These energy sources have considerably displaced coal from the energy mix resulting in a sharp decline in emissions when compared to previous years. Even though oil remained the dominant fuel, the trend of increasing share of RE sources in the world's primary energy mix has been particularly visible over the last two decades (as shown in **Figure 2.2**). In 2019, renewable sources (including hydro) have met nearly 11% of the world's primary energy demand. Considering electricity generation only, the share of renewables mounts to 10.4%, surpassing nuclear power generation for the first time [12, 14].

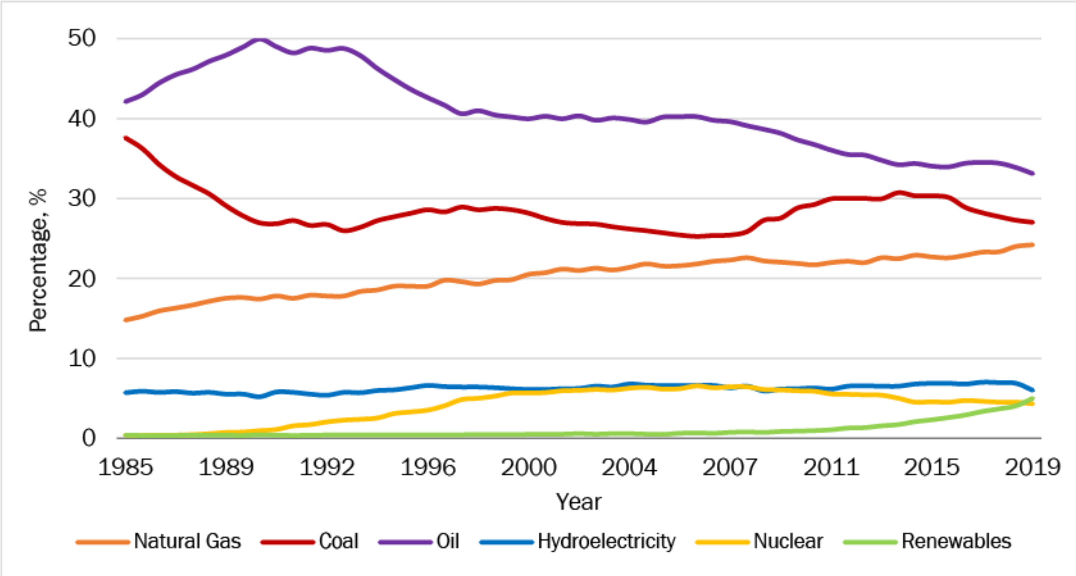


Figure 2.2: Increasing Shares of RE in Primary Energy Consumption **[12, 14]**.

Considering the power sector alone, the year 2017 had seen a 17% increase in RE power utilization, which was higher than the previous 10-years average and the largest increment until then [15]. In 2018, RE sources experienced a comparatively stable global market, while supplying over 26% of the total global electricity generation [16]. But 2019 has been another record-setting year for renewables as over 200 GWs of power capacity has been installed across the globe. For the last five consecutive years, net RE power capacity addition has surpassed net fossil fuel and nuclear installations combined. While public policy is again identified as the major force influencing the RE markets, the private sector has signed power purchase agreements for a record amount of RE capacity. This trend can be attributed largely to the declining cost of certain RE technologies [17].

The *REN21 Renewables 2020 Global Status Report* also provides some commentary on the effect of the global COVID-19 pandemic that hit the world in early-2020 and will definitely leave enduring impacts on the RE sector. Renewables have been the sole source of electricity to experience 'growth' in the Q1 of 2020. Distributed RE systems proved to be vital during this time period. But the growth did not come without major challenges; ranging from electricity networks faced with an unparalleled share of RE generation to project development hampered by labor and supply chain disruptions [17].

Among various types of RE technologies, the market for solar energy has been notably expanding in recent years. According to the *REN21 Renewables 2020 Global Status Report,* solar PV alone is way ahead of all other renewables in terms of annual capacity additions leaving behind even wind and hydro power as shown in **Figure 2.3**. Considering the growth in total electricity generation, however, solar energy came second only to wind energy in 2019 [14]. Other forms of solar energy technologies like the concentrated solar power (CSP), solar heating, solar cooling and air conditioning, etc. lag way behind solar PV power.

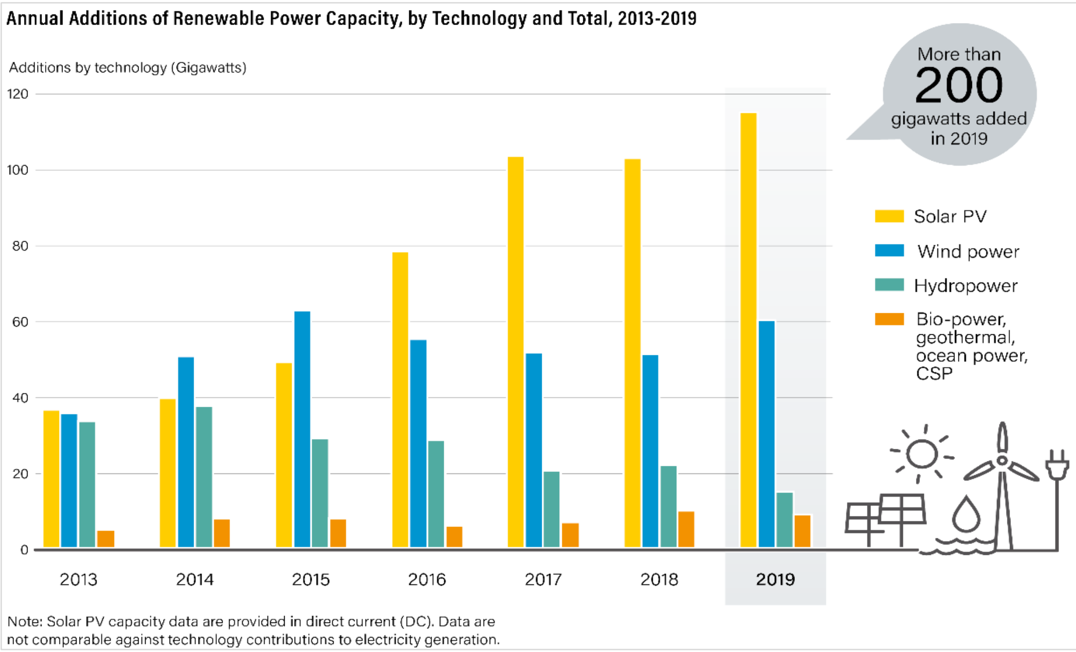
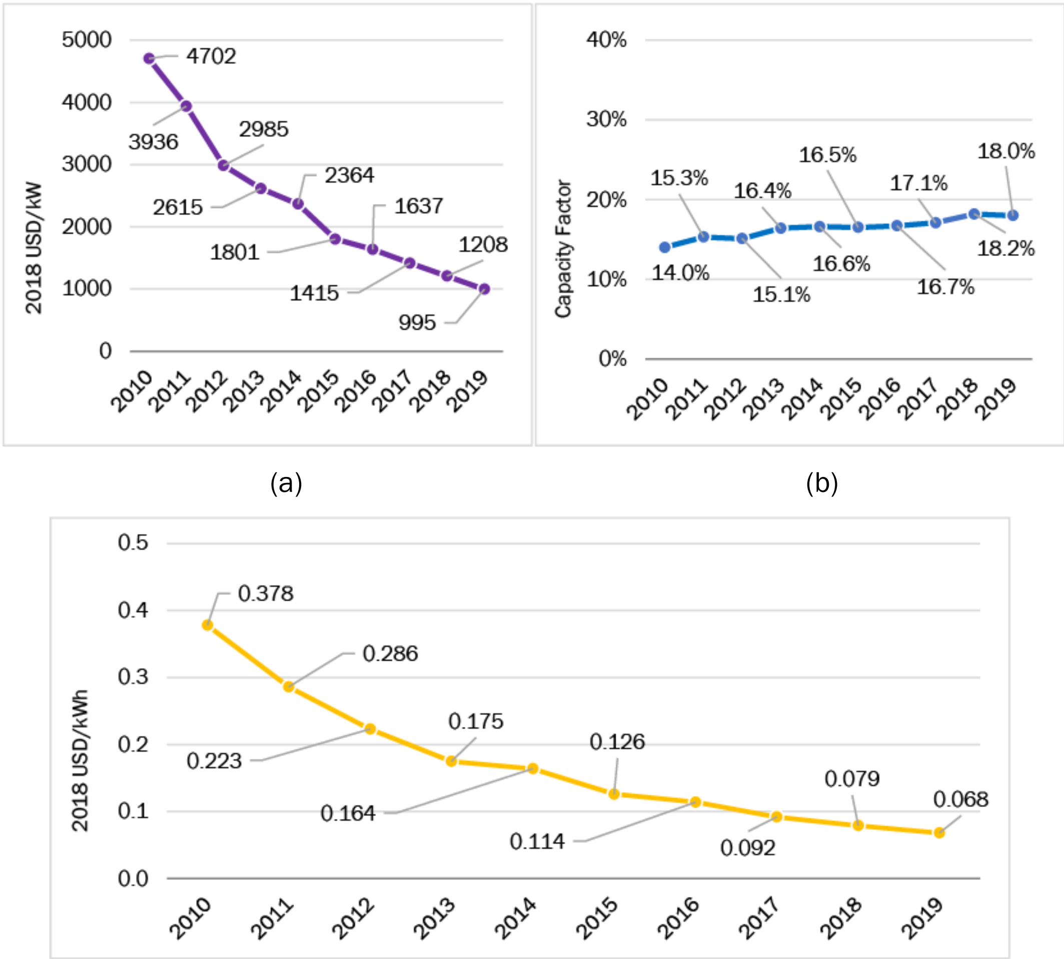


Figure 2.3: Trend of Annual Power Capacity Addition by RE Technology from 2013 to 2019 **[17]**.

The leading status of solar PV power holds true in terms of global electricity generation as well. Reports published by various international organizations like the British Petroleum, International Energy Agency (IEA), etc. present evidence in support of solar PV supplying the highest annual growth of global electricity among all the renewables [14, 18]. Therefore, it is reasonable to assume that solar PV will continue to dominate sustainable energy scenario. The sustained growth of solar PV power across the globe has been mainly due to the decreasing capital cost of the utility-scale projects. **Figure 2.4** shows the trend of total installed cost, capacity factor (CF), and LCOE over the last decade.



(a) (b)

(c)

Figure 2.4: Trend of (a) Total Installed Cost, (b) Capacity Factor and (c) LCOE of Solar PV Power until 2019 **[19]**.

The global weighted-average total installed cost sharply dropped by 79% to US$995/kW by the end of 2019, a drop below US$1000/kW for the first time ever. This drop has been caused largely by the cost reduction of solar PV system components and O&M costs and increasing CF. Within the same time period, the global weighted-average CF increased steadily from 13.8% to 18% as a result of increased use of tracking facilities in large-scale projects, deployment in areas with comparatively higher radiation, reduction in systems losses, etc. All these have ultimately brought down the global weighted-average LCOE for utility-scale solar PV projects to US$0.068/kWh by the end of 2019, a 82% reduction when compared to 2010 [19].

As a result, solar PV continued to become exceedingly cost competitive and the industry has experienced a significant rise all across the world. **Figure 2.5** shows the global solar PV demand and the utility-scale system price, starting from 2007 and projected up to 2022. It is apparent from the figure that with growing demand, the economic viability of large-scale solar PV projects is most likely to increase in the coming years as well. The *Global Renewables Outlook: Energy transformation 2050* report published by IRENA in 2020 predicted that by 2030 the global weighted-average LCOE for solar PV projects will decrease by 58% when compared to 2018 [20].

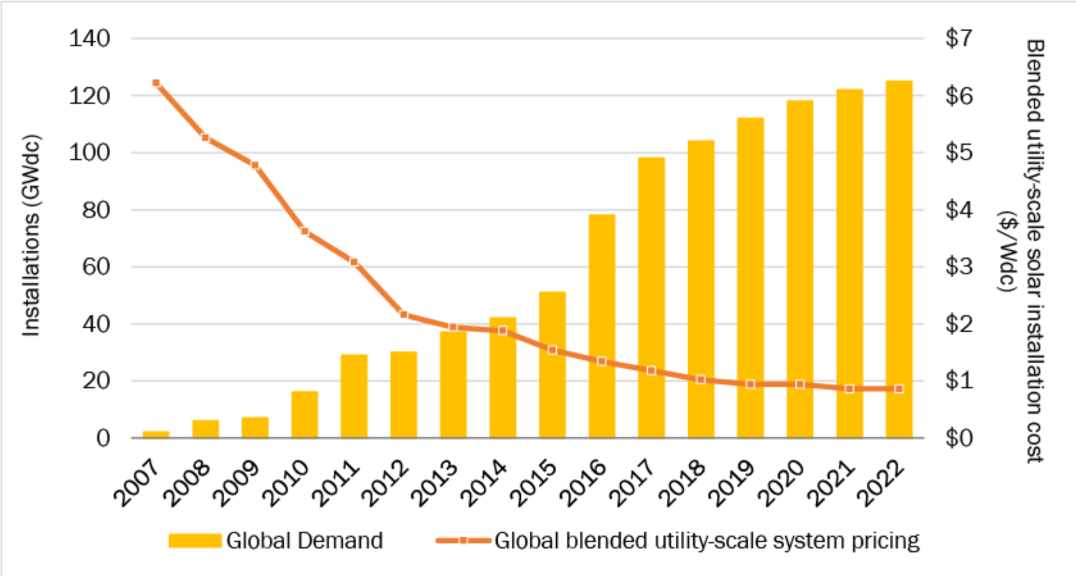


Figure 2.5: Global PV Demand and Utility-scale System Pricing, 2007–2022E **[21]**.

Apart from just the decreasing price of system components, several other factors contribute to make solar PV a sustainable and economically feasible energy option. Policy-drive, investment trends, technological advances, etc. play equally important and inter-related roles in the wide-spread deployment of solar PV systems. The subsequent sections intend to focus on these other aspects of the solar PV industry and then analyze reasonable future projections. But the analysis is begun first by taking a look into the latest solar PV market and industry trend.

2.2 Market and Industry Trend of Solar PV

In this section, the developments in the solar PV market and industry over the last decade are discussed with emphasis on the last three years. **Figure 2.6** demonstrates the number breakdown of new installations by country or region over the last ten years [17]. The figure clearly shows that new solar PV capacity additions have been on the rise since 2009.

In 2017, more solar PV capacity had been added than any other type of power technology, *even higher than net additional capacity of fossil fuels and nuclear power combined*. In several markets such as China, India, Japan, USA, etc. solar PV acted as the largest source of new power capacity [15]. In the following year, the trend remained true for all the RE sources combined, while solar PV dominated among the renewables. Nearly 100 GW of additional solar PV power capacity were added to the existing lot, totaling up to 505 GW. Even though the Chinese market experienced a major declining trend, greater demand in Europe and other emerging markets overcompensated the effect on the global scale [16].

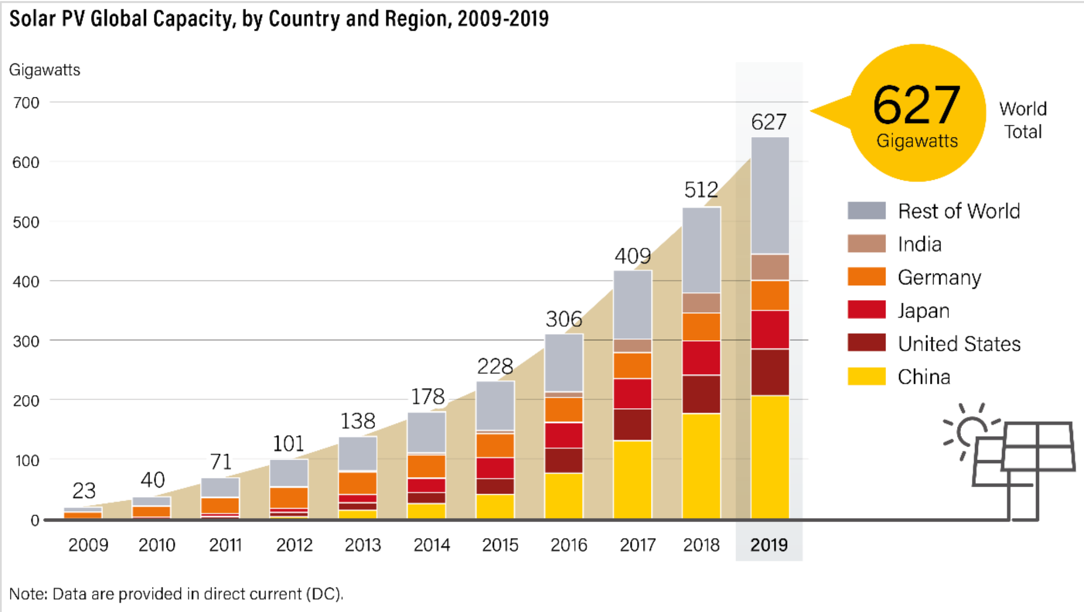


Figure 2.6: Solar PV Global Capacity Addition by Country or Region, 2009–2019 (Source: *Renewables 2020, Global Status Report*).

The upward trend for solar PV continued throughout 2019 as well, resulting in an addition of 115 GWs, reinforcing solar PVs as the leading source in 'new' electricity generation capacity. The **Table 2.1** provides the list of top players in the global solar PV market by the end of 2019 [16].

Table 2.1: Leading Countries of Global Renewable Energy Sector in 2019 **[17].**

New Solar PV capacity additions	Cumulative capacity
China (30.1 GW)	China (176.1 GW)
USA (13.3 GW)	USA (62.4 GW)
India (9.9GW)	Japan (56 GW)
Japan (7.0 GW)	Germany (45.3 GW)
Vietnam (4.8 GW)	India (32.9 GW)

Solar PV is increasingly proving itself to be one of the most competitive power solutions in many locations across the globe—for residential, commercial applications and utility-scale projects alike. For instance, even though the lion's share of the Chinese cumulative capacity comes from some of the world's largest solar plants, significant portion (approximately 40.5%) of the recent addition owes to the distributed systems [22]. The share of distributed capacity continued to rise and reached 43.5% by the end of Q1 of 2020. Considering decentralized and rooftop solar sector, India is following similar direction which is apparent from the country's 2015-policy dedicated to pursuing a low-carbon pathway. The policy has allocated a massive 40 GW out of total 100 GW solar capacity to be added through decentralized and rooftop systems. Clear emphasize has been put on commercial and industrial (C&I) rooftop systems, which are expected to undergo a huge expansion in the upcoming post-COVID years [23]. Among the developed countries, Germany has successfully amassed huge rooftop capacity until now. By June 2019, the country's rooftop capacity had already reached 48 GW [24]. It is of some interest to note the difference in incentive mechanism adopted by these two countries. While it has been long for Germany to have sided with the Feed-in-Tariff scheme, the Indian government opted for net energy metering in recent years to tap the huge potential of rooftop solar PV power.

However, overall, there has been an astounding 14-fold global growth in solar PV capacity between the years 2010 and 2019. For the last three consecutive years, annual solar PV capacity addition has been over 100 GWs. Such market expansion has resulted due to the combined effect of decreasing component and O&M costs, increasing CF resulting into reduction of total installed cost and LCOE, growing competitiveness, strong policy-drive, rising demand and spreading awareness about the potential of solar PV as a low emission and off-grid energy solution [17].

Since the reduction of solar PV installed cost can be mostly attributed to dropping prices of various solar PV system components, such as modules, inverters and balance-of-system (BoS), it is worthwhile to investigate the decreasing price trends of different solar PV system components separately. The following sub-sections are dedicated to such discussions.

Government incentives and regulations have been playing a key role in spreading the awareness about RE technologies and thus fostering the demand for solar PV power. But still challenges remain in terms of unstable regulatory framework in many states, financial viability and bankability, etc. Growing share of solar PV power must be effectively integrated in a fair and sustainable fashion into electricity systems under varying technical and market conditions. Resistance from traditional system operators in dealing with variable solar power has decreased over the decade. Utilities across the globe are increasingly getting involved in the deployment and operation of large-scale solar PV plants as well as medium to small-scale distributed generation. Corporate purchasing and self-consumption have also played an important role in driving the emerging market of distributed systems. But, policy support in terms of regulatory and incentive scheme concerning grid-integration of distributed solar PV is still not adequate in many countries [17].

Price trend of solar PV modules and panels

Various sources report that a considerable portion of the solar PV technology cost reduction trend should be attributed to the declining price of solar PV modules [21, 25]. Between the years 2013 and 2018, 15-40% of the cost reduction of solar PV energy can be credited to the declining average selling price of modules [21]. So, the declining module price has significant effect on the cost of solar PV power. But, as shown in **Figure 2.7**, the module cost drop varies depending on the market and technology. For example, the cost of various types of crystalline Silicon modules declined between 87% to 92% between 2010 and 2019 in Europe. **Figure 2.7** testifies strongly in favor of thin film module price trend as well, depicting a sharp price drop mainly between 2011 and 2013. Such sharp decline in module cost has been driven by multiple factors, such as technological advancement resulting in improved module efficiencies; improved manufacturing process like diamond-wire sawing reducing the material cost; labor cost has been reduced owing to enhanced productivity and increased factory automation; economies of scale in manufacturing; increased competition among suppliers, etc. [19].

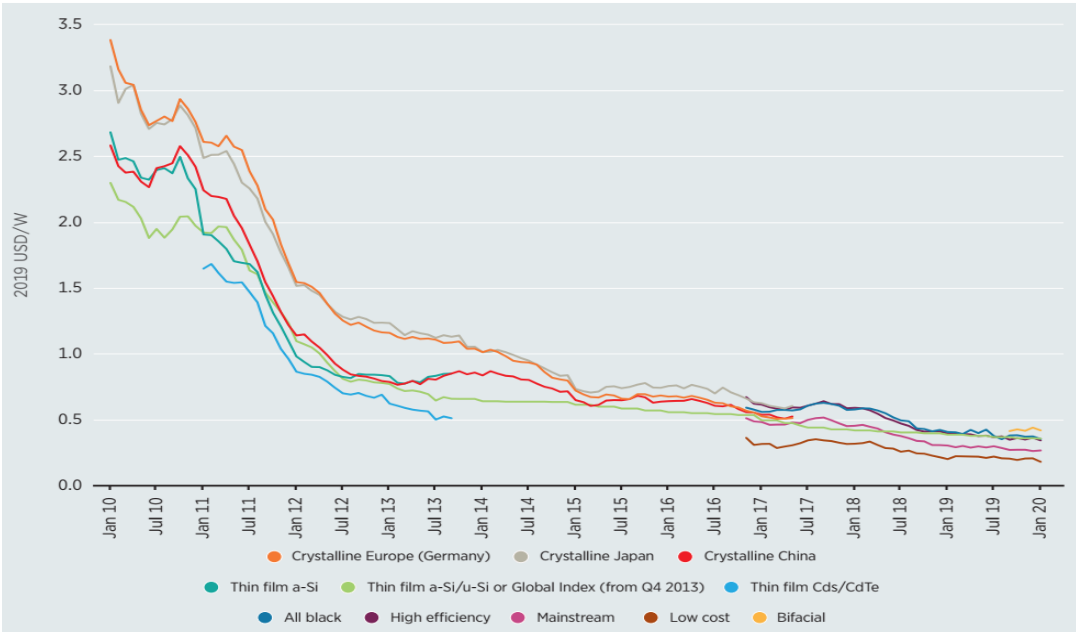


Figure 2.7: Decade-long Global Average Selling Price Trend of Various PV Modules [19].

As shown in **Figure 2.6**, the global solar PV market continues to rely heavily on China. In the first quarter of 2018, China installed a massive 9.64 GW capacity of solar PV power [26]. A GTM Research study published in May 2018 predicted that, until the Q2 of 2023, the global average selling price for Chinese Tier 1 Crystalline Silicon PV modules will continue to drop. In a similar context, the Bloomberg New Energy Finance (BNEF) predicted a decline in the price of the mono-crystalline Si solar panels by 34% by 2018 followed by a further 10% to 15% drop in 2019 [27]. A simulation of 625 auction-tariff scenarios by WoodMac analysts place the median price of solar PV at 2 $cents/kWh in 2022 [28].

However, the Chinese Government issued a notice on 31 May 2018 placing rigid limits on solar PV installations that require subsidies [29]. China's decision to curb solar development efforts in 2018 caused another surplus in supply of solar PV modules leading to a substantial drop in their prices worldwide. Partially due to this phenomenon and other equally contributing factors discussed above, the declining price trend continued in such a way that it defied all predictions. As of May 2020, the price of high efficiency crystalline modules in the EU market has dropped 0.37 US$ cents (according to pv-magazine.com, a website that publishes solar PV module price index for EU market on a monthly basis [30]). But in the Chinese market, panel prices range between US$0.17 and US$0.25. If the trend continues, it can be safely stated that solar PV will continue to become increasingly competitive and economically feasible in the coming decades.

Market and price trend of solar PV inverters

Another key component of solar PV system is the inverter which converts the DC output produced by solar panels into AC power suitable for household appliances. The global solar PV inverter market can be segmented as depicted in **Table 2.2** [31]. Among the three types of inverters mentioned in the table, the central type continues to acquire the largest share of the global solar inverter market, especially the utility-scale market.

Table 2.2: Global Solar Inverter Market Segmentation [31].

Global Solar Inverter Market			
By type:	*By system type:*	*By end-user:*	*By region:*
- Central	- On-grid	- Residential	- North America
- String	- Off-grid	- Industrial & Commercial	- Europe
- Micro		- Utilities	- Asia Pacific
			- Rest of the World

The increasing deployment of solar PV power has already induced inverter prices to decrease sharply, and it is expected to drive the solar inverter market in future as well. The highly competitive market is seeing emerging Chinese manufacturers with existing western ones relentlessly adding to their product paraphernalia. A report by IHS Markit predicted that such efforts are to elicit a fall in prices of solar inverters by 6% from 2018 to 2023 [32]. In September 2017, Market Research Future predicted the global solar inverter market to experience a Compound Annual Growth Rate of 15.65% from 2017 to 2023 [31]. However, the most optimistic of such predictions has been made by a report by IRENA in 2016. According to this report, inverter costs could go down by 33-39% between 2015 and 2025, owing mainly to technological progress and economies of scale driven by the increased presence of Asian players in the international market [33].

Price trend of Balance-of-System (BoS)

According to the latest IRENA report *Renewable Power Generation Costs in 2019*, the combined price reduction effect of modules and inverters accounted for nearly a 62% drop of the global weighted-average total installed cost between 2010 and

2019. This leaves BoS to be a significant cost reduction component, consisting of nearly 64% of the solar PV project cost by the end of 2019. Lower installation cost, racking cost, BoS hardware and a range of smaller categories contributed to 13%, 7%, 3% and 15% of the global weighted-average total installed cost reduction respectively. The major drive has been global competition, growing installer experience, sharing of best installations practices, soft costs, module efficiency enhancement, etc. [19].

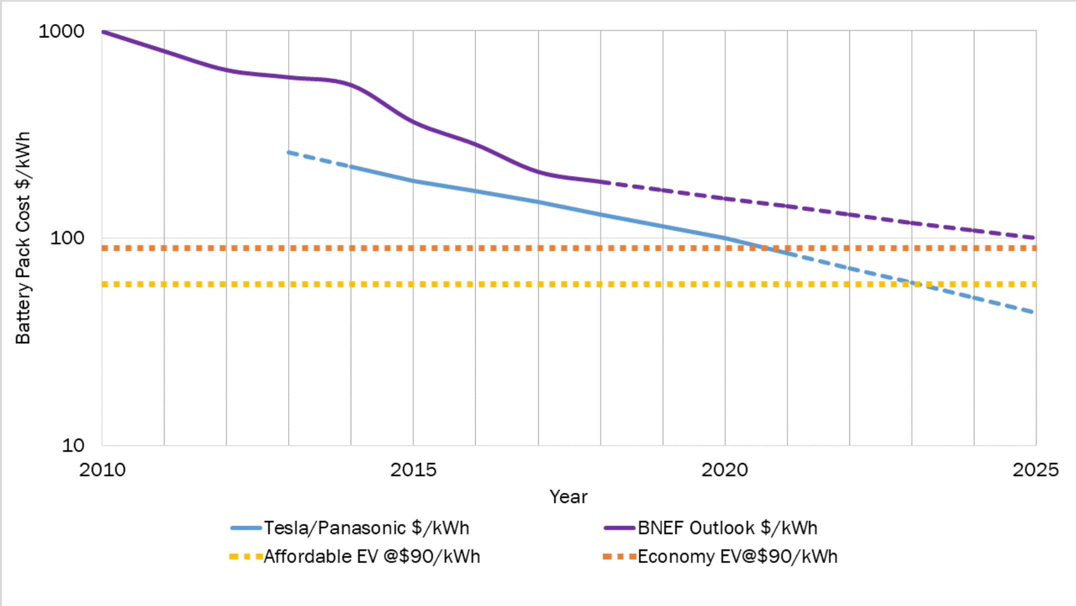
Price trend of battery storage technology

One of the major challenges to solar PV systems for large-scale installation is the intermittent or variable nature of solar power. Therefore, in the coming decades, utility-scale battery storages are expected to play an indispensable role in increasing the share of Variable Renewable Energy (VRE). From the perspective of system operators, they can offer grid services, such as frequency regulation, black start services, flexible ramping, etc. Battery storages can also defer investment in peak generation and grid reinforcements [34, 35].

The US experienced a record year in 2019 for new battery installation adding 523 MW (1,113 MWh), closely followed by China with 520 MW (855 MWh). The case of Australia is also mention-worthy since in the same year they have installed 143 MWh of grid-scale battery capacity [17]. But batteries have been infamous for their high price in the past years, costing around US$10,000 per kWh in the 1990s' [36]. The increasing popularity and potential of electric vehicles (EVs) has induced massive investments in battery technology leading to both market growth and drop in prices.

Lithium (Li) ion batteries, for instance, reached a global market share of USD 45 billion in 2018 and the forecast is to exhibit a Compound Annual Growth Rate (CAGR) of 11% during 2018–2023 [37]. In 2019, they have attracted huge investment and the global manufacturing capacity has been greatly expanded. IHS Markit, in one of its reports, mentions a decline in price of Li-ion batteries by nearly 70% between 2012 and 2017, which makes implementation of cost-effective utility-scale solar storage a feasible reality [38]. A trend line for the battery pack cost of one of the front runners of Li-ion battery producers, Tesla, tracked by BNEF is presented in **Figure 2.8** [39]. According to BNEF's prediction, market-average trend will be slightly less steep than the price trend of Tesla, and by 2025, Li-ion batteries will cost US$100 per kWh.

However, all these estimates mostly concern the transport sector. Li-ion batteries used in stationary applications have a higher installation cost owing to complicated charge/discharge cycles. A report by IRENA predicts that, depending on the battery chemistry, Li-ion batteries may witness a drop in its installation cost price ranging from $145/kWh to $480/kWh [40]. But still Li-ion batteries remain the most prevalent and mature types when it comes to utility-scale battery storage. Their dominance can be largely attributed to the high specific energy and power, high round-trip efficiency, sufficient operational temperature range, high reliability, long calendar and cycle life, low self-discharge rate, satisfactory charging speed, etc. [41]



Note: Cost axis is Log scale, dashed lines are estimated data

Figure 2.8: Trend Data for Battery Pack Cost—Tesla vs. Market Average, according to BNEF Research **[39]**.

2.3 Investment Trend

As the world shifts its momentum towards the green movement, investment in the RE sector is witnessing a remarkable proliferation. Global new investment in renewable power and fuel has been far exceeding any other power technologies for a couple of consecutive years now. Renewables secured nearly 71.2% of global investment in new power capacity 2019, while the value was 58.2% and 65% in 2017 and 2018 respectively [15, 16, 17]. **Figure 2.9** shows the global trend of investment on renewable power and fuel capacity over the last decade. It reveals that 2019 is the 10th year in the row that has seen over USD 200 billion annual RE capacity investment. In 2019, globally, a massive USD 282.2 billion was invested in new renewable power and fuels projects, excluding hydropower projects greater than 50 MW and renewable heating and cooling endeavors. This amount corresponds to a level that was 3 times the combined investment in coal, natural gas and nuclear [17].

However, the global investment scenario can be further delineated based on region or economy, type of technology, type of investment, etc. For the last five years, developing and emerging economies have topped developed economies in renewable investment. Even though the Chinese government's 2018-decision to suspend financial support for solar PV sort of stalled the Chinese market, it still holds the status of largest RE investor. The technology-wise breakdown of new global investment in renewable energy in 2019 is depicted in **Figure 2.10**. It is apparent from the figure that solar power and wind have far outweighed other RE technologies in 2019. While speaking to *The Guardian*, the executive director of

International Energy Agency (IEA), Dr. Fatih Birol forecasted that solar PV's growth will be higher than any other renewables until 2022 [42].

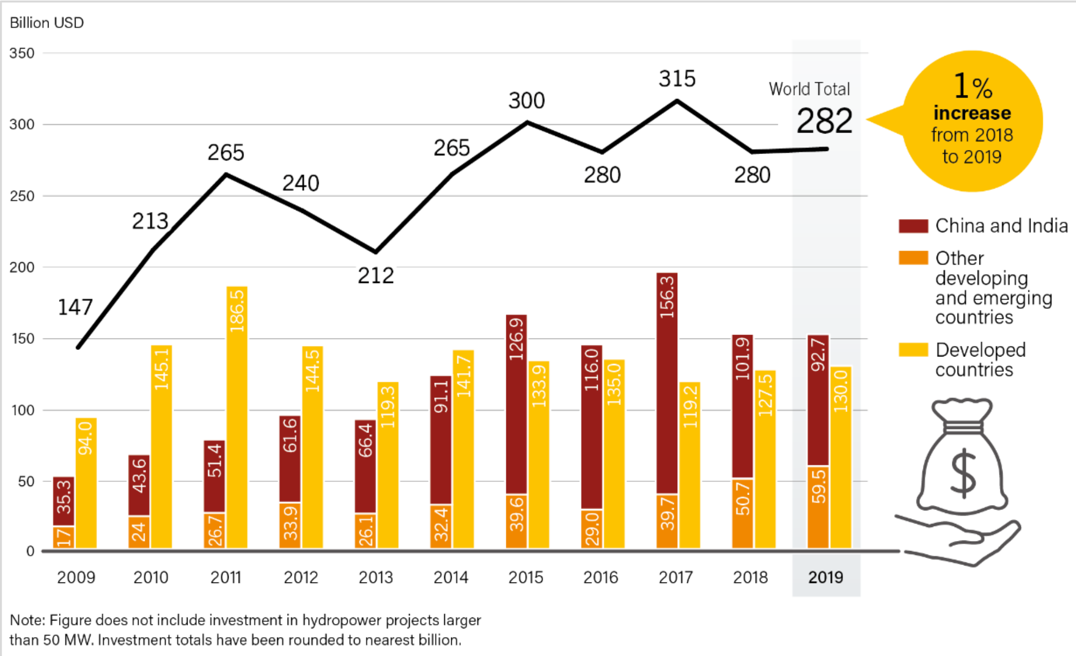


Figure 2.9: Global New Investment in Renewable Power and Fuels in Developed, Emerging and Developing Countries over the last decade (Source: [17]).

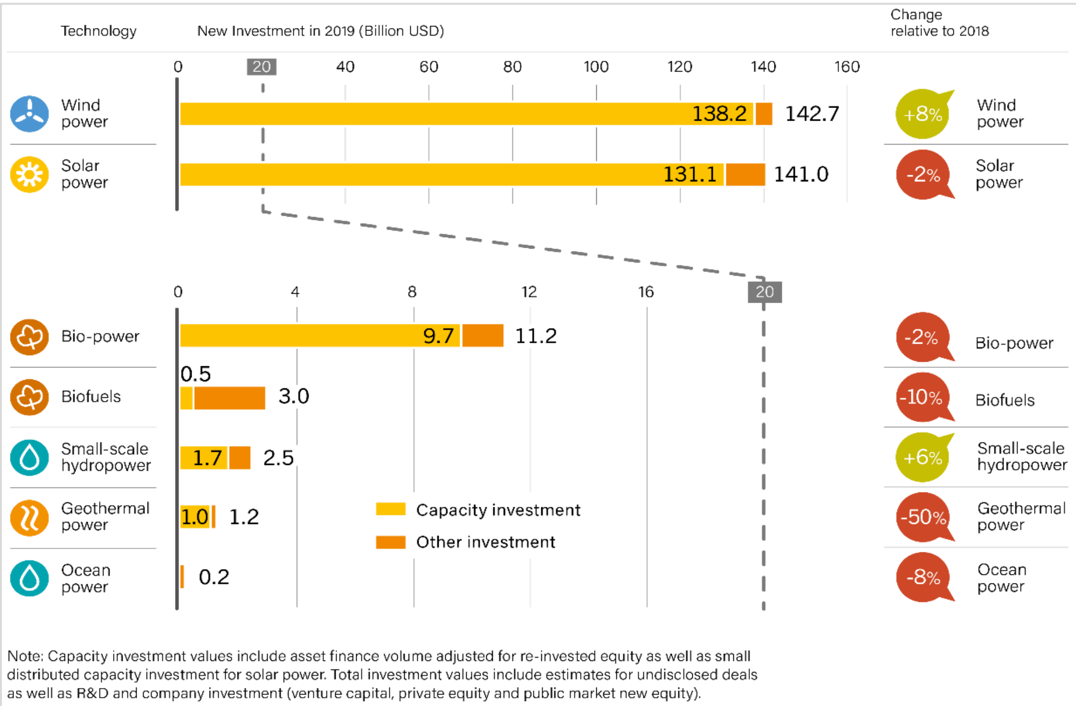


Figure 2.10: Global New Investment in Renewable Energy by Technology in 2019 (Source: [17]).

As for the avenues of investment, **Table 2.3** shows a pretty clear picture [16]. In 2019, asset financing of utility-scale projects accounted for the most of the investment (sustained trend for the last 4 years), seconded by acquisition activities followed by small-scale distributed capacity investment. Investment in solar PV projects of less than 1 MW capacity increased by 37% from last year. Public and corporate bodies have invested nearly USD 13.4 billion for research and development in 2019. Solar power was the receiver of the largest R&D investment among all renewables.

Table 2.3: Investment in Various Aspects of Renewable Energy Technologies [17].

Investment avenue	Amount of investment
Asset finance	230.1 billion USD
Acquisition activity	100.7 billion USD
Small-scale distributed capacity investment	52.1 billion USD
Corporate and government R&D	13.4 billion USD
Public market investment	6.6 billion USD
Venture capital and private equity	3.0 billion USD

The RE projects are financed by a variety of sources ranging from commercial, national and multilateral development banks, independent power producers, utilities, industries and corporate companies, etc. For instance, since its inception in 2008 by the World Bank, the green bonds are becoming increasingly popular and earning credibility as sustainable financing scheme. In 2018, USD 167.3 billion worth green bonds have been issued, and nearly one-fourth of this investment intent is assigned to the energy sector [43]. The values reached a record high of USD 257 billion in 2019 [17].

The continued popularity of large-scale solar PV projects is largely due to its record low prices in government auctions, which are increasingly becoming comparable to the prices of fossil fuels. Following the line of discussion, it is especially mention-worthy that since 2011, the divestment from fossil fuel in gaining momentum every year. Organizations ranging from insurance companies, private and public pension funds, banks, governments, non-governmental and faith-based institutions, health, cultural and educational institutions, etc. are committing to fossil fuel divestment.

However, all of these divestments are not necessarily directed to companies associated with RE [17]. Efforts must be regulated in that direction. IRENA reports that to achieve its 'Transforming Energy Scenario' (for details see **Section 2.6**) by 2030, nearly USD 9.6 trillion of cumulative investment would be required to scale up renewable power to the desired capacity level [20].

2.4 Research and Development Trend

Aligning with the market, policy and investment trends, the solar PV power sector has attracted the largest share of the global renewable R&D efforts as well. The technological innovation is stretched along the entire value chain—from materials, module manufacturing, applications, O&M practices to decommissioning and end-of-life management of panels. The most common research goals include but are not limited to the following:

a. Increase efficiency of the available technologies.
b. Find new efficient ways of converting and storing solar energy.
c. Find methods of reducing the costs.

Solar PV cell material and module technology

According to NREL's (National Renewable Energy Laboratory) *Best Research-Cell Efficiency Chart* (updated periodically), the highest efficiency for a single crystal non-concentrator Silicon cell stands at 27.6% and that of multi-junction concentrator cell at 47.1% as of April 2020 (as shown in **Figure 2.11**) [44]. NREL also publishes *Champion Module Efficiency* chart and updates it on a regular basis (**Figure 2.12**).

In order to push these efficiency levels further up, researchers from across the globe are propounding and investigating new materials as well as advanced solar cell architectures. Apart from Silicon-based cell materials, scientists and researchers are looking into materials like dye sensitized, polymer and Perovskite materials. They are is also investigating techniques such as "improved light trapping; multiple-junction cells to capture more of the sunlight spectrum, multiple excitation generation and quantum dot cells, and plasmonic and hot carrier cells" [45].

An article published in *Solar Guide* highlighted a hybrid carbon/silicon solar cell which scientists at Yale University have fabricated by combining carbon nanotube technology with crystalline silicon materials in an attempt to boost the efficiency [46]. Among the emerging module architectures are bifacial cells, half cells, multi-busbars, solar shingles, etc. [47].

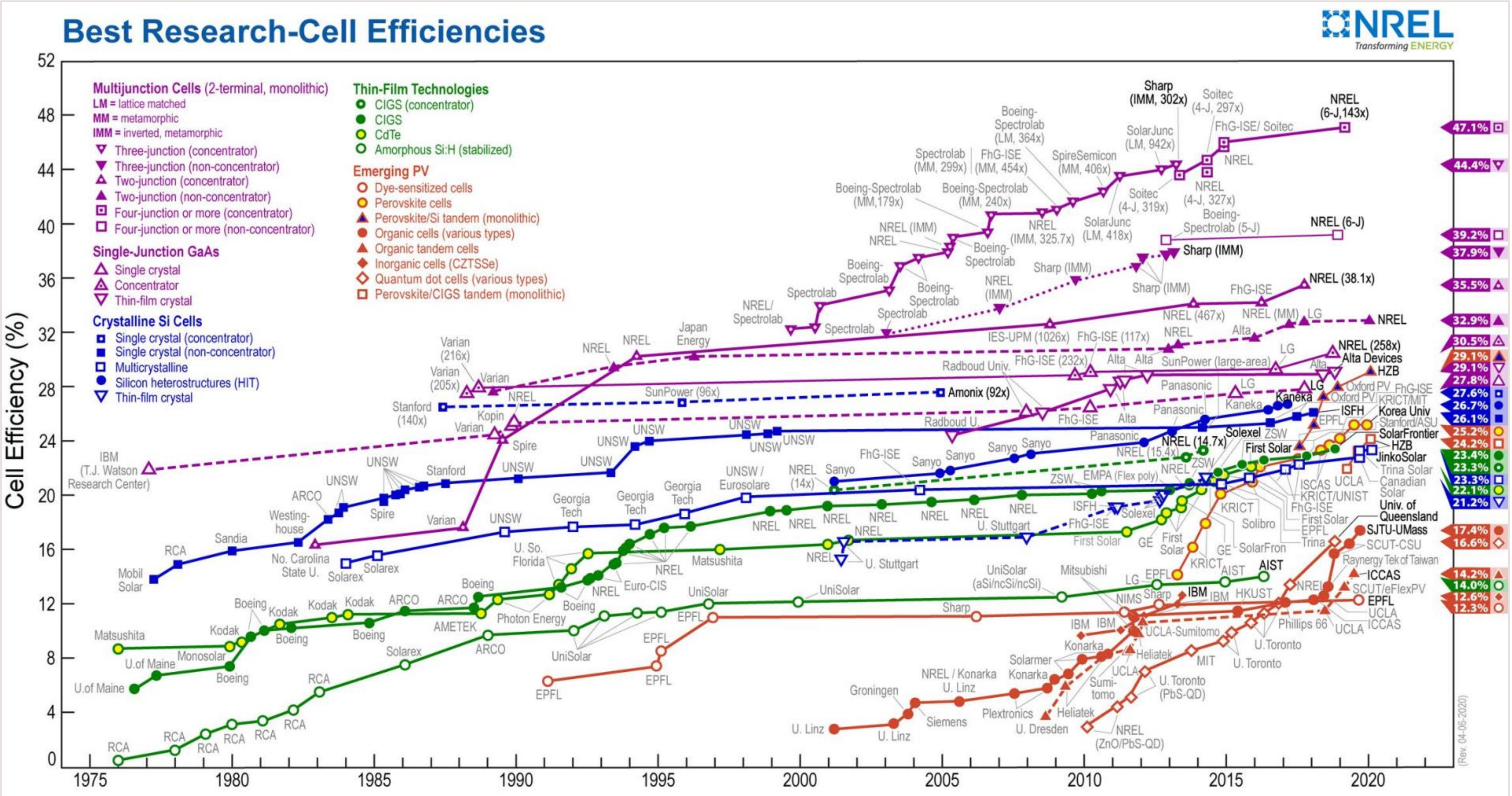


Figure 2.11: Historic Record of Best Research Cell Efficiencies Achieved in Lab [44].

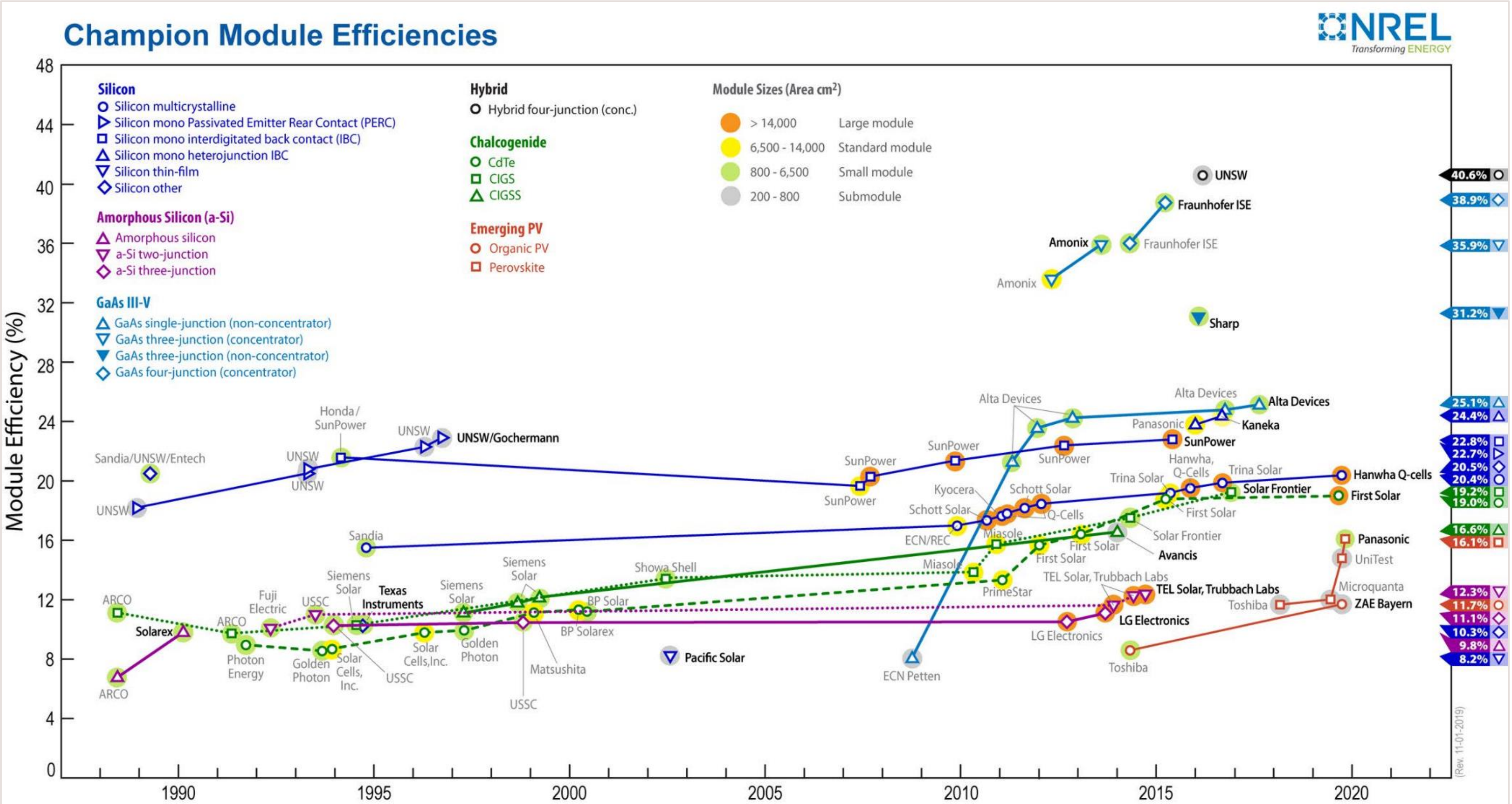


Figure 2.12: Historic Record of Best Research Module Efficiencies Achieved in Lab [48].

Solar PV applications beyond fields and rooftops

R&D efforts are invested in exploring innovative technologies at the application level of solar PVs. Floating PV plants are gaining popularity around the globe mostly due the lower cost of water surface. Among other innovative applications, building-integrated PV panels, solar trees, solar-powered desalination, solar carports, solar PV-thermal systems, agro-photovoltaics, etc. are mention worthy. Very recently, researchers have confirmed that growing crops under the shade provided by the PV panels can produce benefits like higher crop yield, reduced evaporation, lower water requirement, prevention of soil erosion, provision of shade for livestock, etc. in addition to extra income from electricity production [47, 17].

Storage technology

The exigency of energy storage systems stems from the variable and intermittent nature of RE sources. The deployment of electricity storage systems is rapidly emerging as a viable option for decarbonization of energy generation as well as expanding the frontier of electricity access via RE technology usage. Energy storage technology can be broadly categorized into five different types: mechanical, electrochemical, electromechanical, chemical, and thermal.

Until mid-2017, pumped hydro storage (mechanical) comprehensively led the market for energy storage [40]. However, the comparably low maintenance batteries (electrochemical) are becoming the storage technology of choice due to a variety of factors, such as “pollution-free operation, high round trip efficiency, flexible power and energy characteristics to meet different grid functions, long cycle life” etc. [49]. The compact nature of the batteries further makes them suitable for distributed systems. Amongst the options available for batteries, Li-ion outperforms its contemporaries by a large margin owing to a number of factors presented in Table 2.4.

Table 2.4: Parameter Comparison of Different Battery Technologies [50] [51] [52] [53].

Battery technology	Energy Density (Wh/kg)	Discharge duration (h)	Energy efficiency (%)	Lifetime/ Cycles	Storage cost ($/kWh)
Lead-acid	≤ 50	≤8	75-85	3-12 years/ 500-1,200	260 – 500
Li-ion/ $LiFePO_4$	≤ 200	≤ 5	90-94	5-15 years/ 1000-10,000	300 – 400
Vanadium based	≤ 30	≤ 10	70-85	5-15 years/ 12,000-18,000	~ 100
Soldium-sulfur	≤ 240	≤ 8	75-86	5-10 years/ 2,500-4,000	315 – 500
Aluminum-ion	≤ 60	≤ 6	90-94	5-15 years/	300 - 600

Battery technology	Energy Density (Wh/kg)	Discharge duration (h)	Energy efficiency (%)	Lifetime/ Cycles	Storage cost ($/kWh)
				1,000-10,000	

As discussed in **Section 2.2**, the key factor impeding the permeation of Li-ion into the global market had been its high cost in the past years. But profuse introduction of EVs into the transport sector garnered the attraction of important stakeholders causing the cost of Lithium-ion batteries to fall. In view of this, the utility-scale integration of Li-ion batteries is no longer a far-fetched reality. Tesla, for instance, built the largest Lithium-ion battery in the world within 100 days. The 100 MW/129 MWh capacity battery pack uses Tesla's Powerwall 2 utility grade/commercial battery systems and is capable of providing power to 4000 homes in South Australia in the event of a blackout [51]. The revolutionary battery system will charge utilizing the renewable energy produced by the Hornsdale Wind Farm and will later supply electricity when needed to ensure continued and reliable operation of the electrical system. But still, the cost of batteries, and electrochemical storages in general, seems to raise red flags for investors. On-going R&D activities, therefore, continue to focus on the improvement of cost, efficiency, reliability and safety concerns [17].

An alternate easier and cheaper option can be thermal storage. The article published in 2018 by Forbes' priced battery storage to range from $200-$500/kWh_e (depending on specific type) whereas that for thermal storage is priced around $25—$55/kWh_th [52]. But, although cheaper, the efficiency of thermal storage is quite low since additional equipment is needed to convert the heat back to electricity. Therefore, research is underway focusing on improving the efficiency of solar thermal power systems which include but are not limited to polymer collectors, gas filled flat plate solar collectors, façade collector based on vacuum tubes, etc. A paper by Pandey et al. delves into the application of phase change materials (PCM) to solar energy systems which solves the problem of the absence of solar energy during nighttime [53]. Recent advances in PCMs allow them to be used in solar thermal energy systems like solar thermal power plants, solar water and air heater, solar cooker, etc.

2.5 Policy Landscape

The widespread deployment of new RE technologies has heralded the necessity to introduce new policies catering to the promotion and implementation of innovative, environment friendly and resilient mechanisms. History testifies that RE policy support has been mostly extended to the power sector. But, a new trend, bringing forth the marriage of heating and cooling, transport and power sectors, is gradually emerging.

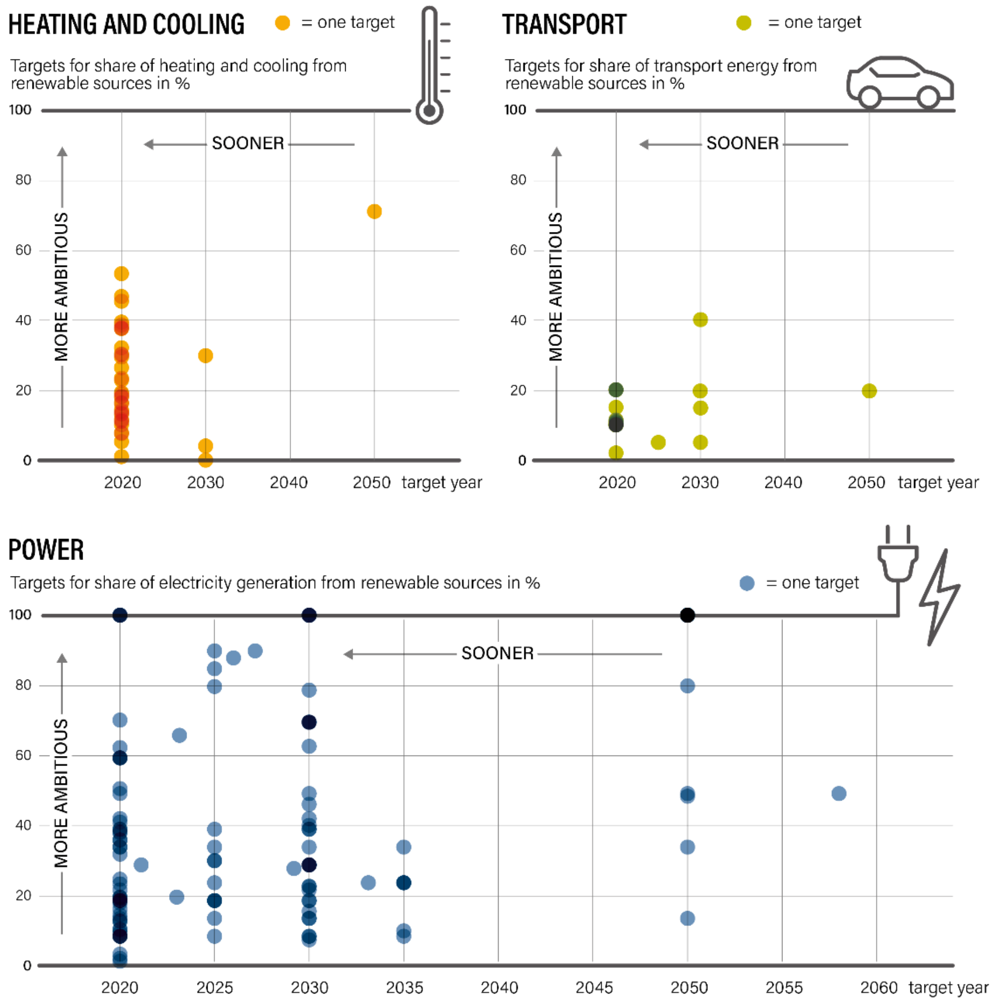
However, in general, RE policy supports can be broadly categorized into direct and indirect ones. Direct policy measures clearly pursue the increased deployment by setting mandates or financial incentives and indirect policies are usually aimed at creating an enabling environment and effective operating conditions for RE technologies. The RE policy incentives also vary depending on the level of RE share on energy mix. The main focus of policy-makers from comparatively matured RE markets remains on the technical and market integration of increasing share of VRE, as for the emerging and less mature markets, the RE related policies are typically aimed at increasing RE capacity and generation to meet demand, create employment, ensure energy security, and enhance access to modern energy services. Public policies also effectively influence corporate sourcing of RE generation [17].

The global scenario of sector-wise RE target by the end of 2019 is depicted in **Figure 2.13**. The *Renewables 2020 Global Status Report* by REN21 states that almost *all the countries* from across the world had adopted some form of RE support policies with varying objectives and degrees of ambition. It is mention-worthy that RE deployment can also be indirectly stimulated by other climate change mitigation related policies, such as bans or phase-outs of the fossil fuel utilization. Germany, for instance, announced its commitment to phase-out coal-fired plants by 2038 [17].

As mentioned above, the power sector has availed the most favors from policy makers, and setting explicit targets remained the most popular instrument in this regard. By the end of 2019, 166 states had set RE power targets. But Denmark still remains the only country with 100% RE target for the *total final energy*. The scenario is more optimistic at the sub-national level. For instance, in 2019, the Australian Capital Territory, large US cities like Chicago, Los Angeles, Philadelphia, etc. have announced 100% RE *electricity* targets to be achieved over different time horizons [17].

The *centralized RE power sector* is experiencing a shift from the traditional fixed price-based systems to more varying auction-based mechanisms. The popular Feed-in-Tariff (FIT) policies are increasingly getting updated, cancelled or scheduled to be cancelled, while more economies are leaning towards RE tenders. At least 41 countries held RE tenders or auctions in 2019 fueling the competitive global market, consequently leading to a fall in the RE technology prices. Among other types of mechanisms adopted across the globe to promote large-scale, centralized projects are the Renewable Portfolio Standards (RPS) and other quota obligations, use of tradeable Renewable Energy Certificate (REC), financial incentives like grants, rebates, tax credits, community choice aggregation programs, etc. [17].

In parallel to centralized RE power, popularity of *distributed RE electricity* is exceedingly gaining momentum in recent years, largely motivated by policy mechanisms, such as mandates, FITs, net metering, virtual net metering, financial incentives, utility procurement, etc. In 2019, California became the first US state to implement a new mandate obliging installation of solar PV for new houses. The net metering policy has been around since 1983, allowing consumers to sell a part of their self-generated electricity, primarily from rooftop solar PV, to the utilities. By the end of 2019, 70 countries had net metering mechanisms at the national level, while at sub-national level, the count is numerous. An alternative to net metering, Virtual Net Metering (VNM), allowing off-site generation by public entities like hospitals, etc., is beginning to emerge. Policies and technical aspects related to integration of VRE need to be polished in order to address the system security and reliability of the grid [17].



Note: Each dot can represent more than one country and is based on the highest target that a country has set at the national level. Figure includes only countries with targets in these sectors that are for a specific share from renewable sources by a specific year, and does not include countries with other types of targets in these sectors. The total number of countries with any type of target for renewable energy (not specific to shares by a certain year) is 49 in heating and cooling, 46 in transport and 166 in power.

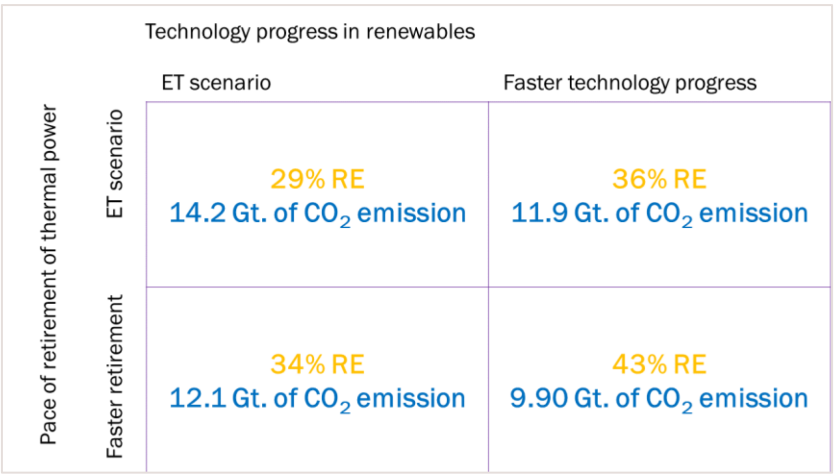
Figure 2.13: Sector-specific Targets for RE Share by a Specific Year, by Sector, in Place at end-2019 (Source: **[17]**).

It is already mentioned that comparatively mature RE markets invest their policy-making effort in achieving greater system flexibility, control and resilience to integrate higher share of VRE. In recent years, such efforts included advance sector coupling, altering power market rules, improving transmission and distribution infrastructure, streamlining interconnection approval process for grid-tied systems, cross-border supply routes, promoting the deployment of enabling technologies (e.g., battery storages), demand-side management, utility-focused regulatory policies, etc. [17].

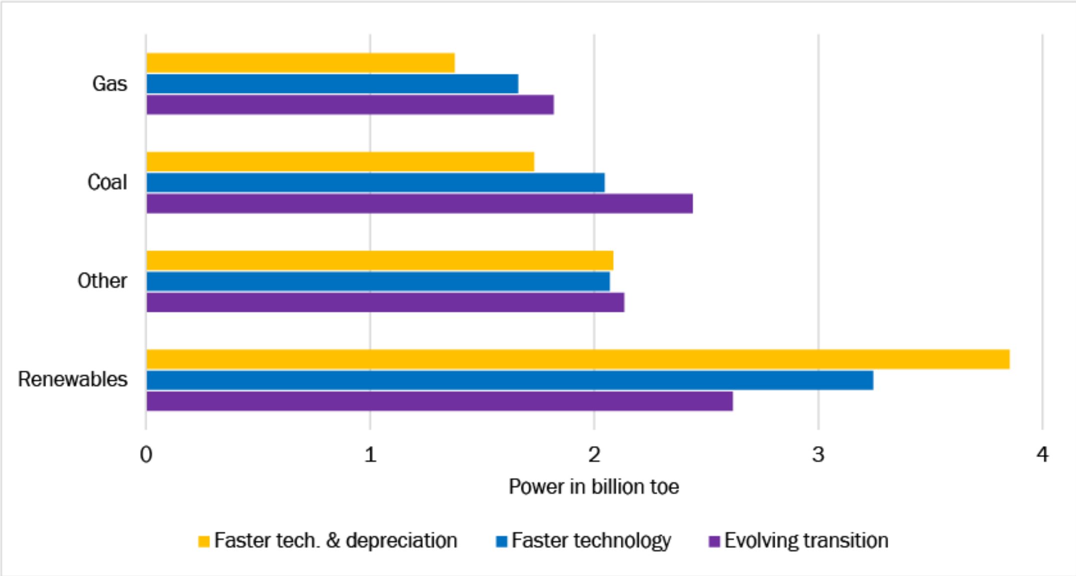
2.6 Future Projection

The Paris accord of Conference of Parties (COP21), held in 2015, is aimed at limiting the global average temperature rise to below 2°C compared to the pre-industrial era. The government and concerned authorities are taking necessary measures in the deployment of RE technologies in order to fulfill the target. A few international agencies have devised roadmaps, until as long as 2050, in view of the goals set by COP21. For instance, in their 2018-report on *Global Energy Transformation: A Roadmap to 2050*, IRENA forecasts that immediate action is critical and cumulative emissions need to be curtailed by an additional 470 gigatons by 2050 if the goals are to be realized [54]. It also suggests that renewables have the potential to constitute 60% or more of many countries' total final energy consumption. IEA forecasts that with the continued growth, RE technologies will be able to meet 70% of global electricity *generation growth* by 2023, solar PV leading the race and wind, hydro, biomass, etc. closely keeping up pace [55].

British Petroleum sketched future RE power growth scenarios up to 2040 based on exploring possible implications of various assumptions and judgment (as shown in **Figure 2.14**). According to the *BP Energy Outlook* (2019), under the Evolving Transition (ET) scenario (assumes that government policies, technology and social preferences continue to evolve in a manner and speed seen over the recent past), renewable would generate 29% of the global power by 2040. The report also shows that, keeping the rest unchanged, only faster technological progress can increase RE by 7%. **Figure 2.14** also shows that if technological progress is coupled with policies/taxes doubling the rates at which existing thermal plant retire, RE's share would increase as much as 43% and carbon emission could be further brought down by 2040.



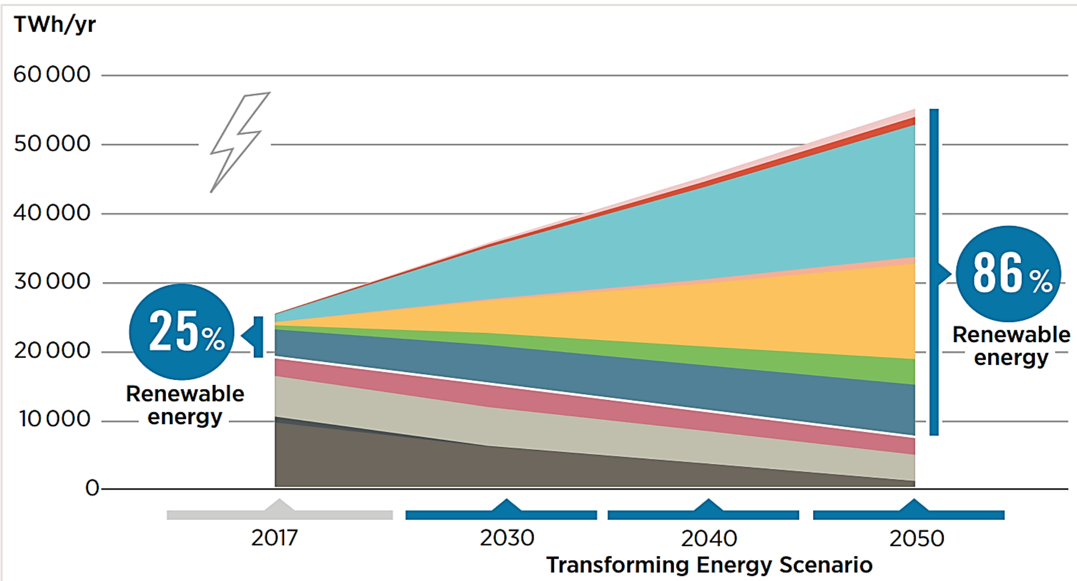
(a)



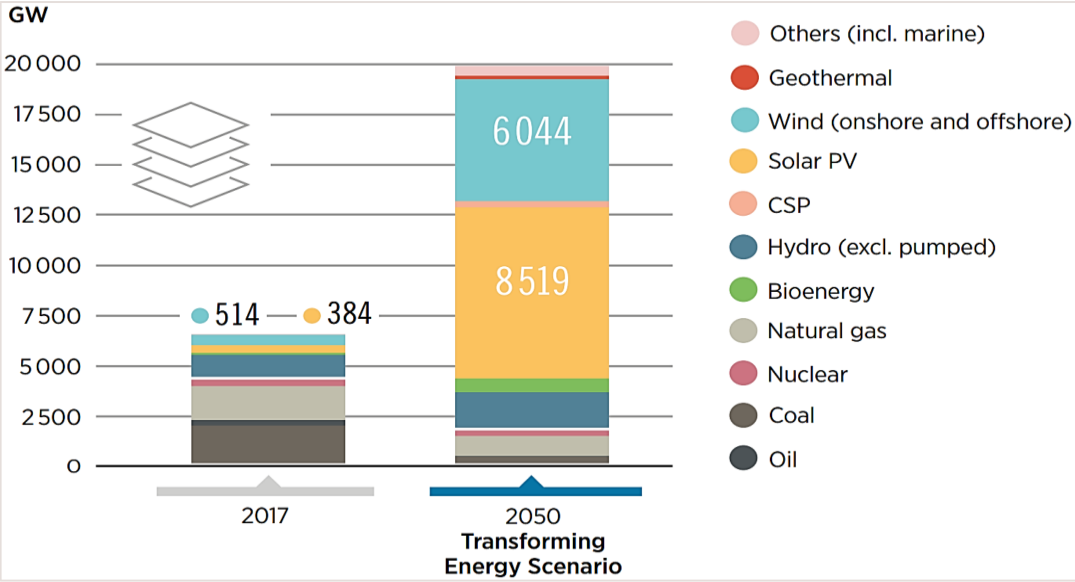
(b)

Figure 2.14: Effect of Technological Progress and Pace of Retirement of Thermal Plants on (a) Share of RE and CO_2 Emissions, and (b) Power Mix in 2040 ([56]).

However, IRENA's latest publication titled *Global Renewables Outlook: Energy Transformation 2050* (2020) reiterates the importance of immediate actions by presenting 'Transforming Energy Scenario'—an elaborate, long-term and 'ambitious yet achievable' energy pathway that can curb carbon emissions to remain within desired limits [20]. Under this scenario, the share of RE in the total primary energy supply and power generation are set to be 65% and 86% respectively by 2050 (as shown in **Figure 2.15**). Wind would dominate (nearly one-third) followed by solar PV supplying 25% of the global electricity demand. In terms of installed capacity, solar PV would have the largest share.



(a)



(b)

Figure 2.15: Breakdown of (a) Electricity Generation, and (b) Total Installed Capacity by RE Technology, 2017-2050 (Source: IRENA [55]).

A model simulated by DNV-GL, in their *Renewable, Power and Energy Use: Forecast to 2050* report, also draws an even more optimistic scenario for RE electricity, especially for solar PV technology. Their projection of market share of the different available renewable technologies in 2050 is demonstrated in the following **Figure 2.16**. According to this simulation, by 2050 solar PV will contribute to nearly 35.8% of global electricity production [57].

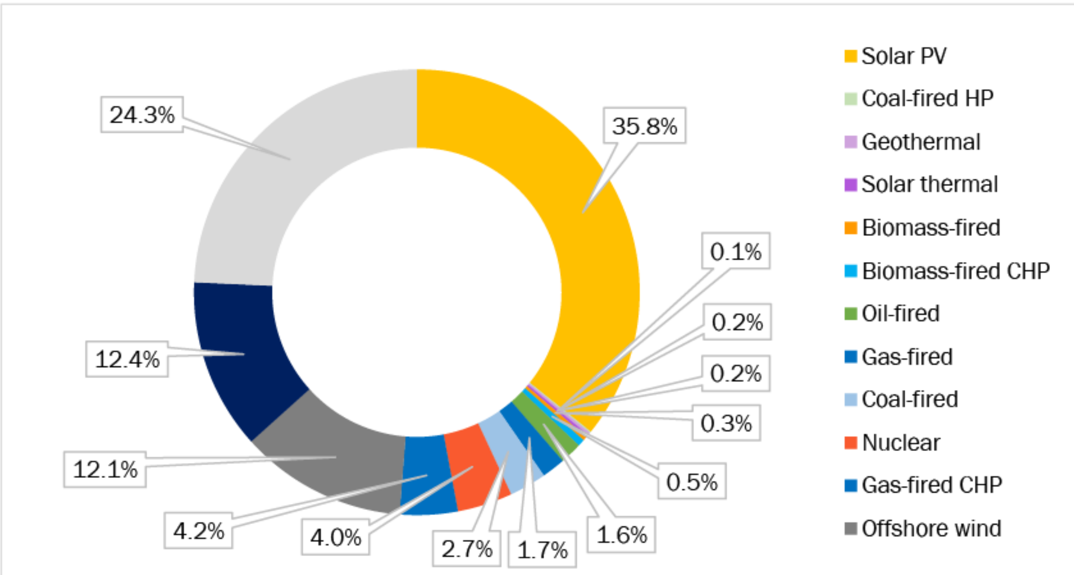


Figure 2.16: Projection of Global Electricity Production Mix in 2050 (Source: DNV GL [57]).

However, it can be asserted that greater level of emission reduction can only be achieved through extensive measures undertaken to simultaneously mobilize the electricity, heat and transport sectors. Capacity deployment must be firmly coupled with EE measures to bring down the overall energy demand. Long-term planning would be essential to effectively plan the energy transformation. Public institutions would have to play major roles to ensure the inclusion of all the stakeholders into the planning process.

2.7 Review of Policy Strategies to Meet High RE Targets

This section of the Roadmap aims to review the roadmaps or strategies of a few countries or legislations that have set 100% RE target. It should be noted that the countries or legislations having renewable targets vary widely depending on available renewable resources, adopted technologies, prioritized sectors, geo-political conditions etc. This makes it difficult to compare the strategies, but a careful and attentive review can surely help to extract some learning points.

Sweden

With 54% RE share in the country's energy consumption, Sweden is currently securing the top position among the EU countries. The Swedish government aims to produce 100% of its energy requirement from renewable sources by 2040 [58]. At present, high shares of energy mix is met by hydropower and bioenergy. One policy incentive that has assisted the deployment of RE is the Green Electricity Certification, which mandates retailers to buy green electricity as part of their normal supply and the power producers are entitled to obtain a certification for RE power generation. With a 230 MW installed solar capacity by 2016, the Swedish government has recently proposed to increase the government funding to favor solar energy that amounts nearly 16 million euros [59].

Denmark

The Danish Ministry of Climate, Energy and Building has signed the DK Energy Agreement on 22 March 2012. In this document, Denmark has declared to have reached a broad political commitment to achieve 100% RE target by 2050 in all sectors (electricity, heating, industry and transport). Similar emphasis is put on energy efficiency efforts and RE initiatives. The main elements of the agreement are presented below [60]:

- By 2020, the energy companies are directed to increase their energy efficiency effort by 100% compared to 2010-12.
- A total of 1.8 GW wind power capacity is to be installed up until 2020.
- The Danish Heating Supply Act will be amended to encourage the gradual phasing out of coal with biomass from the large-scale power plants and also to promote geothermal and large heat pumps.

- In the building sector, a generous funding is committed to replace oil and natural gas fired boilers with renewable means by 2020.
- The agreement also commits to drawing up a comprehensive strategy to establish a smart grid that will ease the integration of large shares of variable wind power, expand biomass and biofuel utilization, maintain high levels of R&D in energy technology etc.
- A few financing options are mentioned, such as, tariff on energy distribution, Public Service Obligation schemes, introduction of security of supply tax, efficient improvement efforts in the energy sector that will reduce the cost by 2020.

It should be noted that the agreement focuses the efforts towards a 2020-time horizon despite declaring a 100% RE target by 2050. As for the dissemination of solar PV power in Bangladesh is concerned, the potential of building and transportation sector is still untapped.

Tanzania

In May 2017, the Climate Action Network (CAN) Tanzania, World Future Council and Bread for the World have jointly published the 'Policy Roadmap for 100% Renewable Energy and Poverty Eradication in Tanzania'. In this document, Tanzania's prospect of achieving 100% RE target (as pledged by the Tanzanian govt. at the COP22) has been looked into and the intention has been reiterated [61]. The document starts by presenting an elaborate discussion on the Tanzanian energy and development context, identifies the potential and barriers lying on the path of 100% RE targets, heavily draws on the example of Bangladesh and puts forth a few recommendations. The suggested actions are categorized into policy, financing, technical and behavioral elements.

Washington DC

The City Council of the District of Columbia (Washington, DC) has signed the 'CleanEnergy DC Omnibus Amendment Act of 2018' [62] on 18 January 2019, which is an amendment of the original 'Renewable Energy Portfolio Standard Act' of 2004. The amended Act raised the renewable target up to 100% and that to be achieved by 2032, including a 10% share of solar energy. The major provisions of the legislation include:

- Removing of restriction on energy efficiency measures;
- Implementing New Building Energy Performance Standard and targeting the privately-owned commercial building as the district's largest GHG emitters;
- Passing rules to incentivize the purchase of fuel-efficient vehicles and
- Strengthening the funding for low-income households by slightly increasing the SETF (Sustainable Energy Trust Fund) fee for electricity and gas consumption [63, 64].

Vancouver

The city of Vancouver has a long history of supporting initiatives related to climate change and in that line of action it has very recently adopted the 'Renewable City Strategy and Plan'. Its optimistic yet obtainable action plan targets to derive 55% of the energy consumption from RE sources by 2030 and 100% before 2050 [65]. The city aims to reduce energy usage by introducing advance Energy Efficiency and Conservation (EE&C) programs, enhancing building insulation requirements; promote RE power utilization by improving existing infrastructures to extract the full potential, increasing support for rooftop solar PV systems; integrate transportation sector by promoting electric vehicles and hybrid biofuels, improving bike networks etc.

Uruguay

Following the same line of discussion, another worthy example is that of Uruguay. Uruguay has dramatically shifted its stance to produce nearly 94% of its electricity demand (as of December 2015) from renewable sources in less than 10 years. The country has also lowered electricity prices, greatly reduced its carbon footprint—and all these without any nuclear power in the energy mix or any government support. One of the main contributors has been the tapping of wind resource potential by opening the market for foreign investors and project developers. Apart from this unambiguous decision-making process, favorable regulatory environment and sound cooperation between the public and private sector have also exerted positive influence [66].

Bhutan

Among the neighbouring countries of Bangladesh, the case of Bhutan deserves serious mention. Despite being a small country, Bhutan has invested praiseworthy efforts in grasping the benefit of renewable energy sources. The current overall electrification rate is 99%, and almost all of the electricity (nearly 28% of the total energy consumption) is generated using hydropower. But much of the hydropower potential still remained untapped. According to a report by IRENA, Bhutan had installed nearly 1.6 GW of power capacity, harnessing mere 6% of its techno-economic feasible hydropower potential [67].

India

Bangladesh's neighboring country India has recently been very active in promoting the utilization of RE sources, especially solar energy, to: (a) meet its ever-increasing energy demand, (b) ensure universal access to energy, and (c) mitigate the impacts of climate change. Even though the history of India's RE utilization dates back to the 1970s', 42% of the total capacity was supplied by large-scale hydro plants only [68]. The utilization of grid-tied solar energy emerged later. An overview of historical developments of India's on-grid solar power sector is presented in the article by Moallemi et al. [68].

As part of their National Action Plan for tackling climate change, India has launched an ambitious and elaborate initiative titled Jawaharlal Nehru National Solar Mission (JNNSM) on 11 January 2010 [69]. The initial target was to generate 20 GW power from grid-tied solar plants including rooftop systems, 2 GW of power from off-grid solar applications, and to install 20 million square feet of solar collector across the country by 2022 [70]. Despite the initiative appearing to be ambitious, both the central and state governments have been very active in realizing the goals of JNNSM.

Following up on JNNSM, the current Government has revised and expanded the targets in 2015. According to the updated resolution, the initial target of generating 20 GW electricity from grid-tied solar plants have been increased to 100 GW [71]. To facilitate the large-scale deployment various sub-components have been devised. Around 60 GW has been set for ground-mounted medium- and large-scale grid-connected solar power projects, while the remaining 40 GW is planned to be generated from grid-connected rooftop solar PV systems. Various favorable policies and regulations have also been adopted, and solar project schemes have been launched to encourage private investments. Notable policy initiatives by the Government of India (GOI) are summarized as follows [72]:

- Ministry of New and Renewable Energy (MNRE) has proposed the development of 7.5 GW of solar by 2022 using locally produced components during the 2nd phase of Central Public Sector Unit (CPSU) program.
- The guidelines for the disbursement of the National Clean Energy Fund (NCEF) has been amended by the MNRE for the development of inter-state transmission systems under the Green Energy Corridor Project in several states.
- MNRE has also issued an advisory note to state governments requiring the utilization of unused spaces available near sub-stations/transmission systems by giving priority to solar projects.
- Waiver period for inter-state transmission charges and losses for solar projects has been extended by the Ministry of Power.
- Ministry of Power has issued final guidelines for tariff-based competitive bidding process for large-scale solar projects.
- MNRE is in the process of formulating an INR 50,000 crore scheme titled 'Kishan Urja Surakshaevam Utthaan Mahabhiyan (KUSUM)' for harnessing solar power in rural India [73].

As a result, the current share of renewable power in India's power mix has reached nearly 36.2%, with solar accounting for nearly 9.8% of the total. As of March 2020, the cumulative solar technology installation was about 37.2 GW

[74]. In the second quarter of 2017, the lowest bid for tariff reached down as low as INR 2.5 per kWh, making electricity generated from solar energy cheaper than thermal power in some cases. The declining tariff trend continued and reached a record-low of INR 2.44 per kWh in 2018 as well [75]. Therefore, an in-depth review of the on-going scenario in India in the domain has the potential to offer useful insights for determining a tariff structure in Bangladesh.

Apart from the above-mentioned policy updates, the GOI has launched a special scheme for incentivizing large-scale solar projects across India, the main features of which are discussed in the next section.

Incentives for India's large-scale solar PV project developers: In March 2017, the MNRE has sanctioned the "Scheme for the Development of Solar Park and Ultra Mega Solar Power Projects". Under the framework, the MNRE aims to set up at least 50 solar parks with 500 MW capacity each that are defined as "concentrated zone of development of solar power generation projects and provides developers an area that is well characterized, with proper infrastructure and access to amenities and where risk of the projects can be minimized" [76]. Around 34 solar parks have already been approved by MNRE in 21 states with a total capacity of 20 GW.

The scheme identifies the Solar Energy Corporation of India (SECI) as the nodal agency to administer the scheme and regulate MNRE funds, and terms Solar Power Park Developers (SPPD) as development agencies. The SPPDs are entrusted with activities that will not only speed up the establishment of the solar parks but will also ensure significant and wide-ranging incentives for the investors. The noteworthy features of the scheme are as follows:

- **Site selection and land acquisition**: The SPPD with or without support from the State or Union Territories (UT) governments will select the site, and acquire and develop the land for setting up the solar parks. For private entrepreneurs, there are provisions for long-term lease and the State/UT government is again responsible for ensuring dispute free acquisition of land in such cases. The scheme recommends the selection of sites with higher solar irradiation, water availability and locations that have easy access to spare transmission capacities from either Central Transmission Utility (CTU) or State Transmission Utility (STU).
- **Facilities to be provided**: SPPD will ensure specialized services throughout the solar park in a "central, one-stop-shop, single window format". Such facilities include:
    1. Approved land with necessary permissions;
    2. Proper road connectivity (both approach roads and smaller access roads leading to each individual plots);
    3. Dedicated water reservoir with demineralization plant within the premise, boundary fences and security service;

4. Flood mitigation measures such as flood discharge and internal drainage systems;
5. Telecommunication facilities and centralized weather monitoring station;
6. Transmission facilities including pooling stations with suitable voltage levels; and
7. Parking, warehouses and housing facilities for basic manpower wherever possible.

- **Financial models**: The SPPD will be responsible for estimating the total cost of the project and then formulating a recovery model to ensure the sustainability of the solar parks. SPPDs will also be allowed to put in its own equity, raise loans, create small corpus for working capital and invest in the operation and maintenance of the parks, activities related to marketing and publicity. The SPPDs will also be responsible for organizing the registration process for prospective project developers. Apart from the one-time registration fee, the investors are to pay in four installments at different stages of the project development.
- **Grant support from MNRE**: MNRE will provide grants of up to INR 25 lakhs to the approved SPPD in order to conduct necessary surveys and to prepare Detailed Project Report (DPR). Based on the DPR of the solar park, Central Grant will be channeled in installments to the SPPDs for development of the solar park (INR 12 lakhs per MW or 30% of the cost, whichever is lower) and to CTU/STU for the construction of external transmission systems (INR 8 lakhs per MW or 30% of the cost, whichever is lower).
- **Transmission and power evacuation systems and relevant funds**: The cost of constructing transmission and power evacuation infrastructure is a significant component of the total project cost. While the CTU/STU is held responsible for setting up sub-stations close to the solar parks and the SPPDs are to set up pooling stations inside the parks, the project developers will have to only interconnect each project plot with the pooling station via underground, over-ground or overhead cables. The scheme mentions that such infrastructures should be designed as per the highest possible standards and a list of latest technologies is provided. There are also provisions for applying for MNRE grants to build the power evacuation infrastructure.
- **Obligatory power purchase by state governments**: The scheme also partially creates a secure investment arena by obliging the state governments to purchase at least 20% of the generated electricity through its utility companies. However, the scheme doesn't guarantee the PPA or the tariff.
- **Extended deadline for project implementation:** The MNRE of India has very recently extended the project implementation deadline up to 2 years for

solar IPP projects with capacity over 250 MW. Previously, the implementation deadline was 15 months [77]. The rationale is that this will allow the project developers more time to procure equipment and thus reduce the cost even further.

It is apparent from the above discussion that the policy incentives provided for prospective project investors of large-scale solar PV projects are manifold. These incentives have triggered India's recent global record of one of the lowest tariffs.

At this point, it is worthwhile to investigate the key differences between the solar energy sectors of these two countries. The primary objective of this attempt is to identify and distinguish between the natural and other factors that are or can be either organised or systematized by humans. A brief list of main differences between the solar sectors of these two neighboring countries is presented in **Table 2.5**.

Table 2.5: Comparison of Solar Power Sector between India and Bangladesh.

Factors	Details of comparison
Availability of solar resources	It has been mentioned earlier in this report that some parts of India benefit from higher GHI compared to Bangladesh. For example, annual average GHI in Ahmedabad, Gujarat and Jodhpur, Rajasthan are 5.76 and 5.78 kWh/m^2 per day respectively [78, 79]. In Bangladesh, it is about 4.5 kWh/m^2 per day. Moreover, Bangladesh's annual climate cycle is heavily influenced by a long monsoon period that results in low and irregular solar insolation for several months in a row.
Availability of land	The solar sector development landscape in India also benefits from the availability of vast land, whereas in Bangladesh there is serious competition over land use. Under the Solar Park scheme launched by the MNRE (India), selection of location, acquisition and development of the land is carried out by the implementing agency, while in Bangladesh the project developer has to do all these by itself. This not only reduces the cost, but also makes the process more efficient and convenient.
Civil and electrical construction cost	Under India's solar park scheme, the implementing agency will construct not only the required roads and transportation systems, but also the transmission line and substation. These are significant cost components for a large-scale solar plant. In Bangladesh, the project developers have to build such infrastructure on its own and also has to get the necessary permit for this. Bangladesh is also comparatively prone to frequent natural calamities, such as seasonal storms, floods, tornedoes and cyclones. This requires that special care is taken in the design and construction of mounting structures for the solar

Factors	Details of comparison
	panels, leading ultimately to increases in the cost of construction.
Benefit of economy of scale	India is advancing in the path of extracting benefits from economies of scale by planning, incentivizing and implementing large-scale solar projects. But for Bangladesh, it will be very difficult to adopt similar measures due to numerous practical issues.
Public grant support	In India, public grant support is made available on comparatively easy terms either from the state or the central government.
Obligatory power purchase by the state utility	The GOI also guarantees that the state-owned utility will buy electricity from the solar PV plant for a certain period of time, whereas in Bangladesh such clear and binding provisions or policies are still absent. The tariff is also determined in a transparent and open process.

From the table it is apparent that the key dissimilarities arise not only from the variation in available natural resources, but also from the effort put in by the Indian central and state governments in creating a low-risk, investment-friendly environment. Factors belonging to the latter category appear to be of interest to the policy-makers of Bangladesh. It is undeniable that India benefits greatly from its sheer vastness, the innumerable stretches of usable land and also the solar radiation incident upon them. But India is also favoring large-scale projects, where the government bodies facilitate the site selection, land acquisition and development steps. The interests of the investors are further safeguarded by obligatory power purchase agreements. The Bangladeshi counterparts may pick a few leads and delve into checking their practical feasibilities.

3 Implement Status of Solar PV Technology in Bangladesh

This chapter of the Roadmap is focused on the implementation status of the solar PV technology-based programs in the domestic context. The solar energy development programs undertaken under private and public initiatives can be divided into different groups, which are: (a) Large-scale grid tied solar PV projects, (b) Solar Home Systems or SHSs, (c) Solar Mini-grids or SMGs, (d) Solar Irrigation Pumps or SIPs, (e) Rooftop systems under NEM, (f) Solar drinking water systems, (g) Solar-powered telecom towers, (h) Solar-powered street lights, (i) Solar-powered charging stations, and (j) other applications including vehicles, etc.

3.1 Large-scale Grid Tied Solar PV Projects

The first-ever grid-tied solar PV project of Bangladesh has been installed in Sharishabari, Jamalpur in 2017. With 3.28 MW of installed capacity, the project has been implemented on IPP basis by the sponsor company Concord Progati Consortium Ltd. and is still in operation. Until June, 2020, a total of 27 large-scale solar IPP projects have been taken up by the GOB (Letter of Intent or LOI issued) with total installed capacity of 1695.77 MW (PPA has been signed for 09 [80]). The details of these MW-scale solar IPP projects are provided in **Appendix B: Large-scale grid connected solar PV project status.**

It is worthwhile to take a look into the trend of approved tariff of these projects. **Figure 3.1** shows the tariff record with respect to the date of LOI issuance. A declining trend is clearly visible. If this trend continues for the next couple of years, solar power may become the cheapest power option available in Bangladesh.

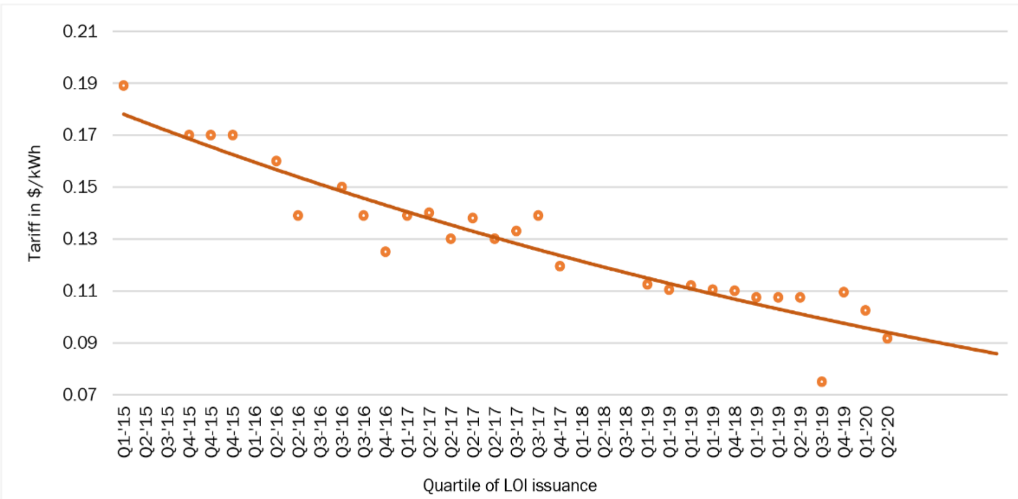


Figure 3.1: Tariff Trend of Solar IPP of Bangladesh in Recent Years.

The utility companies have been mandated to add certain amounts of renewable component to their existing capacity, which if implemented shall account for 700 MW of solar power. The GOB has also received proposals for 3 large-scale solicited grid-tied solar IPP projects. All of these IPP projects are of 50 MW capacity and are to be located on land available near the 132/33 kV grid sub-station at Boriahat, Rangunia and Netrokona.

3.2 Solar Home System (SHS)

IDCOL's Solar Home System Program has been launched in 2003. The program kick-started with initial grant support from the World Bank and GEF with the general objective to avail electricity access to the remote and off-grid communities of the country and to materialize the GOB's vision to ensure universal access to electricity by 2021. Later other development partners such as GIZ, JICA, KfW, ADB, IDB, GPOBA, USAID etc. joined force. The program has established itself to be one of the most successful off-grid electrification programs across the world. Distribution of SHS installations under this program is shown in

Figure 3.2.

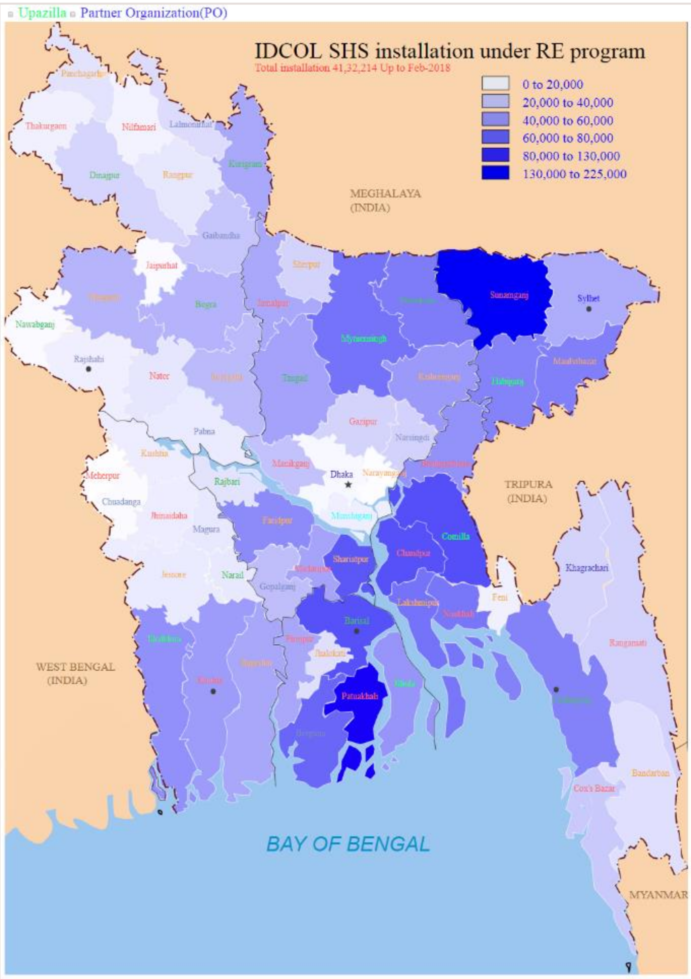


Figure 3.2: Distribution of SHS Installations under IDCOL's RE Program [81].

Until December 2019, a total of 5,804,225 SHSs have been installed across the country, nearly 77% of which have been installed under IDCOL's SHS program launched back in 2003. Around 25 million off-grid people are gaining benefit from the program and approximately 1.14 million tons of kerosene worth USD 411 million has been saved so far. Almost 75 thousand people are involved in the program in some way or other. The installation rate has slowed down after reaching a peak in 2013 due to the rapid expansion of grid and increased rate of electrification [82, 83, 84]. The present electrification is about 98% of total population and programs have been taken to achieve 100% by December, 2020. **Figure 3.3** shows the year wise installation of SHS in Bangladesh.

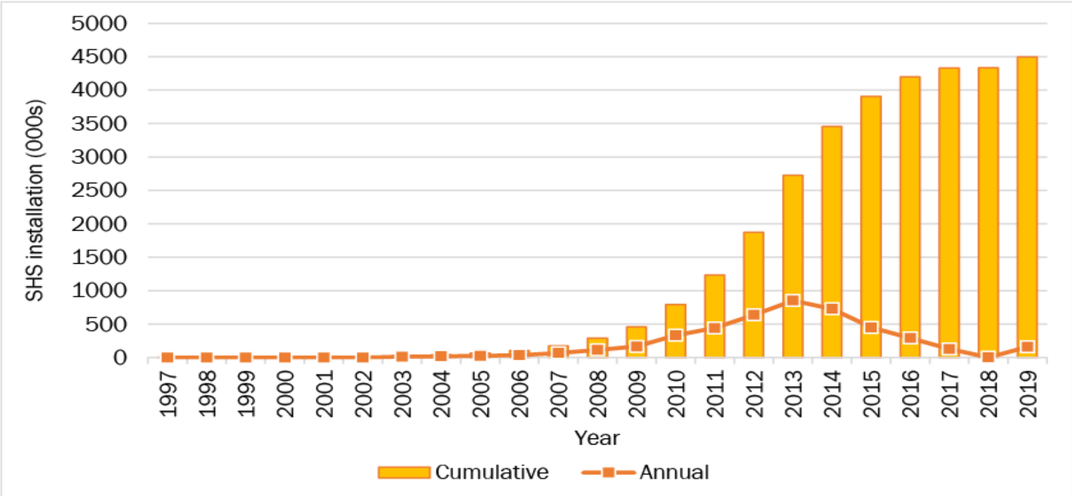


Figure 3.3: Trend of IDCOL's SHS Installation in Bangladesh.

3.3 Solar Mini-grid (SMG)

The first ever successful and commercial off-grid solar diesel mini-grid of Bangladesh has been implemented as early as in the year 2010 in the Sandwip Island. The 100 kW_p plant was sponsored by Purobi Green Energy Limited (PGEL) and the company set the tariff at Tk. 32/kWh [85]. As of June 2020, there were 27 solar PV powered off-grid mini-grids having capacity of 5.656 MWp with diesel generators as backup [11, 89]. A summary of these mini-grids are shown in **Table 3.1** and **Figure 3.4** shows the geographical locations of these SMGs.

Table 3.1: Summary of Off-grid Solar Mini-grids Financed by IDCOL in Bangladesh.

Feature	Details
Capacity	100-700 kW_p
Location	Remote and isolated areas such as river and sea islands
No. of customers	400-1500 per grid

Feature	Details
Implementation agency	Private limited companies or non-governmental organizations
Financing agency	IDCOL
Project life	20 years
Average tariff	38 US cents/kWh
Financing structure	Sponsor's equity: 20%; Loans: 30% and Grant: 50%

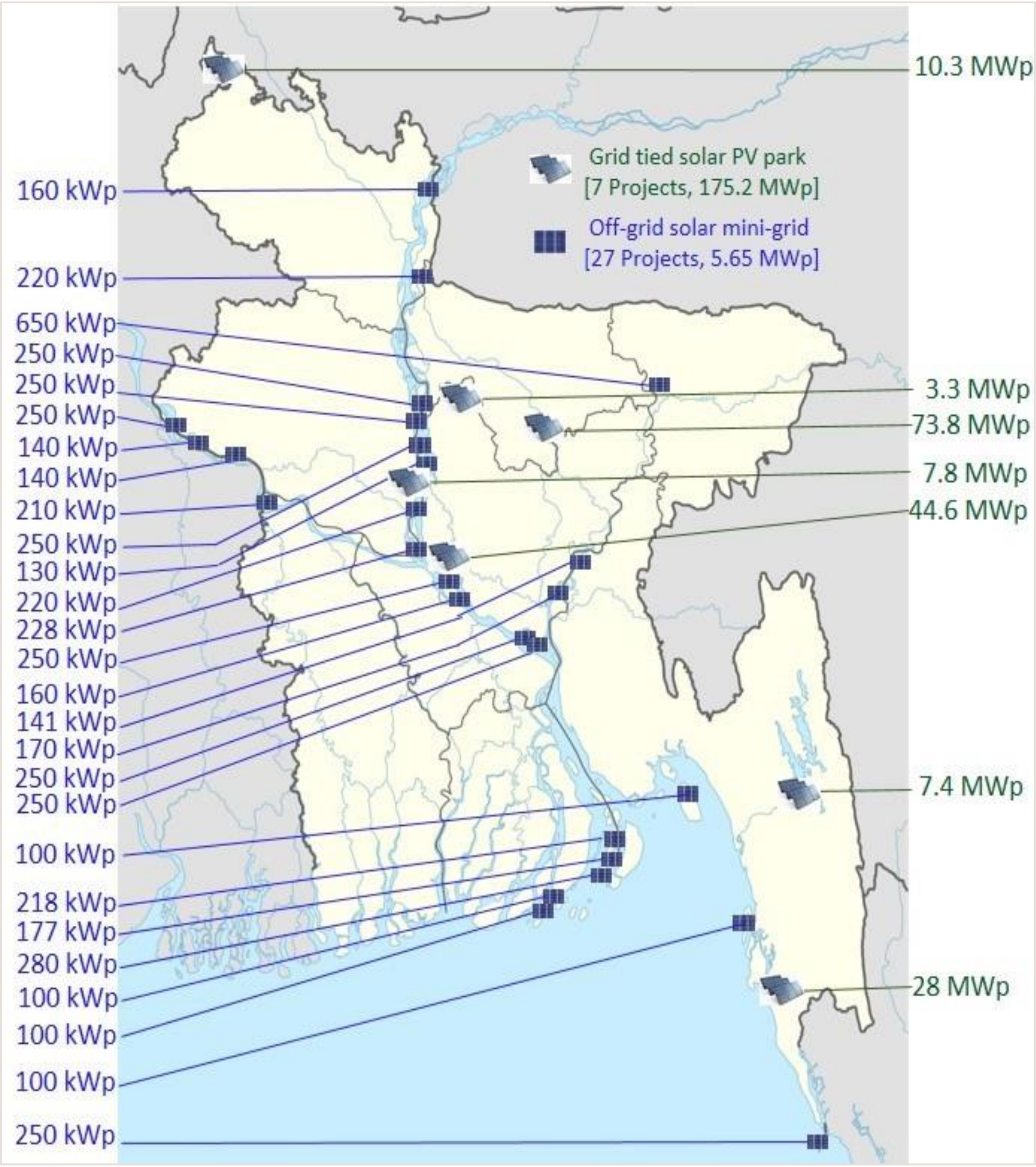


Figure 3.4: Installed Grid Tied Solar Parks and Off-grid Solar Mini-grid Projects of Bangladesh.

3.4 Solar Irrigation Pump (SIP)

Following the global trend of increasing utilization of solar energy to power irrigation pumps, the Government of Bangladesh has initiated various projects to promote the use of SIPs across the country. Government organizations, such as Bangladesh Agricultural Development Corporation (BADC), Bangladesh Rural Electrification Board (BREB), Barind Multipurpose Development Authority (BMDA) and IDCOL have acted as implementing agencies in realizing SIP projects. The following **Table 3.2** shows the status of SIP implementation by different agencies, while the SIP installation trend in depicted in **Figure 3.5**.

Table 3.2: Status of Agency-wise SIP Implementation as of December, 2020 [11].

#	Name of Agency	No. of SIPs	Installed capacity (MW)
1.	REB	40	0.24
2.	IDCOL	1523	35.46
3.	BADC	137	2.055
4.	BMDA	106	1.785
5.	RDA	15	0.21
6.	Misc.	51	3.428
	Total	**1872**	**43.178**

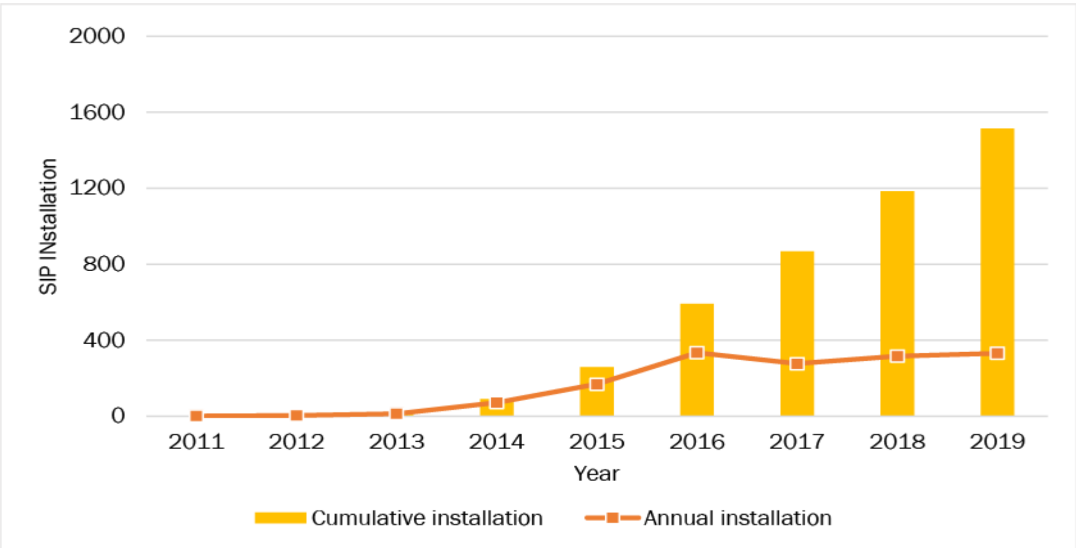


Figure 3.5: Solar Irrigation Pumps Installation Trend in Bangladesh.

From **Table 3.2** it is apparent that among the concerned organizations, IDCOL has the highest share of SIP project implementation with 1514 SIP systems already in operation. These SIP systems have an average installed capacity of 22.42 kW_p, resulting in nearly 35.11 MWp of installed capacity in this sector [81]. To keep the price of delivered irrigation water within tolerable limits, IDCOL will support in securing up to 85% of the total project finance from various funds and grants. At present IDCOL is using two types of business models to finance off-grid solar irrigation projects, which are the Fee for Service Model and the Ownership Model [87, 81].

3.5 Net Energy Metering for Rooftop Solar PV Systems

The *Net Metering Guidelines-2018* has been launched by the GOB on 28 July 2018 with an aim to motivate consumers to install solar PV systems on rooftops, integrate with the main grid and thus become active prosumers. Public utilities have been mandated with capacity limits to installation under this scheme. As private organizations and industries are increasingly showing interest to invest in solar rooftop under net metering scheme, the programme has started to gain momentum recently. According to SREDA, a total of 1140 projects with a total capacity of 16.9 MWp have already been completed and are in operation. Details of these project are available on SREDA's website [11].

3.6 Solar Drinking Water

Until December 2019, solar-powered drinking water systems of nearly 1.6 MW capacity has been implemented. After the Cidr cyclone hit the coastal area of Bangladesh in 2010, there was an acute shortage of safe drinking water. During that time Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) installed a total of 143 solar powered drinking water systems in those affected areas. Among those systems, 3 employ reverse osmosis technique for purifying water. The task was accomplished in cooperation with the Comprehensive Disaster Management Programme (CDMP) of the Bangladesh Ministry of Disaster Management and Relief [88]. By January 2019, a total of 400 solar drinking water systems have been installed by GIZ in the coastal region and DPHE has installed 32 systems in various remote areas [89].

3.7 Solar-powered Telecom Tower

So far, a total of 1933 solar PV-powered telecom towers have been installed in Bangladesh, which translates into a total of 8.06 MW of solar capacity [11].

3.8 Solar Street Light

According to the website of SREDA, 202,017 solar-powered street light systems have been installed with a capacity of 10.59 MW in the country until December 2019 [11]. The Local Government Engineering Department (LGED) under its City Region Development Project (CRDP) is installing nearly 3000 solar powered street lights along 114 kilometers of road within the Gazipur city corporation area. The project has been in effect since July 2011 and was supposed to continue until December 2018, with an estimated budget of 139597.57 Lac and the donor agencies are namely ADB, KfW and SIDA [90].

Among other noteworthy attempts, on 26 April 2017, BPDB has signed a joint agreement with China based companies Gloria JCEGCL and JED MAC LTA to implement solar street light program in eight city corporations of the country [91]. If successfully implemented, the solar LED lights are expected to cover 20 kilometers of road.

3.9 Solar Charging Stations

Solar powered battery charging stations are another important component of solar PV sector. Building a charging infrastructure is imperative for the wide-spread utilization of electric vehicles. IDCOL and World Bank have already sponsored a pilot R&D study of such a station at Chuadanga [92]. According to this study there are nearly 900,000 easy bikes operating on batteries all across the country. Combinedly, these bikes consume approximately 9000 MWh of electricity from the grid. To reduce this huge burden on the national grid, GOB has already started to implement solar-powered charging stations at various locations.

According to SREDA's website, so far 12 solar charging stations have been installed with total capacity of 0.253MW. The stations are owned and financed by different utilities, such as, BPDB, BREB, DESCO, DPDC and WZPDCL.

3.10 Others

Among other types of solar PV projects are the solar powered vehicles, boats, aquaculture, pico systems, etc. So far only 1 MW capacity of such systems has been implemented. There have been a few research projects which have reportedly developed prototypes of solar powered rickshaw and boats.

4 Review of National Policy Landscape

This chapter of the Roadmap aims to provide a brief overview of various relevant national policies, regulations, guidelines, survey reports and national program documents that are relevant for the development of renewable sector in Bangladesh. The main objective is to review the existing policy framework, identify scopes for future implementation and assess the necessity or gap for any revision or development. Following is the list of policy documents that are reviewed in this chapter:

- Electricity Act (2018);
- Bangladesh Energy Regulatory Commission Act (2003);
- Sustainable and Renewable Energy Development Authority Act (2012);
- Bangladesh Energy and Power Research Council Act (2015);
- Private Sector Power Generation Policy of Bangladesh (1996);
- Bangladesh Renewable Energy Policy (2008);
- Policy Guideline for Enhancement of Private Participation (2008);
- Policy Guideline for Power Purchase from Captive Power Plant (2007);
- Policy Guideline for Small Power Plant (SPP) in Private Sector (2008);
- Bangladesh Climate Change Strategy and Action Plan (2009);
- Guidelines for the Implementation of Solar Power Development Program (2013);
- Nationally Determined Contribution of Bangladesh (2015);
- Energy Efficiency and Conservation Master Plan up to 2030 (2015);
- Power System Master Plan (2016);
- Net Metering Guidelines (2018);
- Bangladesh Environment Conservation Act (BECA), 1995
- Bangladesh Delta Plan 2100 (2018);
- Perspective Plan of Bangladesh 2021–2041 (2020); and
- Draft Eight Five Year Plan FY 2021 – FY 2025.

4.1 Electricity Act

The Electricity Act, 2018 is considered to be the foremost act for the power sector of Bangladesh. Before the enactment of the latest version of the act, the Electricity Act, 1910 was in place. All the following rules, policies, guidelines, etc. have been prepared as per the provision of the Electricity Act.

4.2 Bangladesh Energy Regulatory Commission Act

The Bangladesh Energy Regulatory Commission (BERC) was established on 13 March 2003 through a legislative Act of the GOB. The commission became effective on 27 April 2004. The BERC has the mandate to regulate the electricity, gas and petroleum products for the whole of Bangladesh. It also undertakes the following tasks:

- issuing, canceling, amending, and determining the conditions and exemption of licenses;
- ensuring efficient use, quality services;
- determining the tariffs and safety enhancement of electricity generation and transmission, marketing, supply, storage and distribution of energy;
- extending co-operation and advices to the government, if necessary, regarding electricity generation, transmission, marketing, supply, distribution and storage of energy;
- encouraging to create a congenial atmosphere to promote competition amongst the licensees;
- ensuring appropriate remedy for consumer disputes;
- resolving disputes between licensees and between licensees and consumers, and refer to arbitration if necessary;
- framing codes and standards and make enforcement of those compulsory to ensure quality of services, etc.

4.3 Sustainable and Renewable Energy Development Authority Act

The Sustainable and Renewable Energy Development Authority Act is the law enacted to establish an authority named Sustainable and Renewable Energy Development Authority (SREDA). It has been created with objectives to take necessary measures for the implementation of energy efficient and RE activities in the country. The activities of SREDA includes the following:

- formulating necessary laws, rules, regulations for sustainable energy development;
- preparing and updating the inventory of RE resources and associated technologies for devising short, medium, and long-term development plans to extend the use of RE with specific targets, and taking necessary steps to implement those;
- providing technical and financial assistance in research and development, demonstrations, and training on RE;
- taking necessary steps for creating public awareness and motivation in order to encourage the use of RE in the public and private sector;
- making necessary arrangement to provide financial incentives to attract and encourage private investment in RE sector;

- coordinating with different stakeholders in matters related to sustainable energy development.

SREDA also works to establish linkage with regional and international, etc.

4.4 Bangladesh Energy and Power Research Council (BEPRC) Act

This Act paved the path of creating the Bangladesh Energy and Power Research Council (BEPRC). It details the composition, duties, and responsibilities of the above-mentioned Council, which is entitled to the research and development of the country's power and energy sector. It also specifies the authorised use of electricity and fuel diversification for the identification, conservation and conversion of energy to ensure the safety of the power and energy sector in the country with a view to long-term planning study of the sector. The BEPRC is the apex body of energy and power research, and it has chalked out several research areas, such as, power supply, smart cities and communities, smart grids, energy efficiency and conservation, energy innovation and market uptake, etc.

4.5 Private Sector Power Generation Policy of Bangladesh

Private Sector Power Generation Policy of Bangladesh was first announced in 1996 with an aim to ensure that energy sources are properly explored, produced, distributed, and used rationally by various sectors and consumers in a sustainable manner to match the ever-increasing demand for energy. The policy was adopted with the objectives to attract private investment in power generation and to provide financial incentives and benefits to the private parties. The following incentives and benefits were declared through this policy document:

i. The private power companies shall be exempted from corporate income tax for a period of 15 years;

ii. The companies will be allowed to import plant and equipment and spare parts up to a maximum of 10% of the original value of total plant without payment of customs duties, VAT (Value Added Tax) and any other surcharges;

iii. Repatriation of equity along with dividends will be allowed freely;

iv. Exemption from income tax in Bangladesh for foreign lenders to such companies;

v. Tax exemption on royalties, technical know-how and technical assistance fees, and facilities for their repatriation;

vi. Tax exemption on interest on foreign loans;

vii. Tax exemption on capital gains from transfer of shares by the investing company, etc.

4.6 Bangladesh Renewable Energy Policy

The *Renewable Energy Policy* (2008) has been developed by the Power Division of GOB with multiple objectives related to RE implementation [9]. In general terms, the goal is to spread the utilization of RE technologies across the country by strengthening a favorable technical, financial and legal environment. In specific terms, the policy document guides the necessary institutional arrangement. In doing, so it has laid the foundation for SREDA. The policy document also outlines a few resource, technology and program development steps, and lists potential investment, fiscal and regulatory incentives. A target has been set to meet 10% of the *power demand* from RE by 2020.

4.7 Policy Guideline for Enhancement of Private Participation in the Power Sector

Through this 2008-policy document, the government basically opened the national grid for commercial use. The main objectives of the policy are to introduce and regulate competition by allowing private investment in the power sector, and to establish new commercial power plants and rehabilitate old ones through Public Private Partnership (PPP). The main features of this policy guidelines can be summed up as the following points [93]:

viii. Private investors are allowed to build commercial power plants that comply with the existing environmental laws & regulations, technical standards of grid interconnection and operation.

ix. Considering the depleting natural gas reserve, they are allowed to use any fuel including renewable ones, and are free to find their own buyers to sell electricity at a mutually negotiated tariff. Non-competition from public utilities is ensured in case there is a contract with large consumers. However, depending on the location, they have to sell 20% electricity to public utilities at a bulk tariff rate as determined by BERC.

x. The private investors are allowed non-discriminatory open access to the transmission and distribution facilities owned by PGCB or any other Distribution Licensee, given that adequate capacity is available and they pay the wheeling charge and surcharge as determined by BERC.

xi. The private investors are to enjoy certain fiscal incentives, such as corporate income tax waiver for 15 years, relaxed customs duties on a certain amount of import for 12 years, possibility of land lease support from the GOB etc. and many more.

xii. Private investors can rehabilitate publicly owned, old and inefficient power plants based on Rehabilitate, Own and Operate (ROO) or Rehabilitate, Operate and Transfer (ROT) model;

xiii. Public Private Partnership (PPP) is allowed for joint venture power plants under certain terms and conditions.

4.8 Policy Guideline for Power Purchase from Captive Power Plant

The Power Division published the guideline for power purchase from captive power plants (CPP) in 2007 with an aim to reduce the gap between supply and demand, and to enhance the utilization of energy resources [94]. The guideline allows CPPs to sell electricity to any Distribution Licensee following the prescribed tariff structure and interconnection requirements upon approval and issuance of permit from the BERC. The CPPs are also allowed to transmit power through the transmission network, provided that adequate capacity is available and the CPP pays wheeling charges fixed by the BERC. It is mention worthy that according to this guideline, the CPPs are not exempt from any custom duties, VAT or income tax, etc. unless otherwise mentioned.

4.9 Policy Guideline for Small Power Plant (SPP) in Private Sector

Originally published in 1998, this policy guideline has been revised in 2008 [95]. The main features are quite similar to that for private participation enhancement. However, this guideline is particularly aimed for small-scale plant with capacities up to 10 MW. Another difference is that there is no obligatory Power Purchase Agreement (PPA) with the government. Also, except in the areas covered by BPDB/DESA/REB, the sponsor shall be free to negotiate the tariff with its consumers.

4.10 Bangladesh Climate Change Strategy and Action Plan

The potential risk faced by Bangladesh as a highly vulnerable victim of climate change only adds to the GOB's intention of favoring clean and environment friendly sources of energy. The *Bangladesh Climate Change Strategy and Action Plan 2009* (BCCSAP) presents itself as the all-embracing strategy document addressing climate change and directs the relevant policy landscape of Bangladesh. Even though it prioritizes adaptation and disaster management measures, it reasonably includes issues like 'low carbon development, mitigation, technology transfer and the mobilization and international provision of adequate finance' [2].

The document outlines 6 main pillars or themes and lists 44 programs under these themes along with proper justification, details of activities to be undertaken and responsible parties in the Annex. Renewable energy development is listed as the 4th program under the 5th theme titled 'Mitigation and Low Carbon Development'. The recommended set of actions are:

- A1. Investment to scale up solar power programs;
- A2. Research and Investment to harness wind energy, particularly in the coastal areas;
- A3. Feasibility studies for tidal and wave energy;
- A4. Study of the techno-economic, social and institutional constraint to the adoption of improved biomass stoves and other technologies.

Apparently, the development of solar power has received highest priority among RE programs, with an immediate timeline suggestion, and the identified responsible authorities are the Ministry of Power, Energy and Mineral Resources (MPEMR), Ministry of Environment and Forests (MOEF), and private entrepreneurs.

4.11 Guidelines for the Implementation of Solar Power Development Program

In October 2013, SREDA has developed the 'Guidelines for the Implementation of Solar Power Development Program' [96] to meet the 10% power generation target from RE sources by 2020 as mentioned in the *Renewable Energy Policy 2008*. Accordingly, the GOB has launched a 500 MW Solar Power Generation Plan with two types of projects, namely, the Commercial and Social Solar Power Projects. The main distinction between these two types of projects is that the commercial project shall adopt the business model of earning from services charges paid by its beneficiaries, while the social projects shall be publicly developed and financed by grants [96]. The commercial type projects are meant to be developed mostly by the private sector. Several types of projects are then listed under each of these categories, which are mentioned below:

- Commercial projects include–
    1. Solar parks built on 'Build, Own and Operate' (BOO) basis in empty & fallow land owned either by the government or privately;
    2. Solar mini-grids in off-grid areas;
    3. Solar rooftop systems in residential and commercial buildings;
    4. Solar power systems in industries;
    5. Private solar power projects in government or semi-government buildings through IPP model;
    6. Solar powered irrigation pumps, etc.

- Social projects include solar electrification of–
    1. Rural Health Centers;
    2. Educational institutions at remote areas;
    3. Union Information Service Centers;
    4. Religious institutions;
    5. Railway stations at remote areas;
    6. Government office in off-grid areas, etc.

The document then recommends specific measures that can be taken to implement each type of solar project.

4.12 Nationally Determined Contribution of Bangladesh

The *Nationally Determined Contribution of Bangladesh* was published in 2015 by the Ministry of Environment and Forestry (MOEF) of the GOB. The official document articulated Bangladesh's commitment in joining global force to combat climate change. It sets both unconditional and conditional (with international support) GHG emission reduction targets for three major sectors, namely power, transport and industry, and includes further mitigation actions to be carried out in other sectors like buildings, agriculture, waste, LULUCF, etc. **Figure 4.1** shows Bangladesh's intended contribution of GHG emission reduction under the two above-mentioned circumstances [1].

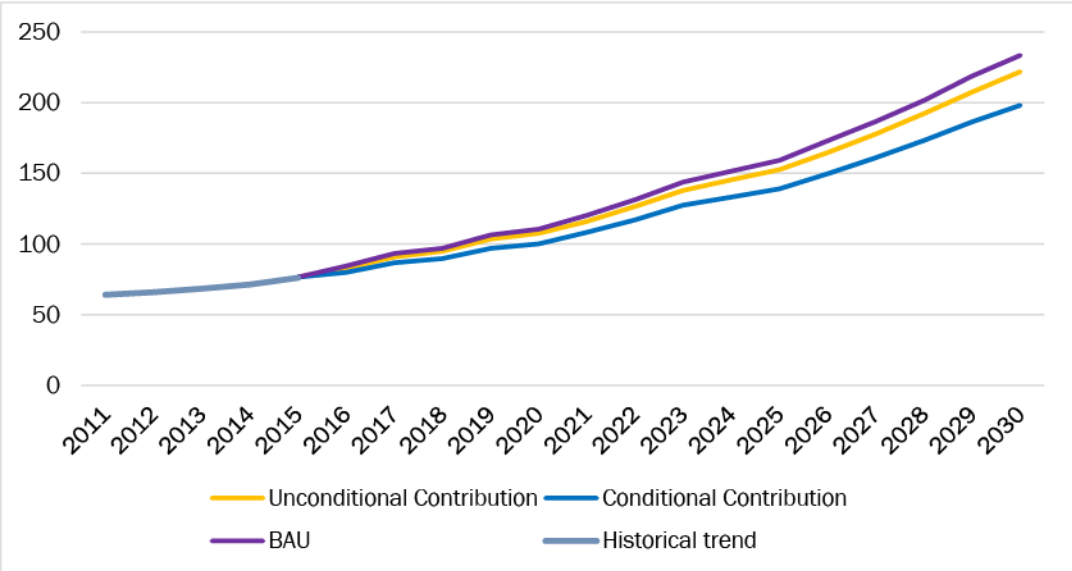


Figure 4.1: Projection of GHG Emission ($MtCO_2e$) for Three Sectors from 2011 to 2030 (Source: **[1]**).

While referring to BCCSAP, as mitigation measure the NDC rightly recommends the installation of RE technologies, especially grid-tied, utility-scale solar PV power plants to diversify the existing energy mix.

4.13 Energy Efficiency and Conservation Master Plan up to 2030

SREDA and Power Division of the Ministry of Power, Energy and Mineral Resources (MPEMR) have jointly developed and published the *Energy Efficiency and Conservation Master Plan up to 2030* in March 2015. In this document, GOB has declared the intention in necessary details to reduce 20% primary energy consumption per GDP by the year 2030. The **Figure 4.2** below shows the highlights of the 'Energy Efficiency and Conservation (EE&C) Roadmap'.

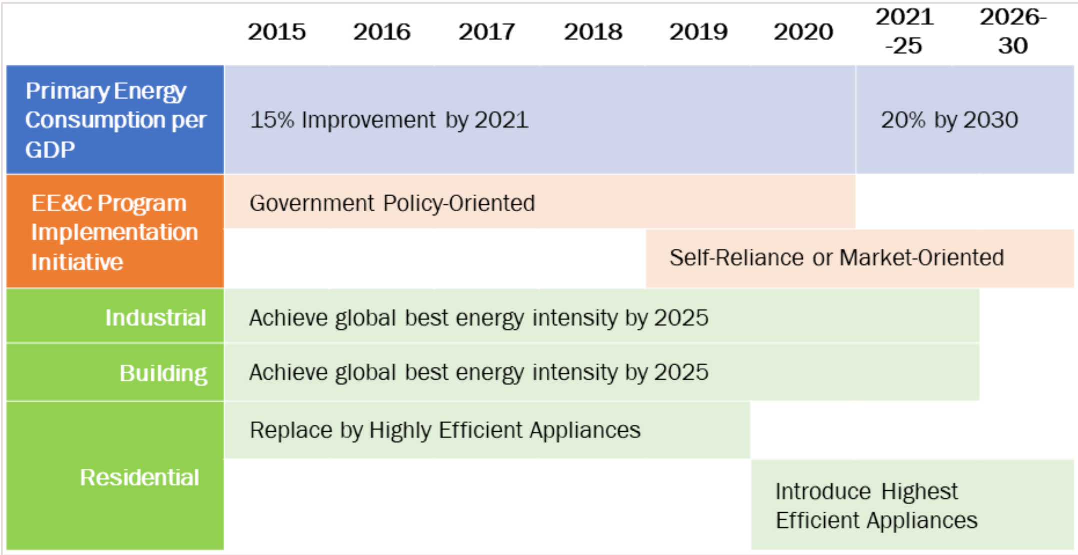


Figure 4.2: EE&C Implementation Roadmap, 2015–2030 (Source: [89]).

4.14 Power System Master Plan 2016

The principal objectives of the 2nd *Power System Master Plan* (PSMP), released by GOB in September 2016, are to set the targets and formulate an elaborate plan for the energy and power sector to achieve the national goal of becoming a high-income country by 2041 [97]. The document has articulated the VISION 2041, with five value-up plans. These are:

- Value-up Plan 1: Robust infrastructure for primary energy import;
- Value-up Plan 2: Domestic energy resource development and efficient use;
- Value-up Plan 3: High-quality and robust power system development;
- Value-up Plan 4: Advance deployment of green energy;
- Value-up Plan 5: Policy and human capital development for stable energy supply.

This elaborate document analyzed the country's historical trends of energy consumption in details. More importantly, it proposes future energy demand projections until 2041 for three different economic growth scenarios using the energy-GDP elasticity method. The results are then validated using the sectorial analysis (macro demand forecast) method. **Figure 4.3** shows a comparative picture of the peak demand projections estimated using these two methods.

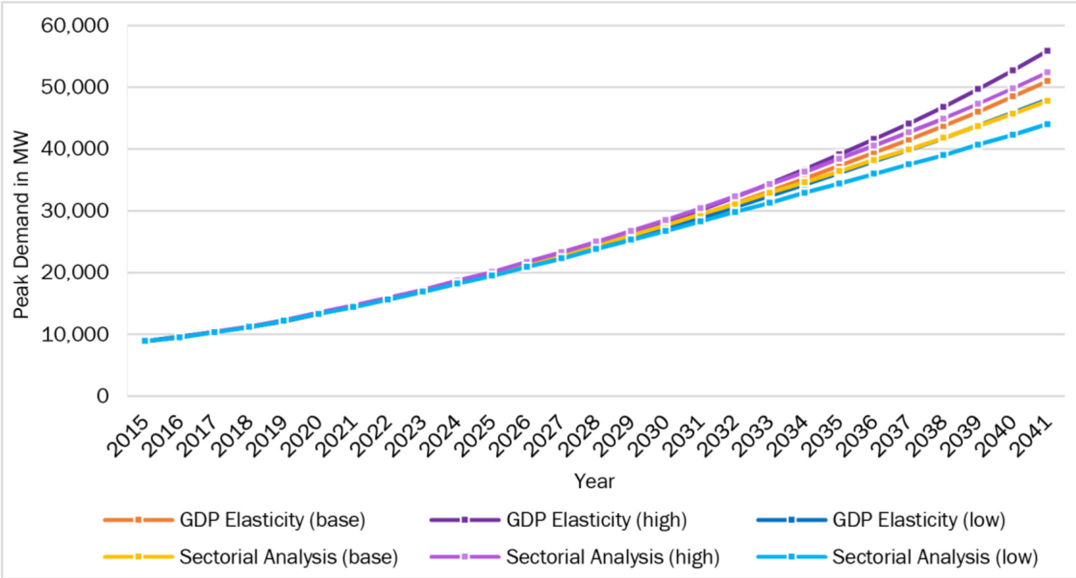


Figure 4.3: Comparison among Peak Demand Projection using the GDP Elasticity and Sectorial Analysis Method (Source: [97]).

For all the economic growth scenarios (base, high, and low), the difference between the two methodologies stand around 5%. But owing to the simplicity of the GDP elasticity method, the *PSMP 2016* adopts it to forecast the future demands. But more importantly, the Master Plan also compares the peak demand projections by taking into account the EE&C targets as detailed in the *Energy Efficiency and Conservation Master Plan up to 2030* (discussed in **Section 4.13**). **Table 4.1** and **Figure 4.4** show the different projected peak demand scenarios of Bangladesh by 2041 and as estimated by the *PSMP 2016*.

Table 4.1: Peak Demand Projection Scenarios of Bangladesh by 2041 **[98]**.

Growth Scenario	GDP Growth rate by 2041	GDP Elasticity Method	
		Without EE&C	With EE&C and captive power to the grid
High	5.0%	67,710 MW	55,900 MW
Base	4.4%	61,681 MW	51,000 MW
Low	4.0%	57,946 MW	48,000 MW

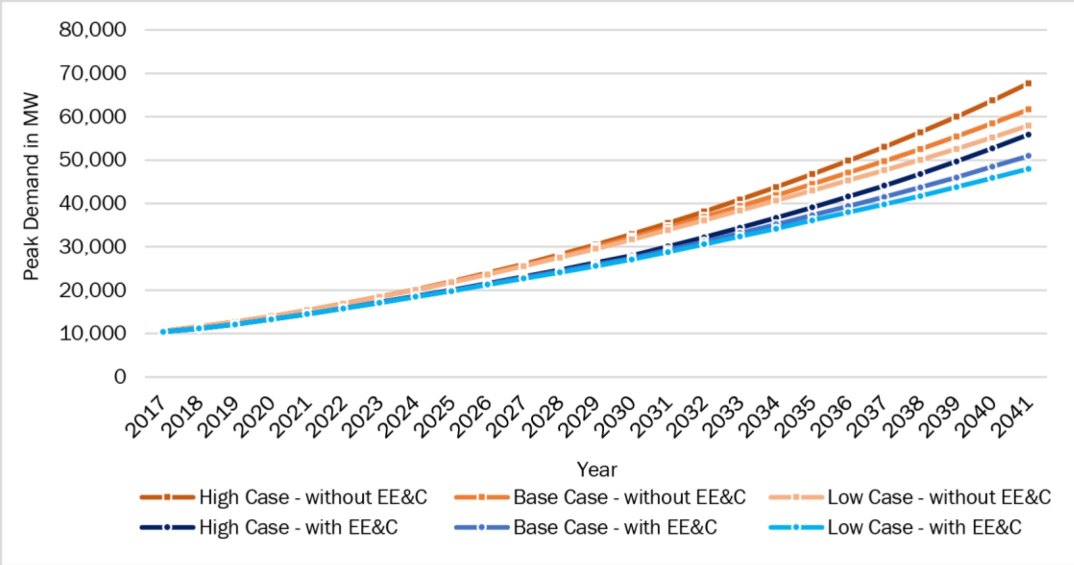


Figure 4.4: Effect of EE&C Measures on Peak Demand Projection until 2041 for the Base Case (Source: *PSMP 2016* [97]).

From the table and figure, it is visible that the differences in peak demand projections for all the economic growth cases become quite significant when EE&C efforts are taken into account. The PSMP 2016 also attempted to integrate the peak demand projection and energy supply-demand projection. The following figure shows the projection of total electricity consumption until 2041. The apparent gap between the consumption and available electricity from the grid is assumed to be supplied by captive plants. It is noteworthy that this gap tends to reduce over the years implying that the grid will eventually increase its capacity and absorb the captive power.

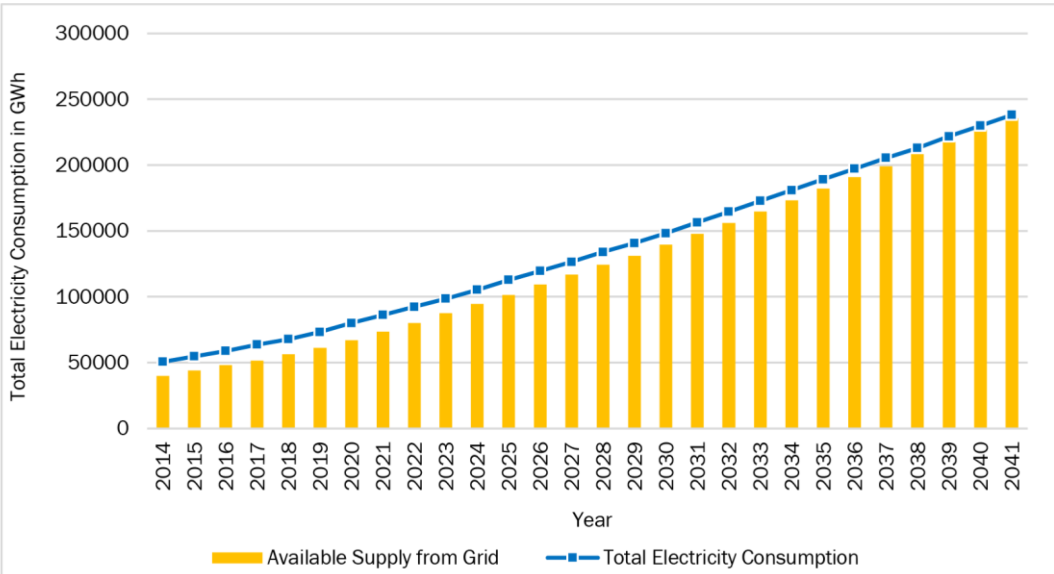


Figure 4.5: Projection of Total Electricity Consumption until 2041.

Assuming that international linkage will be strengthened and nuclear power generation will be introduced by 2025, the Master Plan predicts that the reliability of power supply will increase, which will reduce the required percentage of reserve margin. The **Figure 4.6** shows the projected reserve margin until 2041. These values indicate the generation capacity that will be required to meet the projected demands.

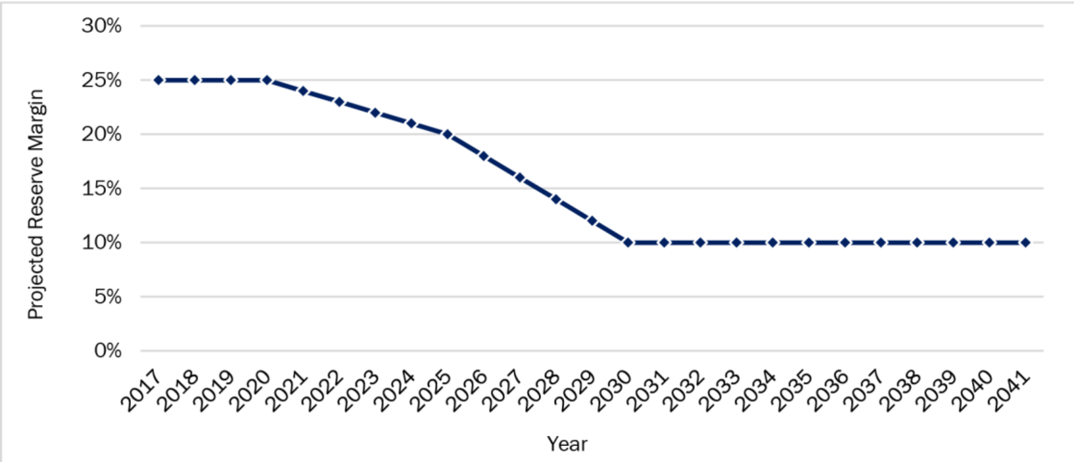


Figure 4.6: Projected Reserve Margin until 2041 (Source: *PSMP 2016* [97]).

The *PSMP 2016* analyses several possible future energy mix scenarios, having varying shares of RE. After conducting the 3E (total of economy, environment, and energy security) value analysis, two optimised cases are put forward as the best energy mixes. The projected fuel mixes for the two RE scenarios are shown in **Figure 4.7**.

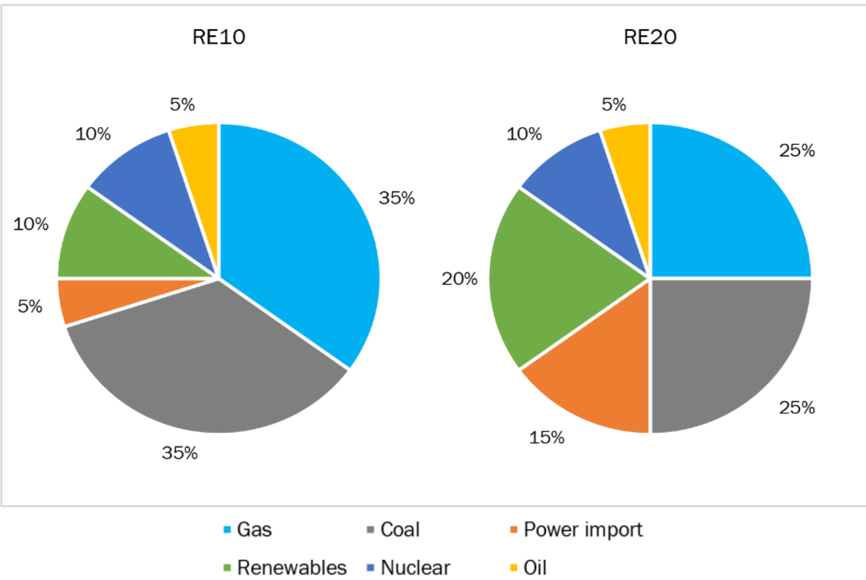


Figure 4.7: Best Energy Mixes as Proposed by the PSMP 2016 (Source: [97]).

From the figure it is apparent that both the scenarios still heavily rely on fossil fuels. However, in the Section 13.2 of the said document, it is mentioned that even though not specified, the GOB intends to extend the 10% renewable capacity target till 2041. It also mentions that according to the latest power sector development plan of the GOB, the generation capacity of Bangladesh will be more than 56,000 MW. So, in order to meet the 10% RE target at least 5,600 MW of renewable capacity will be required. The document also indicates several challenges that lie on the path of introducing large shares of RE into the existing power systems. It also reiterates the limited land availability factor while assessing the potential for large-scale solar PV power plants in the country.

4.15 Net Metering Guidelines, 2018

In July 2018, the Power Division of the MPEMR has launched the *Net Metering Guidelines-2018* that aimed to incentivize installation of rooftop solar PV systems on a massive scale [10]. The main idea behind net metering mechanism is that it allows consumers to become 'prosumers' (the consumer who also produces electricity) by connecting their RE systems to the distribution grid via a bi-directional smart meter. The prosumer consumes the electricity produced from the RE system, if there is any excess production that will fed into the grid via the net meter. The prosumers accumulate kWh credit for any excess electricity supplied to the grid after self-consumption. The kWh credit is allowed to roll-over until the end of settlement period and by the end of it, the prosumer is entitled to receive the equivalent price of net export.

Since the scheme is launched on an experimental basis and GOB does not intend to burden the distribution utilities, there is a limit imposed on the installed capacity. Also, at the preliminary stage, only three phase consumers are made eligible to adopt net metering scheme. The capacity and energy export limit of NEM system is as follows [according to revised *Net Metering Guideline, 2019*]:

- Any three-phase consumer can be considered eligible for the net metering system;
- A consumer can install (capacity of solar PV system) up to 70% of his sanctioned load;
- The maximum output AC capacity of the installed RE system for NEM can be up to 10 MW; and
- For a medium voltage (MV) consumer, the installed capacity of the RE system can be a maximum of 70% of the rated capacity of the distribution transformers.

4.16 Bangladesh Environment Conservation Act

Bangladesh Environment Conservation Act (BECA) is set of laws enacted by the GOB in 1995 with an aim of conserving the nation's environment. Its main goals are to "provide for conservation of the environment, improvement of environmental standards and control and mitigation of environmental pollution" [99].

4.17 Bangladesh Delta Plan 2100

One important addition in the RE related policy landscape is the approval of *Bangladesh Delta Plan 2100* in September 2018. It is the first time that GOB has ever taken up such 'a long-term strategy to prevent floods and soil erosion, manage rivers and wastes, and supply water throughout the country [100]. The document is important to the RE landscape from multiple viewpoints. In it, a renewed target of generating 30% of the total energy from renewable sources by 2041 has been proposed [101].

The document also indicates significant land reclamation potential along the major river banks and in the estuary region. It speculates that the large piece of land gained by accelerating the natural reclamation process through building cross dams and other infrastructures, can be used for any preferred purposes like urbanization or industrialization.

4.18 Perspective Plan of Bangladesh 2021–2041

The General Economic Division of the Planning Commission (GOB) has published the final draft of its *Perspective Plan of Bangladesh 2021-2041* in January 2020 [102]. Chapter 8 of this long-term planning document concerns the energy sector. The visions set for the energy sector by 2041 include: capacity to meet the demands of a upper-middle- and high-income economy, sustained and universal access, ensure efficient supply of electricity at a globally competitive price, achieve 100% energy security, maintain consistency between environmentally safe energy production and supply, and build a nationwide pipeline network for fasters, safer and environment-friendly transportation of petroleum products.

Following these broader visions, the document then outlines key objectives & targets and briefly discussed several strategies & policies that would be instrumental in achieving the targets. For instance, the Plan projects that by 2041, there should be no gap between the peak demand and supply owing to a massive 115 GW of generation capacity. The renewables and energy imports are predicted to jointly supply 35% of the energy mix. Such predictions with greater emphasis on the sustainable energy sources present a great contrast when compared to the previous Perspective Plan published in 2012 by the Commission [103]. Another important point of deviation is the choice of least-cost power generation expansion path phasing out quick rentals and the establishment of low-cost primary fuel supply infrastructure.

4.19 Draft Eight Five Year Plan FY 2021 – FY 2025

The latest addition to the policy documents concerning the development of renewable energy technologies in Bangladesh is the Draft *Eight Five Year Plan FY 2021 to FY 2025* [104]. The government's commitment towards low-carbon sustainable energy and power technologies has become more apparent in this document. For instance, since the government plans to lay emphasis on coal projects as a short-term strategy, parallel importance is put on renewables to compensate the negative impact of this dirtiest fossil fuel. The 8th FYP has set the target for renewables including hydropower to supply 5% of the total electricity by the year 2025.

The 8th FYP recognizes the significant role to be played by the private sector in setting the initial stage based on which the more active and visible energy transformation that may take place in the coming decades. Several solar PV and wind IPP projects are mentioned in this document which are either under planning or will be implemented within the time period of FY2021–2025. The document also mentions that there is still a gap in the policy and regulatory framework concerning financial incentives and technical rules that will appear to be indispensable with the increasing grid-penetration of variable renewable energy technologies.

The review of the policies concerned with climate change and energy sector of Bangladesh presented in the preceding sub-sections reveal a few crucial findings. The findings are briefly discussed below:

- Inconsistency exist not only in the general sector development strategies, but also among set targets for renewables. For instance, the *PSMP 2016*, even though not stipulated, states that the GOB is likely to extend the *capacity wise* RE target of 10% to be achieved by 2041, the value would translate roughly 5.6 GW. The *Delta Plan 2100* (approved in September 2018), on the other hand, has declared a target to generate 30% of the *total energy* from renewables by 2041. The *Perspective Plan* (a fairly recent publication) predicts that a staggering 115 GW of generation capacity would be required to diminish the gap between demand and supply by 2041. Without further delineation, the document sets an ambitious target of 35% of the energy mix to be covered by renewables and energy imports.

  Apparently, none of these long-term planning documents seem to be in clear agreement. Consequently, it is only natural that any relevant policy formulation effort and process would suffer from the lack of a singular and concrete vision and target set for the sector.

- The key policy documents should be dynamic and flexible enough to adopt requirements as well as trends of the domestic, regional, and global energy and power sector. The *Renewable Energy Policy* has been published in the year 2008. Over a decade has passed since then, and the energy and power sector has undergone significant changes at all levels during this time. It is high time that GOB attempt to revise the decade-old RE policy. Provision should be kept for such policy document to undergo revision at regular intervals, for e.g. 5 years.

- One really important phenomenon has occurred in the domestic power sector that can be attributed mainly to the introduction of incentives brought upon by policies like 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 launching of *Private Sector Power Generation Policy* in 1996 (as mentioned in **Section 4.3**), the private sector started net generation as early as FY1999-2000. The subsequent revisions around the years 2007 and 2008 resulted in a significant rise in installed capacity as well as net generation. The **Figure 4.8: Comparison between Public and Private Sector Net Energy Generation (Source:).** shows the sector-wise net generation trend of Bangladesh since FY1998-1999.

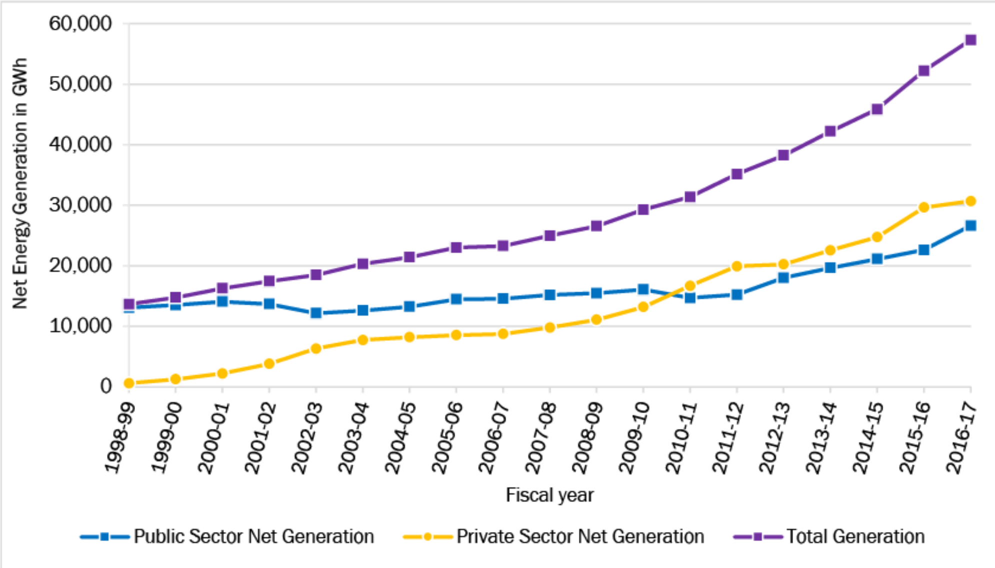


Figure 4.8: Comparison between Public and Private Sector Net Energy Generation (Source: [105]).

As apparent from the figure, the private net generation surpassed that of the public sector as early as 2010. Then the GOB launched the *Power System Master Plan 2010* and in it stated its short-term strategy of utilising Quick Rental Power Plants (QRPP) to further diminish the gap between demand and supply by backing the private sector. The drastic measure to opt for QRPPs drew severe criticism from experts as well as sects of civil society. But this ultimately resulted in significant hike in the country's capacity addition, and thus bring down the power scarcity.

5 Solar PV Capacity Targets from 2021 to 2041

In this chapter, three target scenarios of solar PV implementation are presented. Before delving into specifics, the principal rationale behind the scenario development is described in some details.

5.1 Basis of Devising the Scenarios

This section aims to describe the basis or rationale based on which the three scenarios are developed and presented in this *National Solar Energy Roadmap*.

The general methods and sources of information that have been repeatedly used to complete the task are: desk-based study and analysis, stakeholder consultation, simple spreadsheet-based calculations, web-based research, consultation of similar reports of other countries and regions etc. Most of the numerical data presented and referred to in the Roadmap has been collected from various nationally approved documents, such as, the Power System Master Plan of 2016, annual reports of government agencies like BPDB etc. In a few cases, peer reviewed journals have also been consulted, and accordingly acknowledged. Important concepts and additions incorporated in the Roadmap have arisen from the consultant's expertise and experience in the field as well.

In the following points, the rationale and methods of some of the most important aspects of the Roadmap are briefly described:

- *Study of the global context of the solar PV industry:* This has been achieved mostly by web-based research and study of reports published by notable international agencies actively engaged in the global renewable sector, such as, REN21, IRENA, IEA etc. Since, much of the Roadmap is likely to be implemented in the future, it is imperative to include information regarding the latest technological developments and then look into the plausible future projections of both the market and relevant technologies. The current progression of solar PV system related devices and equipment reveal that the efficiency is improving and the cost is on the decline. Improved efficiencies of solar cells are translated into requirement of lower spaces, which is still an important concern for solar PV plants. These discussions are appropriately supported by graphic content or evidence that are, in most cases, taken directly from the various online-magazines, websites, electronic versions of reports published by different international agencies and companies with adequate acknowledgements.
- *Review of international best practices:* Renewable energy related policy documents and roadmaps of a few countries and provinces with high RE targets have been studied. The main goal has been to gain insight about how these administrations or policy-makers plan and implement their respective targets. Special focus has been given to the neighboring country India that has in recent

years invested notable resources in promoting and patronizing RE usage across its borders.

- *Review of energy, climate change related national policy and long-term planning documents:* A rigorous study of relevant national policies and regulations have been conducted and summaries of each of these have been presented to rationalize GOB's active interest in favor of the RE sector, and solar PVs in particular. The review also reveals the current targets and programs undertaken by the relevant public stakeholders so far.
- *Review of the current solar PV sector implementation status:* This has been done to establish the understanding of the recent trend of the national solar power industry. This part of the Roadmap has been largely backed by the following sources:
    - Stakeholder consultation;
    - Online database of concerned agencies like SREDA, IDCOL etc.;
    - Annual reports and meeting minutes of agencies like, MPEMR, SREDA, BPDB, BADC etc.; and
    - Personal experience of the consultant.

    A graph has been presented that project the future tariff trend of large-scale solar PV projects considering the tariff trends of recent approved solar PV projects of Bangladesh. Optimistic inference has been deduced from this projection that the tariff is likely to decline in upcoming years, especially for large-scale projects. Therefore, quite understandably, the large-scale grid-tied projects have received considerable emphasis in this Roadmap.
- *Review of impending barriers and challenges:* The review of implementation status has been followed by an important aspect of the Roadmap that is the understanding of existing barriers and challenges of the sector. The findings presented here are mostly the result of the consultant's decade-long experience in the sector and consultation with other key stakeholders. This analysis sets the basis for many of the general recommendations proposed in Chapter 6.

It has been discussed in Chapter 2 that the cost or price of solar PV power technology is rapidly decreasing both globally and nationally. Apart from that, factors like strong backing from the policy-makers, heavy flow of investment, technological advancements, etc. are making the solar PV power increasingly popular not only as distributed sources but also as large-scale power plants. The decreasing price trend is visible in the Bangladeshi domestic market as well. On the other hand, the prospect of wind energy in Bangladesh is yet to be adequately explored. Therefore, at this point, it can be reasonably assumed that the majority of the renewable capacity in near future will be generated from the solar PVs.

5.2 Decade-wise Solar PV Targets from 2021 to 2041

In this section, three solar PV capacity deployment target scenarios from 2021 to 2041 are presented, which are the base (or business as usual, BAU), medium, and high case. The scenarios will aim for different levels of RE share in the installed capacity mix. However, the following points should be kept in mind while going through the three scenarios:

- All the cases are developed based on either existing or developing technologies. The possibility of entirely new or emergence of unknown technologies is not considered. For instance, if equipment (panels, etc.) with higher efficiencies are invented and duly commercialized, then the scenarios may be subject to drastic changes. Consequently, the required resources will be affected.
- All the scenarios proposed considering the forecasted power development targets of the *PSMP 2016*.
- Distinctions have been marked between utility-scale solar PV projects and the solar power hubs. The main points on which the differences will rest are the scale, the process of land identification, acquisition and development, the construction and permission of using the transmission infrastructure, etc. (details are mentioned in Chapter 7).
- The land requirement and other estimations are based on the state-of-the-art technology available in the market. In the coming decades, commercialization of solar cells with higher efficiencies, cheaper and more reliable storage technology, etc. may drastically change the entire landscape. Higher efficiency of solar cells or panels, in particular, may translate into lower land requirement, which is currently one of the major cost components and resource bottleneck specially in a small densely populated country like Bangladesh.
- A clear emphasis has been put on the large-scale implementation of solar PV technology. The key rationale behind this is to extract the maximum possible benefit from the economies of scale.

5.2.1 Business as usual (BAU) solar PV deployment scenario

In several important policy documents, including the *Renewable Energy Policy*, the GOB has fixed a target of generating 10% of the total power from RE sources by 2020. *Power System Master Plan 2016* indicated that GOB is likely to extend the target until 2041 (as discussed in Section 4.14). This is set as the BAU or low case scenario in the present Roadmap. It is proposed on the basis of the following assumptions:

- Existing acts, rules, policies, guidelines will be followed;
- Present incentives, benefits, facilities will be continued;
- Both public and private sector will actively participate;
- Integration of RE into the national grid will be ensured.

The GOB also intends to drive the economic growth rate in a way that would assist the country to become a developed one by 2041. In that case, considering the implementation of EE&C measures and a reserve margin of 10%, the generation capacity would be nearly 60,0000 MW (see Table 4.1 and Figure 4.6).

If the RE generation capacity is projected to be 10% of the total installed capacity by 2041, it will translate into nearly 6000 MW. The Table 5.1 and Figure 5.1 show the details of the BAU scenario or the base case of the solar PV target until 2041.

Table 5.1: Solar Photovoltaic Targets to be Achieved by 2041 (BAU case).

Component	until 2020 MW	2021-2030 MW	2031-2041 MW	Cumulative MW
Solar Power Hub (Utility + IPP)	0	500	1200	1700*
Solar PV power capacity addition by Utilities	15	400	800	1215
Solar PV power capacity addition by solar IPPs	160	450	800	1410
Rooftop solar PV systems	50	250	405	705**
Solar irrigation pumps	40	300	205	545**
Solar mini-/micro-/nano-grids	6	10	0	16
Solar home systems	252	5	0	257***
Solar-powered telecom towers	9	10	14	33
Solar street lights	11	8	10	29
Solar charging station	1	25	54	80
Other solar-powered systems	2	3	5	10
Total	**546**	**1961**	**3493**	**6000**

Notes:

** The PSMP 2016 identified this component as 'Solar Park'.*

*** Capacities correspond to the numbers specified in the PSMP 2016. However, the document clearly states that these do not reflect the theoretical potential, but are based on the planned projects.*

**** The PSMP 2016 mentioned a much lower value (100MW). This value mainly corresponds to the sector-wise RE roadmap set by SREDA (targets to be achieved until 2020). See Table 1.2.*

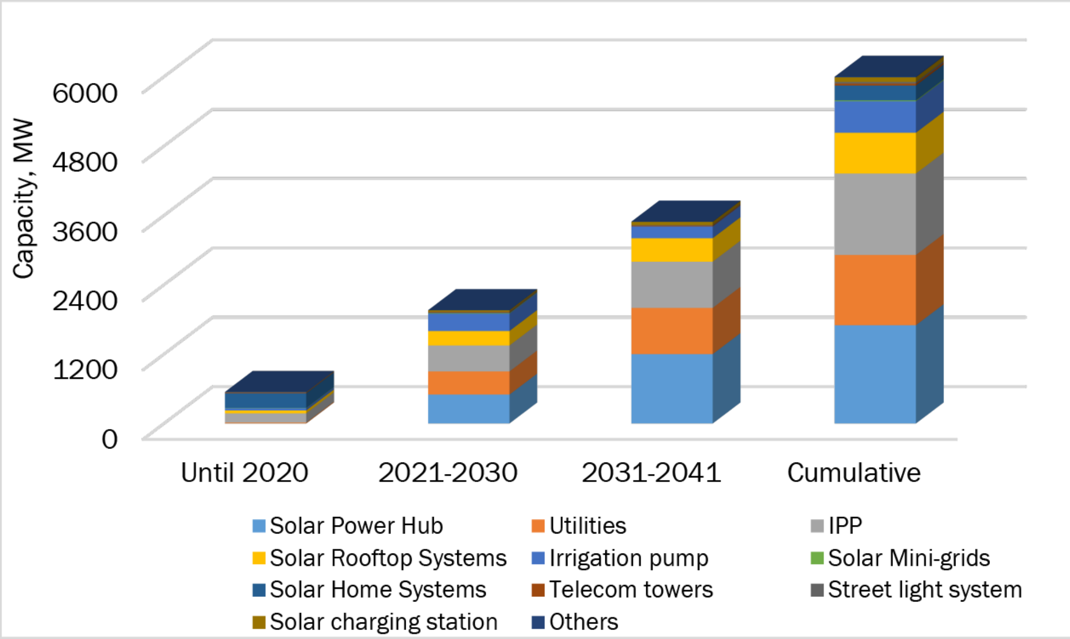


Figure 5.1: Solar Photovoltaic Targets from 2020 to 2041 (BAU case).

The Table 5.1 shows that according to the BAU case, the cumulative solar PV capacity will be 6,000 MW by 2041, which will be approximately 10% of the total generation capacity excluding hydro and bioenergy. Component-wise breakdown shows that the highest contribution will come from capacity additions by the Utilities and the IPPs, followed by large-scale solar parks to be implemented by the GOB. According to the *PSMP 2016*, the rooftop and SIPs sectors will contribute up to nearly 1,180 MW of the solar PV capacity by 2041.

5.2.2 Medium solar PV deployment scenario

The medium deployment case is developed based mainly on the assumption that resources, especially the land and essential policy incentives, will be available at least at a moderate level. Along with government patronage, the sector should receive international support as well in the coming decades. Following is the list of other factors that are assumed while devising the mid case:

- Existing policies, guidelines will be updated;
- Present incentives, benefits, facilities will be continued;
- Minimum purchase obligation for the utilities like RPO may be considered;
- Contract documents may be revised considering the grid security and investment risk in RE projects;
- Similar level playing field will be created for conventional power and RE;
- Power evacuation facility will be developed by the transmission company near to the project sites;

- Support and cooperation from the relevant ministries on resources (specially land and water bodies) utilization will be strengthened;
- Both the public and private sector will actively participate;
- RE projects will be developed including storage facility;
- National grid will be upgraded for Integration of RE.

Considering the above-mentioned assumptions, the Roadmap proposed 33% of total power capacity from solar energy under the medium case scenario. Accordingly, solar PV-based power capacity may sum up to 20,000 MW by 2041. The **Table 5.2** and **Figure 5.2** show the decade- and component-wise breakdown of medium level targets set until 2041.

Table 5.2: Solar Photovoltaic Targets to be Achieved by 2041 (Medium case).

Component	until 2020 MW	2021-2030 MW	2031-2041 MW	Cumulative MW
Solar Power Hub (Utility + IPP)	0	2000	7000	9000
Solar PV power capacity addition by Utilities	15	585	800	1400
Solar PV power capacity addition by solar IPPs	160	640	800	1600
Rooftop solar PV systems	50	1000	5550	6600
Solar irrigation pumps	40	500	400	940
Solar mini-/micro-/nano-grids	6	10	0	16
Solar home systems	252	6	0	258
Solar-powered telecom towers	9	10	16	35
Solar street lights	11	10	18	39
Solar charging station	1	30	70	101
Other solar-powered systems	2	4	5	11
Total	**546**	**4795**	**14659**	**20000**

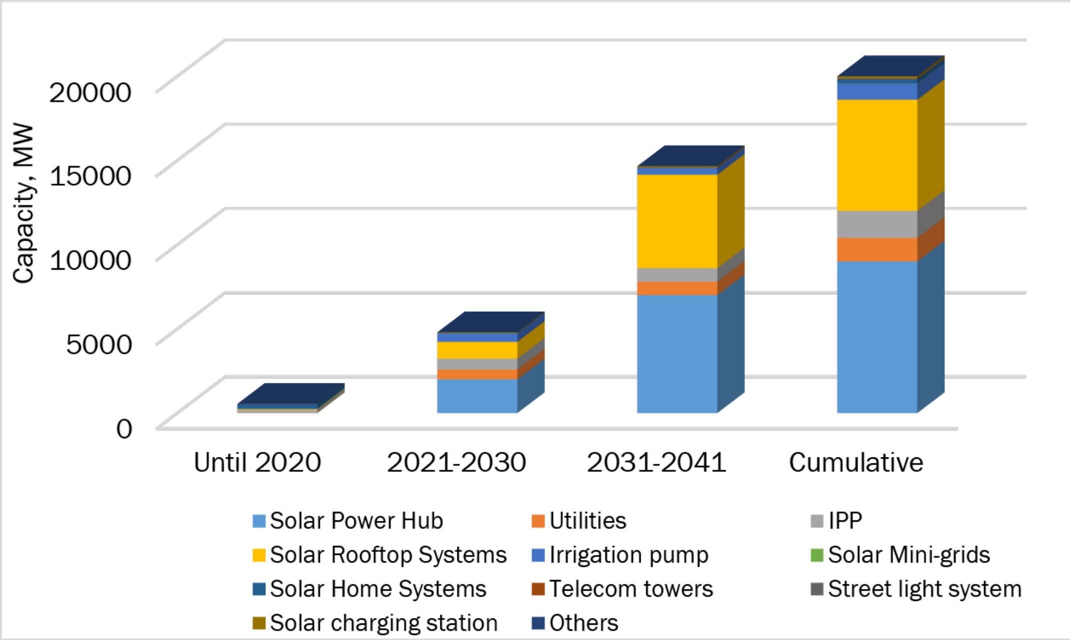


Figure 5.2: Solar Photovoltaic Targets from 2020 to 2041 (Medium case).

It is apparent from **Table 5.2** that like the BAU scenario, due emphasis has been put on the large-scale projects with 9 GW to come from solar power hubs, followed by capacity additions by rooftop solar PV systems and capacity addition by the IPPs and the public utilities. The sheer emphasis on large-scale projects and the rooftop systems is clearly visible from the **Figure 5.2** as well. The remaining large chunk of power capacity will be covered by solar-powered irrigation pumps.

It can be mentioned that nearly 3.125% of the prospective reclaimed or accrued land as per the *Bangladesh Delta Plan 2100* should be made available for the deployment of the Power Hubs. Also, GOB should take the leading role in developing these hubs by developing the land and building the required transmission infrastructure.

5.2.3 High solar PV deployment scenario

Compared to the base and mid case, the high case scenario assumes more aggressive attitude of the government and reliable international financial support. For instance, for the high deployment case to be feasible, the land accretion and reclamation as per the *Bangladesh Delta Plan 2100* will have to be realised and nearly 5% of the land will have to be allocated to the development of the Solar Power Hubs. The following is a list of major assumptions on which the high case is based upon:

- More advanced technology will be available in the market;
- Solar cells with higher efficiencies, and cheaper and more reliable storage technology will be commercialized;
- Solar power from neighboring countries will be imported;

- The required land and water bodies will be allocated to the Power Division for the development of solar power;
- Strong support from development partners will be available;
- Existing policies, guidelines will be updated;
- Present incentives, benefits, facilities will be continued;
- Minimum purchase obligation for the utilities like RPO may be considered;
- Contract documents will be revised considering the grid security and investment risk in RE projects;
- Similar level playing field will be created for conventional power and RE;
- Power evacuation facility will be developed by the transmission company near to the project sites;
- Support and cooperation from the relevant ministries on resources (specially land and water bodies) utilization will be strengthened;
- Both public and private sector will actively participate;
- RE projects will be developed including storage facility;
- National grid will be upgraded for the integration of RE.
- Maximize the utilization of industrial rooftop for installation of solar PV systems and
- Utilization of planned reclaimed lands in the river banks and Meghna estuary.

Depending on the above-mentioned assumptions, the Roadmap proposed 50% of total power capacity from solar energy under the high case scenario. Accordingly, solar PV base target for high case will cover up to 30,000 MW by 2041. The following **Table 5.3** and **Figure 5.3** show the decade-wise and component-wise targets to be achieves by the year 2041.

Table 5.3: Solar Photovoltaic Targets to be Achieved by 2041 (High case).

Component	until 2020	2021-2030	2031-2041	Cumulative
	MW	MW	MW	MW
Solar Power Hub (Utility + IPP)	0	3000	9000	12000
Solar PV power capacity addition by Utilities	15	985	1000	2000
Solar PV power capacity addition by solar IPPs	160	1000	1040	2200
Rooftop solar PV systems	50	3950	8000	12000
Solar irrigation pumps	40	700	460	1200

Component	until 2020	2021-2030	2031-2041	Cumulative
	MW	MW	MW	MW
Solar mini-/micro-/nano-grids	6	10	0	16
Solar home systems	252	8	0	260
Solar-powered telecom towers	9	10	20	39
Solar street lights	11	13	20	44
Solar charging station	1	60	165	226
Other solar-powered systems	2	7	6	15
Total	**546**	**9743**	**19711**	**30000**

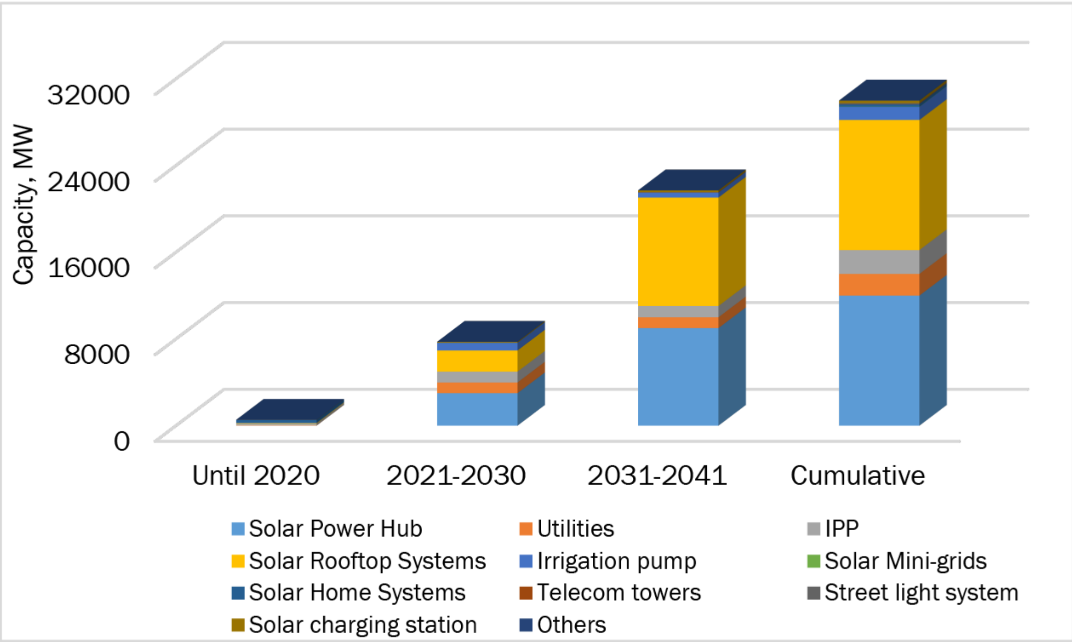


Figure 5.3: Solar Photovoltaic Targets from 2020 to 2041 (High case).

Both **Table 5.3** and **Figure 5.3** show that out of the 30 GW solar PV capacity 40% would be covered by large-scale solar PV power projects developed within the solar power hubs. Around 40% will be covered by rooftop solar PV systems. Large-scale solar PV projects developed by utilities and IPP outside of the solar power hubs will contribute significant role in the scenario. Solar-powered irrigation pumps will also have significant shares in the capacity mix. Even though on a very small-scale, solar charging stations are likely to gain some importance owing to the probable commercialization of electric vehicles in the future.

In all the scenarios presented above, a few common traits are clearly noticeable. For instance, the solar homes systems, solar mini-/micro-/nano-grids are likely to lose financial and technological viability in the long-run due to the penetration of national grids in the off-grid areas. However, the following **Figure 5.4** shows comparison among the decade-wise growth trend of solar PV sector for the three devised scenarios. It is clear enough that majority of the capacity addition are likely to occur in the decade ranging from 2031 to 2041. The coming decade should be utilized as the preparatory phase for the rigorous implementation planned to occur in the next one.

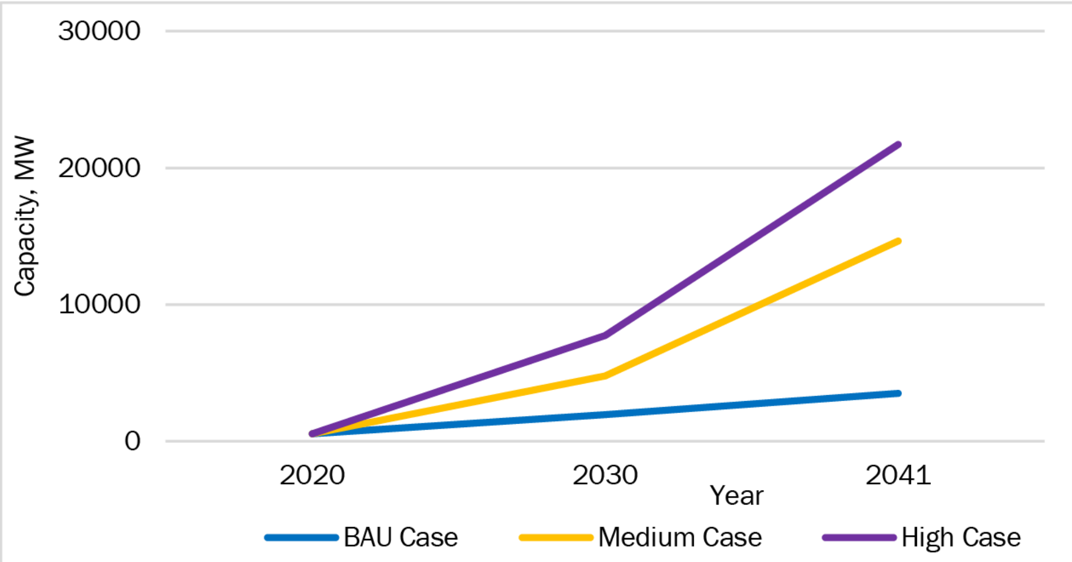


Figure 5.4: Comparison of Three Solar Deployment Scenarios.

5.3 GHG Emission Reduction Potential of Different Scenarios

GHG emission reduction potential is calculated considering the grid emission factor of Bangladesh to be 0.67 tons/MWh, and solar energy generation per MW (AC) of installation is 1560 MWh/MW (AC capacity).

Table 5.4: Estimated solar photovoltaic energy generation and yearly GHG emission reduction potential for different scenarios.

	Scenario	2020	2030	2041	Cumulative
BAU Case	Solar PV Capacity Target (MW)	546	1,961	3,493	6,000
	Annual Generation of Electricity (MWh)	851,760	3,059,160	5,449,080	9,360,000
	GHG Emission Reduction ($MtCO_2$ Equivalent)	570,679	2,049,637	3,650,884	6,271,200
Mid Case	Solar PV Capacity Target	546	4,795	14,659	20,000

	Annual Generation of Electricity (MWh)	851,760	7,480,200	22,868,040	31,200,000
	GHG Emission Reduction ($MtCO_2$ Equivalent)	570,679	5,011,734	15,321,587	20,904,000
High Case	Solar PV Capacity Target	546	7,743	21,711	30,000
	Annual Generation of Electricity (MWh)	851,760	12,079,080	33,869,160	46,800,000
	GHG Emission Reduction ($MtCO_2$ Equivalent)	570,679	8,092,984	22,692,337	31,356,000

5.4 Scenario Selection and Rationale

As the primary fuel diversification strategy, GOB has put major emphasis on coal-based power plants, nuclear energy and as well as electricity import from neighboring countries. The unpopularity of coal-based solutions as detrimental to the environment, massive risk factor accompanying nuclear plants and vulnerability associated with dependence on energy import impart clear unsustainability attributes to these solutions. Understandably, the nation still has plethora of reasons to look for an 'affordable and clean' or in other word a truly sustainable source of energy.

Some recent publications indicate a quite high potential for renewable technologies in Bangladesh, especially for solar PVs [101, 106]. According to Shiraishi, Shirley and Kammen, there is 53 GW of low-cost utility-scale PV potential in Bangladesh [106]. The current Roadmap itself presents a review of the global context in terms of market & price trend, investment flux, research & development status etc. Taking into consideration all these indications and findings, this Roadmap recommends the high deployment scenario along with a suggested set of general and specific actions.

A document published jointly by IRENA, REN21 and IEA has been particularly pivotal in understanding the different phases of renewable sector development [107]. Insights from this document served as an important basis for the decade-wise division of development phases of the national solar PV sector and corresponding technological measures to be adopted. It has been previously mentioned that the solar power-hubs have received special emphasis among all other sector components. Major portion of this proposed large-scale solar PV power capacity, 9 out of 12 GW, is recommended to be deployed in the 2nd decade between 2031 to 2041. Understandably, several aspects of the large-scale solar PV that demand further clarification, which are discussed in the following points:

- ***Selection of locations:*** Bangladesh is one of the most densely populated countries in the world. Vast stretches of land for large-scale solar PV project development is scarce in Bangladesh. The suitable locations for implementing the large-scale projects have been identified after consulting nationally approved documents, such as, the *Bangladesh Delta Plan 2100*, PGCB's grid extension plan etc. Land reclamation plan is stated in the *Bangladesh Delta Plan 2100*, which are mainly in the river banks and close to the coastal region. Almost all the solar power hubs have been recommended to be established into these reclaimed lands. The detailed selection criteria have been mentioned in **Section 7.1.1**.

- ***Inclusion of large-scale storage facilities:*** Renewable power sources like solar and wind energy are variable in nature. Implementation of these technologies in large-scale risks the stability of the grid. At comparatively earlier stages of RE penetration measures such as modifying grid operation practices, enhancing system flexibility, matching demand with supply by shifting the demand curve prove to be sufficient.

  However, at more advanced stages of RE implementation, large-scale storages along with reliable forecasting systems are more reliable and tend to be feasible economically. Integrated storage systems with solar PV projects effectively reduce the variability and make it possible for renewable sources to supply the base-load as well. So, installation of large-scale storage facilities will be imperative starting from the end of the first decade and throughout the whole of 2nd decade. It has been recommended that once the variable renewable (solar, wind etc.) power generation capacity surpass 10% of the national base load (grid), each new VRE plant must integrate storage facilities to neutralize the variability on the generation side. It can be anticipated to occur sometime in second half of the first decade. Beyond this stage, VREs with integrated storage facilities can be expected to supply the country's base load.

6 General Recommendations

This chapter of the Roadmap will focus on the general measures that can be attempted to meet the solar PV targets (high case) as set forth in **Chapter 5**. Even though the recommended actions will be presented according to the decade-long timeframe in this chapter, they can be grouped under the following broad themes:

Theme 1: Developing a favorable policy framework

A solid legal, policy-wise and regulatory framework is essential for achieving any well-defined national energy target. Therefore, understandably, the foremost step shall be setting a target that will generate and propagate an essential high-end priority signal to all the stakeholders and actors involved in the sector. In Bangladesh a couple of very important steps have already been implemented, and there is still significant scope for policy makers to intervene into. The necessary policy and regulatory actions would vary in terms of type (regulatory/ non-regulatory, administrative/ market-based pricing schemes), timeframe, scale of applicability, etc.

Theme 2: Building a robust power system infrastructure

Solar PV is essentially a VRE technology. The impact of grid-integration of VRE systems are characterized by both positive and negative attributes, such as high variability, uncertainty, localized, modularity, non-synchronous and low short-run costs. Therefore, aiming for higher shares of solar PV automatically introduces crucial technical challenges as well as potential solutions. Global experience of VRE integration has revealed that timely planning and proper management of resources like the 'dispatchable generators, grid infrastructure, load shaping and energy storage' can improve the system flexibility [107].

IRENA has categorized the increasing impact of VRE on the power system into several phases [107]. **Figure 6.1** shows the categorization with main features or challenges and possible solutions of each of these phases in brief.

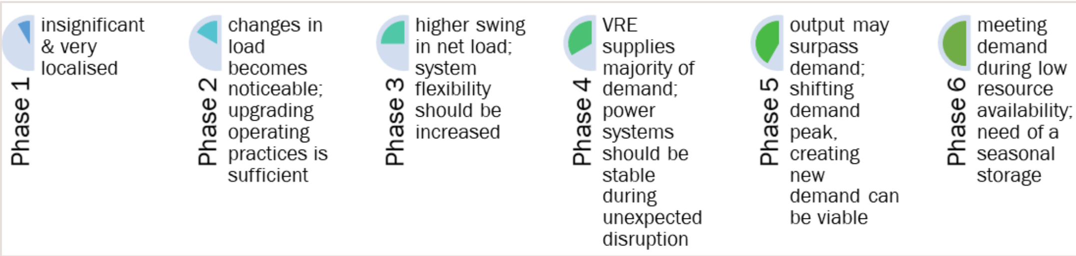


Figure 6.1: Categorization of VRE Integration Phases by IRENA (reproduced from [107]).

A careful study of this categorization certainly helps formulating a plan to tackle the technical challenges that may arise in the future deployment of solar PV in Bangladesh.

Theme 3: Strengthening equipment supply chain

An uninterrupted supply chain is mandatory for smooth construction and, more importantly, operation and maintenance of solar power plants. Except for lead acid batteries, a local market of other major solar plant equipment is simply non-existent in Bangladesh at present. All the projects depend exclusively on the imported equipment, the quality of which must be ensured. Moreover, transportation of equipment to the remotest corners (typical areas suitable for solar PV plants) poses added challenges. Dependence on import and the gap in logistics stretches the downtime and thus greatly hampers the operation and maintenance of the project, be it a standalone SHS or a mega-grid. The waste disposal plan of PV system equipment needs to be taken under consideration for at the end of the lifetime.

Theme 4: Ensuring a safe financial landscape

It has already been realized that the envisioned target must be met by merging the effort of both public and private sector. In recent years, GOB has indeed taken steps to encourage private investment in this sector (see **Chapter 4.3**). Consequently, the effort has delivered clear results. Since the entry of private power producers in FY1998-1990, the net energy generation capacity has increased more than 4 times. The private sector surpassed the public sector in net generation around 2010 and has successfully sustained the trend (as shown in **Figure 4.8**).

The same trend is desired in the solar sector as well and to achieve that a secured investment environment is of utmost importance. Since, the solar market is still in the developing phase in Bangladesh, the private investors understandably foresee higher risks to invest into such projects. However, a few financial incentives are suggested in the 'Renewable Energy Policy 2008' [9], such as Value Added Tax (VAT) and income tax exemption, limited import duties on RE related equipment and raw material, 10% higher tariff than the highest electricity purchase price paid by the utilities, possibility of setting up a micro-credit support system, etc.

Other financial incentives, such as introducing innovative business models, lowering interest rate, mandatory power purchase agreement with the utilities at regulated tariff for larger investors, regulated NEM tariff/green certificates for small to medium scale investors, provision for capacity payments, etc. can be considered for creating a safe financial environment in the long-run.

As for the financing sources, multiple international donor organizations can be approached among which the Green Climate Fund set up by UNFCCC, Global Environmental Facility (GEF) and Climate Investment Fund by World Bank etc. are mention-worthy. Development partners like the UNDP, ADB, GIZ, USAID, JICA, KOICA, etc. are already playing essential roles in promoting RE within the country. Ties with them can be further strengthen to secure a constant and guaranteed flow of finance to realize the targets set in this document.

Theme 5: Enhancing demand and capacity building

For any sector to grow in a sustained manner, all stakeholders should be brought on a sort of common platform of awareness and should be engaged effectively to play their respective roles. In fact, for the energy sector's transition towards sustainability, the stakeholders' awareness and active participation is imperative. The government's intention to favor sustainable forms of energy sources, therefore, must be effectively communicated with all of these factions in order to establish the clear-cut priority across the entire sector.

The stakeholders of the solar energy sector include all sorts of end-users, policy-makers, public utilities, local pool of technical expertise, private sector and foreign investors, educational and R&D institutes, development partners, system operators and technicians, suppliers and manufacturers, etc. It is important to first identify the contributions that each of the sects can offer, and then to assess their need for incentivizing, capacity building or skill development. For instance, the importance of motivating the consumers to opt for environment-friendly solar power and fostering an enabling environment by developing the capacity of all the stakeholders are undisputable to sustain the development of solar power sector. A well-informed base of customers is more likely to become a responsible base of prosumers, which will be valuable in the long run if decentralization of the power sector is intended.

Apart from changing the perception of customers who actually receive electricity as a daily service, it is equally important to flourish an enabling institutional capacity that will provide services to the solar power sector itself. For example, the financial institutions or investors should have at least basic familiarity with the economics and basic technicalities of solar projects in order to better asses the investment requirements. Testing laboratories should have sufficient expertise to test the qualities of locally manufactured or imported equipment.

Based on these five broad themes, the Roadmap suggests a set of several general recommendations in the form of doable set of actions. Achieving the outcomes of these actions over the next two decades (2021–2030 and 2031–2041) will be instrumental in meeting the capacity targets set in **Chapter 5**. For Bangladesh, the solar PV sector is still in its inception stage, which is quite suitable for molding the entire landscape and make it suitable for high share of solar PV power inclusion in future. Therefore, the primary objectives to be achieved in the first decade can be listed as follows:

- Consolidate the initial efforts;
- Enhance the flexibility of power infrastructure;
- Accelerate the deployment of solar PV industry; and
- Create enabling environment for the full-fledged, but steady development of solar PV sector in Bangladesh in the next decade.

The goal is basically to set the premise and prepare the stakeholders for long-term solar PV sector development. This decade can be termed as the phase of enabling support, transition and development. The later decade will be the phase of full-pledged development of the sector. It is expected that numerous stakeholders will participate in the development process in a rigorous and committed manner throughout the decade. The primary objectives of the second decade are listed as below:

- Exploit the country's full potential to be developed in the coming decade;
- Venture into more ambitious steps that will call for power system-wide reform and advanced technologies;
- Fully utilize the support of local research and innovation wherever possible;
- Seek spontaneous involvement of society to a greater length;
- Analyze tariff structure for different locations.

The **Table 6.1** lists all the suggested actions to be carried out over the upcoming decade. These are elaborated later in **Appendix C: Decade-wise General Recommendations.** Each of the actions is provided with brief explanation of the rationale, indication of relevant stakeholders and speculation of the expected outcomes.

Table 6.1: List of General Recommendations.

Time	Actions	Type
2021 – 2030	1. Revise policy documents and set new RE target, especially a solar PV target 2. Devise regulatory and pricing policies for facilitating large-scale solar PV projects 3. Formulate and effectively communicate a clear and definite main grid-extension related policy	Policy and regulations

Time	Actions	Type
	4. Expand the policy implementation scope for incentivizing distributed generation 5. Develop necessary plan of electricity distribution utilities to reduce the generation cost of electricity by adding solar PV in diesel-based electricity supplied off-grid areas 6. Formulate policy and implementation of smart grid to address the variability of generation 7. Introducing policy for industrial storage system for peak shifting and shaving of load and variable RE generation	
	8. Develop and update the Bangladesh Standards (BDS) of solar accessories, related power quality and technical installation suited to local context 9. Review the national grid code and, if necessary, upgrade accordingly to yield only minimum cost 10. Achieve higher power system flexibility by introducing RE ancillary services 11. Modify system operation practices to include variable solar PV plants 12. Upgrade existing grid infrastructure, especially the transmission network 13. Match demand with the variable solar PV supply via demand side management etc.	Technical
	14. Program wise implementation of national standards of solar appliances 15. Accepted laboratory criteria 16. Capacity development of local laboratories for local verification 17. Installation standards and quality designer and installer generation 18. Incorporating the provision of mandatory Bangladesh Standard during import 19. Facilitate the development of the local manufacturing industry and easier access to export to the other countries 20. Create a comprehensive information hub and introduce the national solar help desk service 21. Solar PV waste disposal plan	Supply chain

Time	Actions	Type
	22. Availability of long term and concessionary financing through commercial financial institutes	Finance
	23. Launch nation-wide awareness programs 24. Introduce and expand educational and training programs 25. Initiate and expand solar photovoltaic research and development efforts 26. Create attractive 'solar jobs'	Market Enhancement and capacity building
2031-2041	1. Introduce and cascade down RE/solar PV quotas and obligations to either administrative regions or even to various companies operating in the sector 2. Establish and regulate a tradable RE/solar PV certificate mechanism	Policy and regulations
	3. Establish large electricity storage capacities	Technical

It should be noted that these set of actions are based on a number of speculations. The future technological advancement, successful implementation of the actions mentioned in the previous sections, socio-political condition and commitment of the country, global trend, etc. will certainly influence the course of action in the next decades to follow.

7 Specific Recommendations

This chapter of the Roadmap will present some specific sets of actions that will support achieving the targets mentioned in Chapter 5. Some of these actions are component-specific (for example solar power hub, SIP, etc.), while some are theme-specific (financing sources, transmission network up gradation, etc.).

7.1 Solar Parks and Solar Power Hubs

One of the biggest concerns for planning large-scale solar power projects is that they require vast stretches of land to implement. Being a highly populated, agriculture dominated economy and a relatively small country, the competition for land is fierce in Bangladesh. The process of legal acquisition of land is also quite complicated and long. Therefore, the Roadmap puts considerable emphasize on the aspect of land barrier and recommends several measures to be adopted by the GOB to build the envisioned 'Solar Power Hubs' to meet the solar PV targets.

The solar power hubs are defined as clusters of solar PV power plants, the combined capacity of which should be at least 500 MW. The individual power plants located within the hubs' territory can be owned by either the public utilities or IPPs through competitive bidding process. Eleven solar power hubs are proposed to be developed on land stretches identified.

As mentioned earlier in Section 5.2, apart from capacity, the other points of distinction between the utility/IPP-owned solar plants and the power hubs are: the process of land identification, acquisition and development, construction and permission of using transmission infrastructure, etc. The government is to play the key role in planning and implementing the power hubs. So, besides identification of the suitable locations, the government should also execute the acquisition process, develop the land and take up the construction of the necessary civil and electrical transmission infrastructure.

The principal rationale behind the power hubs is to tap the benefit of the economy of scale. The cost of civil and electrical construction can be expected to be minimized to a considerable extent. Also, since the government will organize the required land, which is still the major barrier for the sector, the opportunity is likely to become more appealing to the project developers and investors.

Apart from the various physical elements, the government should also invest considerable effort in devising a solid policy framework to support the successful development of the power hubs. The following sub-sections of the Roadmap attempt to briefly address two of these important aspects of the solar power hub planning, namely the identification of suitable land stretches and policy interventions.

7.1.1 Identification of suitable land

Identification of suitable land is one of the major challenges while planning utility-scale solar power plants. Some of the important factors that should be considered during the planning phase are listed below:

- Land requirement from high-priority competing sectors such as agriculture;
- Suitability in terms of erosion and other natural disasters;
- Adequacy of solar irradiance;
- Prospect of land accretion and new land reclamation;
- Vicinity of transmission network or future upgradation/extension plans;
- Ownership of land (e.g. *khas* land may get preference);
- Area of land in a single place and required amount of development works;
- Facility of interconnection to the nearest substation.

Keeping all these factors in mind, this subsection aims to identify several possible geographical locations for planning large scale solar PV power plants, or solar parks. The following are some of the prospective areas:

- **Kaptai Lake:** The catchment area of the Kaptai Dam is estimated to be nearly 11,000 square kilometers. **Figure 7.1** shows the geographical location and the satellite view of the catchment area of the Kaptai Lake in Chattagram Division. Out of this vast area, around 750 square kilometers is waterbody. If only 1% of this water surface is utilized for floating solar power plant, nearly 500 MW of solar capacity can be installed. Even though the location is highly suitable, the transmission system should be upgraded to evacuate the generated power.

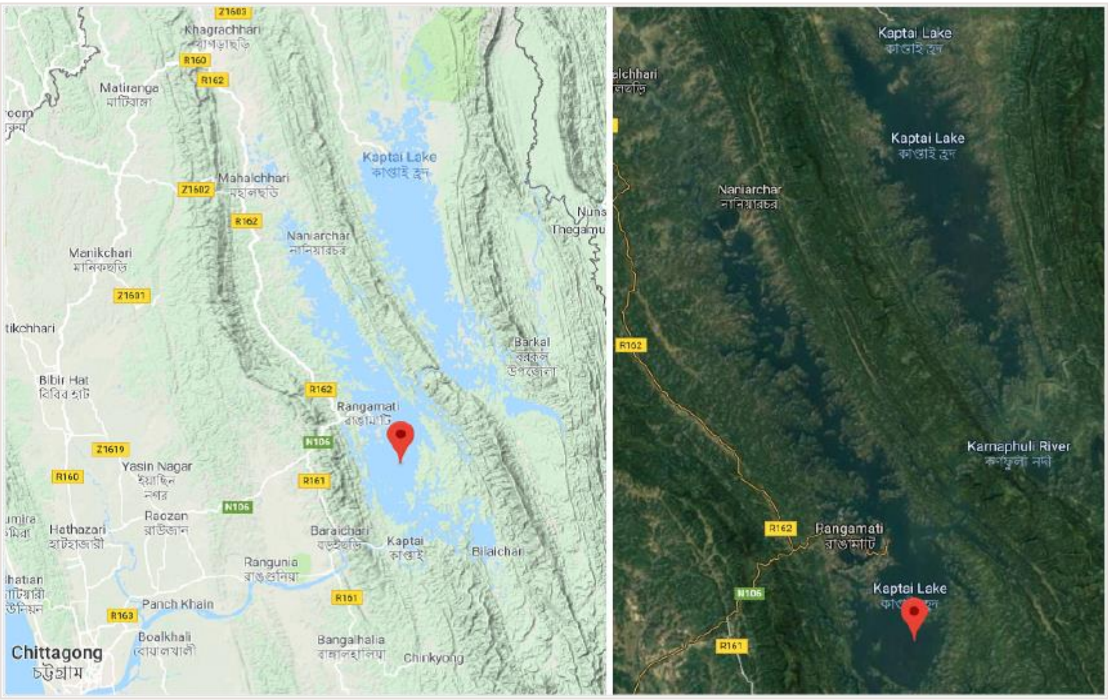
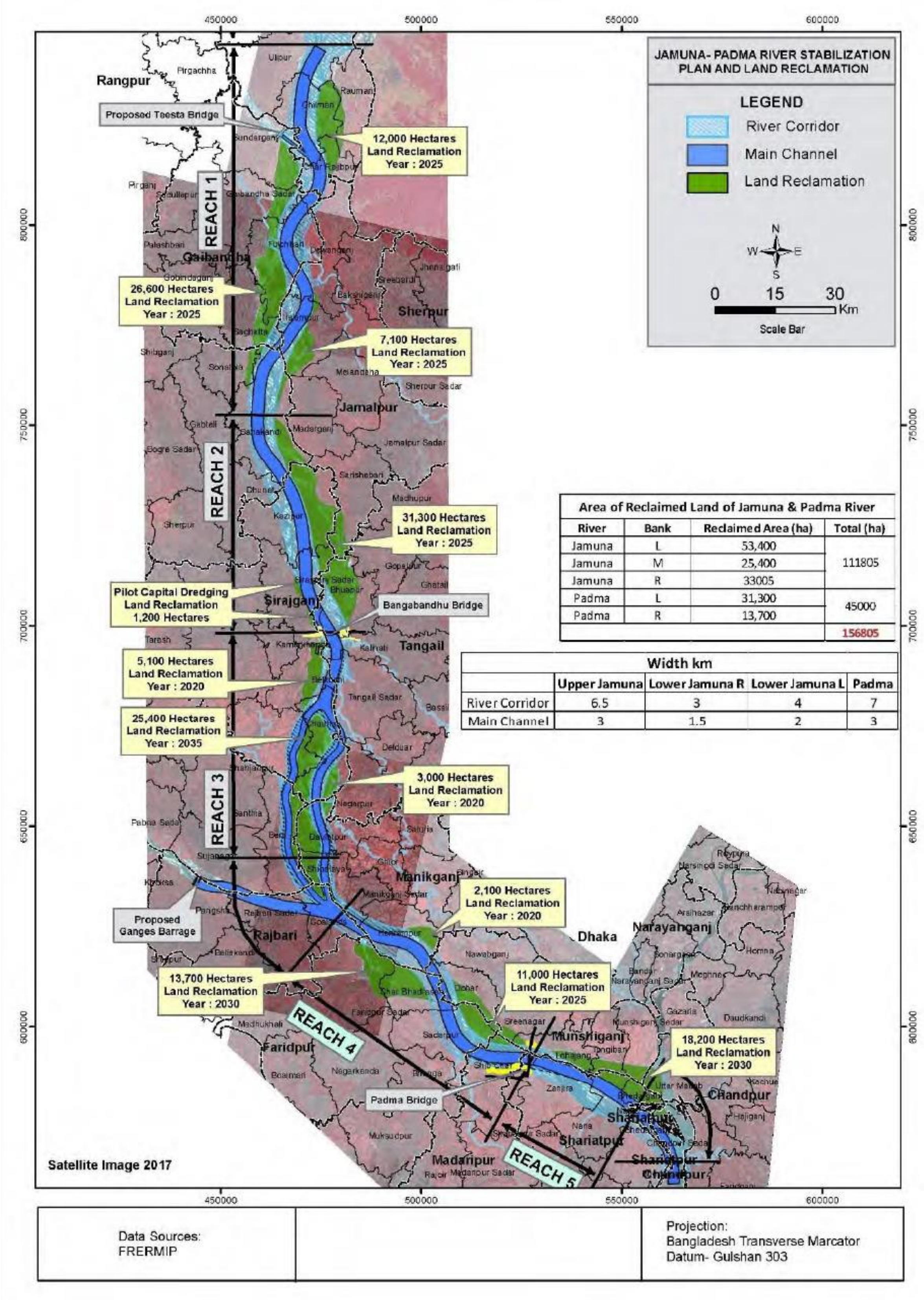


Figure 7.1: Geographical Location of Kaptai Lake (Source: Google Maps).

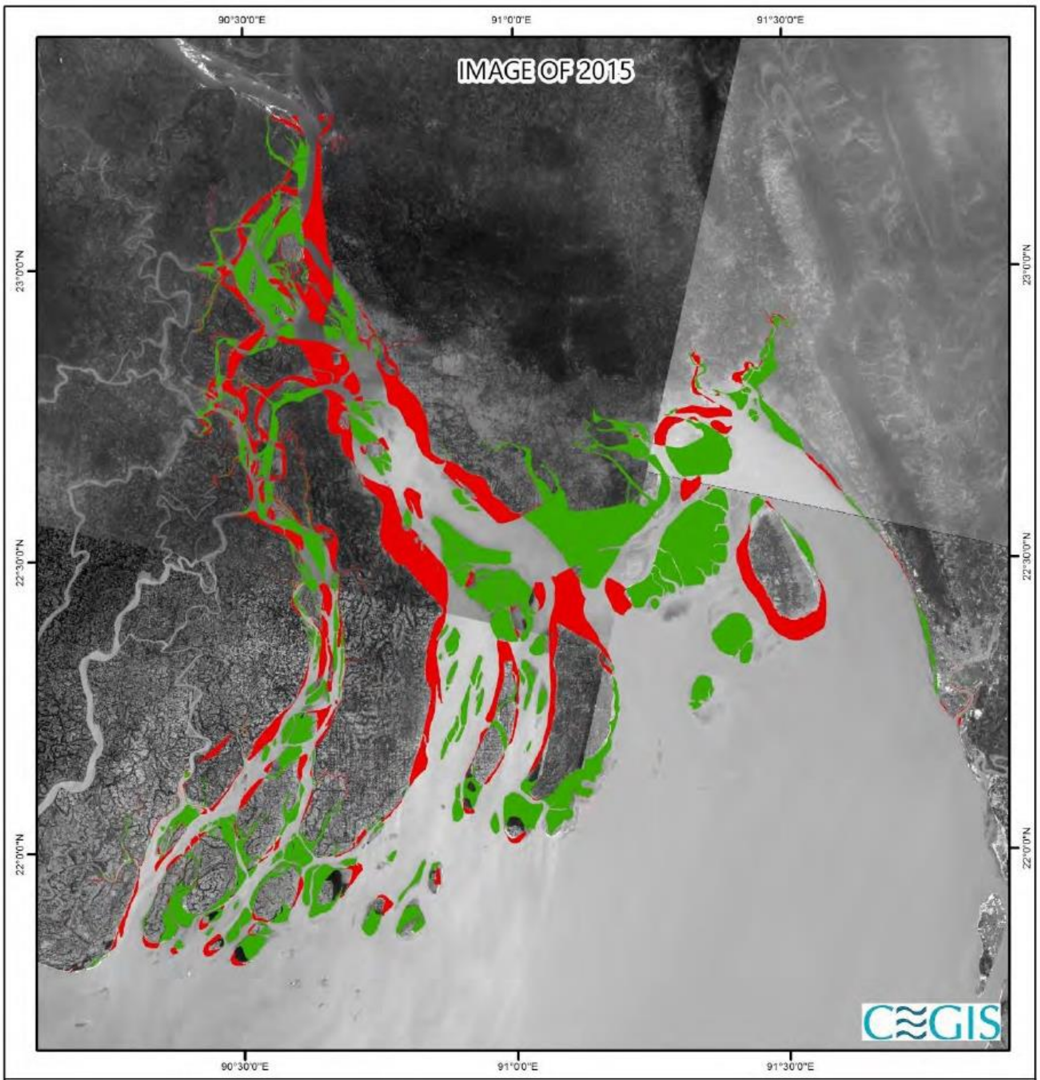
- **River banks and islands:** There are strips of uncultivable and generally uninhabitable land available along the banks of the main rivers of the country, as well as on the low-lying river islands. The *Bangladesh Delta Plan 2100* predicts possible land accretion under certain conditions along the major river banks. Several clusters of such land strips are identified and pointed on the map as shown in **Figure 7.2**. If reclaimed, some portions of these massive stretches of land can be considered for the deployment of gigawatt-scale solar parks making it possible to add substantial renewable capacity to the power sector. But it must be noted that **Figure 7.2** indicates the timeframe of these land accretion along the Jamuna-Padma bank to vary from 2020 to 2035. Therefore, this aspect shall be considered for long-term planning only, i.e., beyond 2025. There are two more factors that should be kept in mind while considering such land strips. Firstly, such locations are typically susceptible to erosion. Such plans should also be made in close consultation with the PCGB and be aligned with their long-term transmission network extension plan. Moreover, development of giga-watt scale solar plants may justify extending transmission line to those regions.
- **Potential reclaimable land in Meghna Estuary:** The *Bangladesh Delta Plan 2100* also declared the possibilities of future land reclamation in the southern coastal region, especially in the Meghna Estuary. **Figure 7.3** shows erosion-accretion status of that region until 2015, while **Figure 7.4** depicts the potential land reclamation in future. This region (Meghna Estuary) offers immense potential to build it as a 'Solar Power Hub' in the long-run. It is mention-worthy that the coastal belt of the country enjoys considerable solar radiation all over the year. But it is also prone to severe natural disasters, such as cyclones. But again, the prospective scale of the power hubs may justify the investment in making the area more disaster-resistant and establishment of suitable transmission network.
- ***Khas* land:** Since the ownership of land is an important issue while planning large-scale power plants, a look at the status of *khas* land may be helpful. *Khas land* is the government owned uncultivated land, of which no one has the property rights and which is available for allocation as per the government's priorities. The Ministry of Land has published the division wise list of *khas* land in their *Annual Report 2018-19* as shown in **Table 7.1** [108]. It is observed from the table that there are around 2 million acres of non-agricultural khas land available in the country, which is also not suitable for habitation. The Power Division, MPEMR can work together with the Ministry of Land to identify the *khas* lands for solar PV project development, especially those which are not agricultural and not suitable for settlement, or not used for any other purpose. These lands can be further developed and made ready for building solar PV projects by the Government. These lands can be provided to the government owned power generation utilities, or can be provided to the IPP through competitive bidding.



Area of Reclaimed Land of Jamuna & Padma River			
River	Bank	Reclaimed Area (ha)	Total (ha)
Jamuna	L	53,400	111805
Jamuna	M	25,400	
Jamuna	R	33005	
Padma	L	31,300	45000
Padma	R	13,700	
			156805

Width km				
	Upper Jamuna	Lower Jamuna R	Lower Jamuna L	Padma
River Corridor	6.5	3	4	7
Main Channel	3	1.5	2	3

Figure 7.2: Jamuna-Padma River Stabilization Plan and Possible Land Reclamation [101].



Erosion-Accretion in the Meghna Estuary Area during 1973-2015

District	Erosion (km²)	Accretion (km²)	Net accreted area (km²)	Rate of net accretion (km²/y)
Barisal	169	155	-14	-0.3
Bhola	385	396	11	0.3
Chandpur	76	44	-33	-0.8
Chittagong	105	256	151	3.6
Feni	11	30	19	0.4
Lakshmipur	133	53	-80	-1.9
Noakhali	179	620	441	10.5
Patuakhali	126	230	103	2.5
Shariatpur	20	27	7	0.2
Total	**1205**	**1810**	**605**	**14.4**

Figure 7.3: Erosion-accretion in the Meghna Estuary Area as of 2015 [101].

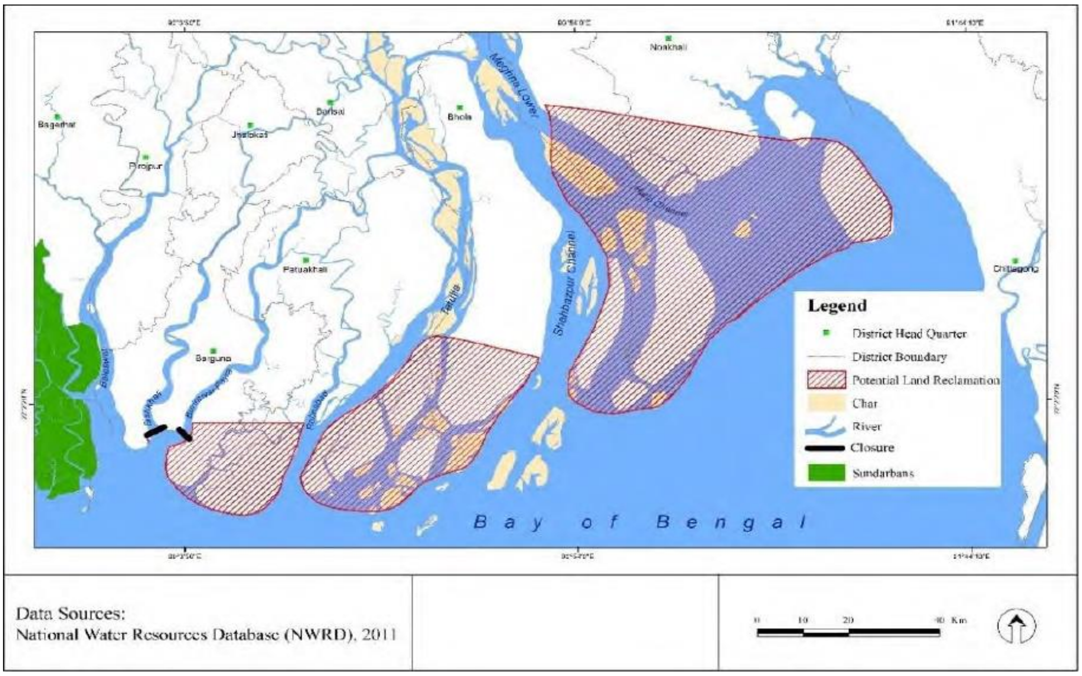


Figure 7.4: Potential Land Reclamation in the Meghna Estuary Region [101].

Table 7.1: Division wise Information on *Khas* Land of Bangladesh [108].

Division	Total *khas* land (acres)		*Khas* land available for settlement (acres)	
	Agricultural	Non- agricultural	Agricultural	Non- agricultural
Dhaka	179832.92	269573.44	71933.25	9600.63
Mymensingh	114821.68	91160.39	61497.78	1700.68
Sylhet	158299.95	216816.96	61871.08	13052.71
Barisal	198503.65	1616.87	23072.37	1127.70
Khulna	94501.36	132757.09	4986.28	868.79
Chittagong	756468.86	1318754.86	116077.70	90747.72
Rajshahi	111346.86	166590.57	42200.62	2672.75
Rangpur	136447.90	117303.50	73609.90	2092.40
Total	**1750223.18**	**2314573.68**	**455248.98**	**121863.38**

- **Protected area on both sides of Bangabandhu Jamuna bridge and Padma bridge:** Vast stretches of land on the both sides of the Bangabandhu Jamuna Bridge and the Padma Bridge area are under the river erosion protection scheme. Protected suitable land on both side of these mega bridges can be identified for large-scale solar PV project development.
- **Canal tops or banks:** According to the information of the Water Development Board, there are 3 types of canals in our country based on width: Primary (width is more than/equal to 20ft), Secondary (width is 10ft to less than 20ft) and Tertiary (width is 5ft to less than 10ft). The canal tops or canal banks can be used for solar power

generation, where suitable. The GK Project, the Tista Project, etc. are mention worthy examples of the kind. However, a detailed study can be conducted to assess the actual potential.

Based on the discussion presented on the identification of suitable lands, a summary of possible solar PV parks and power hubs with suggested capacity and timeline are present in the **Table 7.2**.

Table 7.2: Summary of the Proposed Solar Power Hubs.

#	Prospective location	Capacity (MW)	Land requirement (km^2)*	Potential land availability (km^2)**	Timeframe
1	Kaptai Lake *(floating solar)*	500	5	750	2021 – 2041
2	Kurigram *(Bank of river Jamuna)*	500	5	120	2031 – 2041
3	Rangpur, Nilphamari *(Bank of Teesta)*	600	6	170	2031 - 2041
4	Gaibandha *(Bank of river Jamuna)*	1300	13	266	2031 – 2041
5	Jamalpur *(Bank of river Jamuna)*	1200	12	320	2031 – 2041
6	Sirajganj *(Bank of river Jamuna)*	1200	12	317	2021 – 2041
7	Tangail *(Bank of river Jamuna)*	500	5	60	2031 – 2041
8	Rajbari *(Bank of river Padma)*	600	6	137	2031 – 2041
9	Munshiganj *(Bank of river Padma)*	1500	15	292	2031 – 2041
10	Pabna *(Bank of river Padma & Jamuna)*	1600	16	400	2021 – 2041
11	Payra Port adjacent area***	500	5	-	2021 – 2041
12	Meghna Estuary	2000	20	1000	2021 – 2041
	Total	**12,000**	**120**	**3832**	**2021 – 2041**

** Note: Typically, 1 km^2 of land is required for installing 100 MW solar PV capacity using present technology. This requirement will be lower in the future considering the higher efficient solar PV panels.*

*** Note: Existing and reclaimed land from river banks* [101, 109].

**** Significant land near the Payra port area were earmarked for coal based power plants development but recently the government has decided to discourage coal based power generation plants* [113] [114] [115]. *Some of the earmarked areas, and also other adjacent areas of Payra port (suitable for solar project development) can be used for the development of a solar power hub.*

7.1.2 Required policy interventions

Bangladesh's neighboring country India has already made considerable progress in the utility-scale solar PV power sector, a detailed case study of which has been presented in **Section 2.7**. Careful study of their experience can provide valuable guidance in formulating a favorable and encouraging policy framework for the development of a large-scale solar PV power sector in Bangladesh. Taking from the Indian experience, it can be safely stated that a dedicated policy favoring the development of the Solar Power Hubs can prove to be effective in this regard. So, the GOB should formulate one such policy addressing all the important aspects of utility-scale solar PV power plants in the near future. The policy document should include the following aspects:

- Site selection and land acquisition;
- Facilities to be provided by GOB in terms of land development, civil infrastructure, human resource, utility services during construction etc.;
- Possible business models;
- IPP selection criteria;
- Capital support from GOB (if any);
- Transmission and power evacuation related facilities;
- Details of (obligatory) Power Purchase Agreement; and
- Procurement method, etc.

7.2 Solar Home System (SHS)

Off -grid electrification through the Solar Some System Programme has seen its peak in the year 2013, and since then it is in the declining phase. This is mainly due to the widespread electrification program undertaken by the Government of Bangladesh. At present, the electrification rate is close to 97%. Except for some extremely remote areas, it is highly likely that there will be hardly any off-grid sites in the near future. The government is planning to provide better quality electricity through mini- or micro-grids or grid expansion through submarine cables wherever it will be feasible. So, it is only reasonable to assume that the scope of electrification through SHS will become very limited in the long-run.

7.3 Solar Mini-, Micro-, and Nano-grids

The targets have already been mentioned in Chapter 5. Several solar mini-, micro- and nano-grids have been installed by the private entrepreneurs (some are with the support of the government). But the local people living in those off-grid areas are not satisfied with the tariff. So, the government has decided that both off-grid and on-grid electrification will be carried out by the respective electricity distribution utilities, and it will enable people to get electricity at a price equal to the grid tariff.

The government has also declared that electricity will be purchased from the existing mini-grids, which have been installed with the prior consent of the government. BREB already has a plan that short distance islands will be covered by submarine cables and long-distance ones will be covered by solar or RE projects. Similar off grid islands and hill tract areas of the jurisdiction of other distribution utilities can have similar requirements. Therefore, the following actions need to be taken:

- Conduct review on a case-by-case basis to tackle the existing solar mini-grids once the utility electricity supply reaches the site area;

- Identification of suitable load centers and coverage areas to install solar mini-grid by respective electricity distribution utilities;
- At locations where the solar mini-grid will not be feasible anymore, the distribution utilities can opt for the micro/nano/pico-grid solution based on feasibility studies. Grid solutions can provide grid quality service to the consumers and create scope for commercial activities that SHS can't offer.
- Some existing diesel generator based off-grid electricity supply areas like Hatiya, Monpura, Saint Martins, etc. can adopt the solar-diesel hybrid solution with Fuel Save Controller. It can drastically reduce the generation cost of electricity as well as minimize the liquid fuel transportation hazard and the risk of contamination.

7.4 Solar Irrigation Pump (SIP)

Approximately 1.58 million units of irrigation systems were in operation by the end of FY2018-2019 in Bangladesh, as shown in **Table 7.3** [110]. Around 1.24 million or nearly 78.5% of the units are powered by diesel, resulting in a huge annual consumption of nearly 1 million tons of diesel [111]. The majority of the remaining irrigation units are powered by electricity from the national grid, which places additional strain on it.

Table 7.3: Summary of Irrigation Facility Used in Bangladesh.

<table>
<tr><th>Mode of Irrigation</th><th>No. of Equipment</th><th>% of Total Irrigated Area</th><th>Operated by Electricity</th><th>Operated by Diesel</th><th>Total Units</th></tr>
<tr><td>Deep Tube wells</td><td>37,634</td><td>19.26</td><td rowspan="8">341,634
(21.45% of total)</td><td rowspan="8">1,243,779
(78.55% of total)</td><td rowspan="8">1,585,413</td></tr>
<tr><td>Shallow tube wells</td><td>1,357,532</td><td>53.59</td></tr>
<tr><td>Low lift pumps</td><td>187,188</td><td>22.35</td></tr>
<tr><td>Manual & Artesian well</td><td>-</td><td>0.16</td></tr>
<tr><td>Gravity flow</td><td>-</td><td>4.28</td></tr>
<tr><td>Traditional method</td><td>-</td><td>0.14</td></tr>
<tr><td>Solar pump</td><td>2,787</td><td>0.22</td></tr>
<tr><td>Dug well</td><td>272</td><td>0.01</td></tr>
</table>

The targets for Solar Irrigation Pump (SIP) have already been mentioned in **Chapter 5**. Other sources report that IDCOL aims to install 50,000 solar powered irrigation pumps by the year 2025 [112, 87]. Even if IDCOL successfully reaches the target, huge unutilized potential of the sector will remain unutilized. SIP Draft Roadmap estimated that if all the diesel-run irrigation pumps are converted into SIP systems, the cumulative installed capacity will be nearly 4400 MW [113]. To tap this potential, the solar irrigation pump program should also be effectively scaled-up. IRENA has published a policy brief in June 2016 that can serve as a guiding document in this regard [114].

There are other challenges associated with the future of SIP programs. The subtropical monsoon climatic condition of Bangladesh is characterized by wide seasonal variation in temperature, rainfall and humidity. A hot and humid summer with intermittent rainfall from March to June is followed by a long rainy season lasting from June to October. It is only reasonable to assume that the majority of SIP systems will not be in operation during this long off-season.

SREDA reports that SIP systems in Bangladesh typically supply power for irrigation purposes for around 110 to 115 days [80]. If on the remaining days, power from these systems can be fed to the national grid, significant capacity addition will be realized. A separate grid integration guideline for SIP has been drafted by SREDA and now it is in the approval process. A SIP grid integration pilot project has been implemented in Kushtia. The Asian Development Bank is working to develop a SIP Roadmap for Bangladesh, some statement and recommendations are given below from the report [113]:

- 75% of cultivated land in Bangladesh is irrigated with pumped groundwater, more than half of it using 1.3 million small and itinerant diesel pumps. The operation of diesel pumps is vastly uncontrolled, and this accelerates the depletion of groundwater resources;
- Diesel pumps consume about 1 million tons of diesel per year, costing Bangladesh economy around USD1,200 million per year and emitting more than 3 million tons of carbon dioxide (CO_2);
- Government subsidies to diesel fuel used for irrigation is estimated to be between USD240–312 million per year;
- Possibility to export 60% of all renewable electricity produced to the national grid. Offer the possibility to store energy in the form of water in elevated tanks or in reservoirs;
- If all the diesel pumps used for irrigation in Bangladesh are replaced by modern and efficient SPV pump systems, it would result in 220,000 solar PV pump systems with a total installed generating capacity of 4.4-gigawatt peak (GWp) solar panels and pump capacity of about 2.2 GW;
- The most feasible potential for SPV pump systems is around 30% of the theoretical potential, about 425,000 diesel pumps that can be replaced by 60,000 SPV pump systems. This Roadmap has estimated that it would be possible to realize up to 75% of the feasible potential by 2030. The remaining 25% can be realized in a follow-up Roadmap by 2035;
- SPV pumps for irrigation would be most feasible are Rangpur (Nilphamari, Lalmonirhat, Dinajpur, Thakurgoan, Panchagar), Rajshahi (Naogoan, Joypurhat), Khulna (Jessore, Meherpur, Chuadanga), Dhaka (Dhaka), Mymensing (Mymensing, Netrokona) and Chittagong (Feni, Noakhali, Rangamati, Khagrachari);

- Different sizes of SPV pump systems are considered for minor irrigation in Bangladesh, with pump ratings ranging from 2 kW to 50 kW. Based on current market prices, costs for Bangladesh would amount to USD3,000 - USD4,000 per kW of pump installed, or in terms of irrigated land, USD300 - USD400 per bigha. There is further room for costs reduction in the reduction of taxes affecting these investments. The Roadmap is foreseen to be implemented in three phases:
  - **Flagship phase**, covering the period 2019–2020. This phase will be the learning period to help formulate the large-scale implementation of the SPV Roadmap;
  - **Dissemination phase**, covers the period 2021–2025. This phase aims to facilitate the nationwide proliferation of SPV pumps, with the installation of 18,000 SPV pump systems;
  - **Market uptake phase**, covering the period 2026–2030. This phase aims to install 27,000 SPV pump systems and stabilize the market for SPV pump systems.

Overall, to achieve the target of SIP implementation, policy needs to be reformed to make it competitive with electricity operated irrigation pumps. The implementing agencies like IDCOL, BREB, BADC, BMDA, DAE, BARD, RDA need to take more projects to promote Solar Irrigation Pumps with a viable and competitive solution for the farmers.

7.5 Rooftop Solar PV Systems

As discussed in Section 2.2, the solar power forerunners like India, China Germany are heavily backing the rooftop solar system via different incentive mechanisms. Compared to FiTs, the NEM typically appears to be a low resource intensive scheme, for instance in terms of administrative expenses, required subsidies, etc. Therefore, for Bangladesh, the Net Energy Metering has the potential to be the next promising program for solar PV implementation. While the capacity targets for rooftop solar PV systems under the NEM scheme is specified in Chapter 5, this part of the Roadmap identifies and recommends ways and means to achieve those targets. Following is a list of recommendations that will assist the GOB in achieving the NEM targets.

1. Mandate installation of rooftop solar PV systems for the following public or privately-owned buildings or institution premises if there is sufficient space:
   a. All government offices (BPDB, REB, Department of Roads and Highways, LGED, police stations, prisons, etc.);
   b. All EPZs and EZs (The EZs offers significant potential in this regard. For more details on EZs see **Appendix D: Prospect of NEM System Development in the Economic Zones**);
   c. Bangladesh Railway: rooftops of railway stations, platforms and adjacent land if available;

   d. Cold storages and storage silos;
   e. Jute mills, paper mills and possibly all other roofs of the industries;
   f. Cyclone shelter centres;
   g. Civil aviation centers and land available near the airports with sufficient glare protection;
   h. Public educational institutions, specially schools, colleges and universities;
   i. All the river, sea-ports, jetties;
   j. Stadiums; and
   k. Garments factories (knitting, spinning, textiles, denims, dying, etc.).
2. Analyze the potential and technical feasibility as well as associated risks to include the single-phase residential consumers to adopt NEM in the long run.
3. Revise and reconsider the financial incentive that may encourage more consumers to become prosumers under NEM scheme and thus expand the market.
4. Design and run publicity campaigns to create public awareness in favor of NEM scheme.

7.6 Solar-powered Telecom Towers

In Bangladesh, telecom towers are present in both off-grid and on-grid areas. In off-grid areas, especially char land, islands and hilly areas, telecom towers are completely dependent on solar energy. The technology of the telecom sector has updated from 2G to 3G and then to 4G, and consequently the power consumption also increased. So, the capacity of the existing solar systems of telecom towers need to be increased, as does the number of new telecom towers in the off-grid areas. In on-grid areas, telecom towers are commercial category consumers. They are eligible to get the net metering facilities, as with rooftop solar systems. The government can impose bindings on all telecom operators through BTRC to cover the whole of Bangladesh, including off-grid areas, especially chars, islands, hilly areas, forest areas etc.

7.7 Solar Street Lights

The present status of the solar street lighting project has been mentioned in **Section 3.8.** SREDA aimed to achieve a total of 5 MW of installed capacity in this sector by 2020. This means an additional 2.7 MW are yet to be installed. The target for the cumulative total can be set at 13 MW and 20 MW by the end of the year 2030 and 2041 respectively.

The street lights require a very low amount of power. So, solar street lights appear to have a rather bleak prospect due to limited potential. Possible options for solar-powered street lighting systems are along the major highways, LGED roads, village roads, parks, village markets, and office premises etc. where grid electricity distribution is not available. However, the difficulty of performing regular maintenance works, and the requirement of huge numbers of batteries etc. make this option challenging. It is mention worthy that currently, the Solar Street Light program is under implementation by TR/Kabikha and BCCT programs.

7.8 Solar Charging Stations

Motivations to put adequate emphasis on the installation of solar-powered charging stations are manifold. Apart from adding extra solar capacity, solar charging stations have the potential to greatly reduce the burden on the national grid imposed by the large number of battery-driven electric vehicles, thus diversifying the demand. Keeping an eye on the global development, it can be safely stated that solar charging stations are likely to capture more attention in the future with the commercialization of electric vehicles. To meet the target set in Chapter 5, the government can take an initiative to install solar charging stations in all 64 districts, with special emphasis on the eight divisional cities. By 2041 a total of 121 MW of solar charging station capacity can be installed, 8.125 MW in each divisional city and 1 MW in the remaining 56 districts.

BRTA is working to prepare an 'Electric Vehicle Guideline' and SREDA is working to develop an 'EV Charging Station Guideline'. Solar-powered charging stations with net metering can be prioritized to achieve net zero scenario. Besides the existing demand areas of charging stations, new EV routes can be covered with Solar EV charging stations.

7.9 Electric Vehicles

Even though no specific target has been proposed for electric vehicles in this Roadmap, it still makes sense to include it in the discussion due to the sector's huge potential. The transportation sector is responsible for huge portions of primary fuel consumption and is a major source of GHG emissions, both globally and nationally. So, electrification of this important sector, and that too with assistance from solar PV power, offers multiple benefits. Therefore, electric vehicles are becoming increasingly popular all over the world. The latest report from REN21 presents a global overview of RE utilization in the transport sector. According to this report, when compared to the previous year, the global number of electric vehicles has increased nearly 40% in 2019 [17]. China kept 47% of the global electric car stock. In contrast to the 2018-scenario of Austria being the only country to have adopted a policy that directly links RE with electrical vehicles, nearly 18 jurisdictions have adopted some sort of EV-related policy [16, 17].

It has been already mentioned that a large number of light electric vehicles are currently in operation in Bangladesh, hinting at both huge potential and challenges to come in the long-run. One of the steps to follow would be installing solar charging stations as discussed in the previous section. The latest technological advancements in the sector should be monitored on a regular basis, and viable options should be suitably adopted. For example, recently fast-charging electric vehicles are gaining considerable attention. The quality of exported electric vehicles and their components must be maintained.

7.10 Large-scale Storage

Large-scale electricity storages render various important services to the power system (as shown in **Figure 7.5**). However, their role becomes crucial when it comes to the integration of high shares of renewable power. Considering the VRE power integration, grid storages provide services like improving power reliability, the wholesale energy time-shift, supply capacity, fast frequency response, primary & secondary reserves, voltage regulation, T&D upgrade deferral, capacity investment deferral, retail energy time-shift, etc. [34]. It is worthwhile to discuss some of these services of utility-scale storage with respect to VRE integration before presenting further details of the domestic implementation.

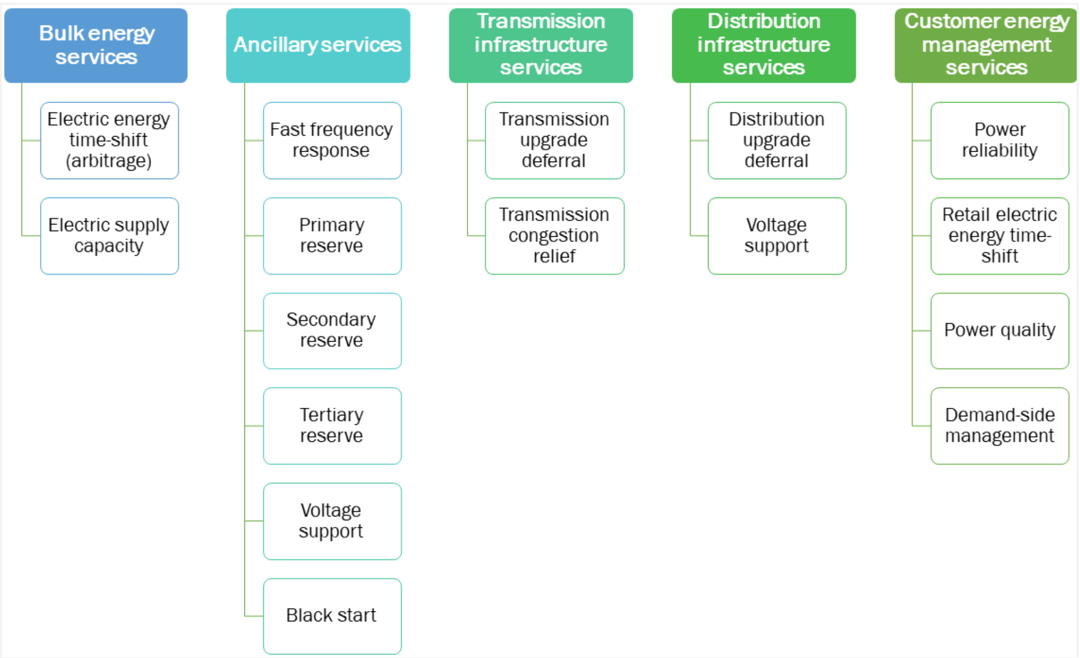


Figure 7.5: Services Provided by Energy Storages (Source: modified from **[34]**).

VRE power smoothing

Renewable sources like solar PV and wind supply energy in a fluctuating and non-dispatchable manner. In case of solar PV, the output power fluctuation is caused mainly by cloud movement, while in case of wind the variability is brought upon by varying wind speed. The variability and uncertainty of power output reduce power reliability and quality by destabilizing the voltage and frequency.

Electricity storages can smoothen the VRE output and control the ramp rate to remove speedy voltage and power fluctuation in the grid. Storages absorb the excess power that is beyond the maximum ramp constraint, which would have been otherwise curtailed. In case of power production below the minimum ramp level, storages discharge energy to avoid loss of load. Such smoothening allows VRE generators to improve their compliance with generation schedule and thus avoid penalties for any deviation [34, 35].

However, typically, grid-scale storages are not installed *only* to smoothen VRE output. This is because at grid-scale level, owing to the geographical dispersion of VREs, the aggregated power output and demand on transmission network results in smooth net load profile. Same is true for distribution level as well. So, variation smoothening should be regarded as a value addition when stacked with other storage services [34].

Decrease RE power curtailment

The variable nature of VRE also results in excess generation curtailment during hours of low demand and high production. Such curtailment restricts inclusion of clean electricity into the energy mix. Due to various grid constraints (transmission capacity, ramping constraints, need for system services from conventional generators, etc.) the excess energy cannot be transported to other regions. Grid-scale storages can effectively reduce such RE power curtailment. During periods of high generation excess electricity can be stored and supplied later at times of peak demand.

Peaking plant capital saving

Balancing the generation and the demand is essential for operating any power system is a secure and reliable way. System operators perform power plant scheduling to achieve this in the short-run. In addition to that the system operators also have to ensure sufficient capacity in the medium- and long-run to supply forecasted peak demand and the required capacity margin. Typically, this is done by utilising hydrothermal generation units since these have clearly defined firm capacity. With the increasing of VRE share, this can pose to be a significant challenge as VRE output can be predicted only partially. Inaccurate capacity evaluation could lead to increase in unnecessary peaking plant investment, and thus overcapacity.

The benefit of saving peaking plant capital investment by large-scale energy storages has been investigated widely. In their report on storage valuation framework, IRENA referred to another report that estimated the benefits of establishing a 1766 MW storage in Massachusetts. The results showed that of benefits worth USD2.3 billion, nearly USD1093 million would be associated with reducing peak capacity. The same IRENA report cites another instance of the 409 MW/900 MWh battery storage to be installed by 2021 in Florida. This FPL Manatee Energy Storage Center is expected to save nearly USD100 million through avoided fuel costs and save 1 million tons of CO_2 emissions [34].

A sample calculation is provided below to show the cost comparison between peak shifting of solar PV energy through battery storage of a 100 MWh capacity and equivalent diesel generator.

As per NREL report [115], Present cost of utility-scale battery storage (Considering $LiFePO_4$) is \$0.375/Wh. It should be mentioned here that this is the international battery price without considering the local import taxes and duty. However, the import taxes and duty are waived for power generation equipment by the GOB [116].

Therefore, the price of a 100 MWh (= 100,000 kWh) battery is

= 100,000 kWh × \$375/kWh

= \$37.5 million

Assuming, depth of discharge (DOD) of the battery = 90%

life time of the battery = 10 years

end of life capacity = 80%

for the 100 MWh battery, the average capacity would be

= (100,000 × 0.9 × 0.9) kWh

= 81,000 kWh per day

Over its lifetime, amount of total electricity shift

= 81,000 kWh/day × 10 y × 365 days/y

= 295,650,000 kWh

So, the cost of shifting electricity is = \$37,500,000 ÷ 295,650,000 kWh

= \$0. 1268/kWh

Cost of solar power production = \$0.09/kWh [19]

Therefore, the cost of 100% shifting of solar electricity

= \$0. 2168/kWh (or BDT 18.38/kWh) [116]

According to the *Annual Report 2019-20* of Bangladesh Power Development Board (BPDB), Bangladesh has 5591 MW of furnace oil based and 1330 MW of diesel based power generation plants [117]. These plants are generally run to meet the peak load. In FY2019-2020 these types of plants operated at a plant factor of 19.32% and 1.2% respectively. The cost of production of these plants are BDT 14.89/kWh and BDT 176.66/kWh respectively. The weighted average cost of production from the liquid fuel-based power plants in Bangladesh are BDT 17.24. So, the cost of liquid fuel-based power and the solar power shifted to peak time are comparable.

However, as discussed earlier, the cost of both solar power and battery storages are predicted to drop significantly in the coming years. Thus, it can be safely stated that the solar energy shifting using battery storage for large-scale projects will become increasingly profitable in future when compared to liquid fuel options, such as HFO or HSD.

Transmission and distribution investment deferral

Transmission and distribution network congestion management is one of the most important tasks performed by the system operator. High share of VRE into the system increases risk of T&D congestion that could disturb the system security and reliability. In such situations, the operators tend to adopt curtailment method to relief the congestion.

The most common and clear-cut method is to build new network lines or to upgrade the existing ones. But building new transmission lines incurs considerable cost, demands time, and also negatively impacts the environment and society. Other options like the dynamic line rating (transmission level) and advanced inverters (distribution level) are also in use. But owing to their reducing price, quick construction, and low impact on the environment and society, energy storages are proving themselves to be another potentially suitable solution [34].

To address some of the challenges brought upon by VREs on T&D networks, storages can be established at both transmission and distribution levels. The principal concept is to build the storage in the proximity of the location where congestion is observed and allow them to absorb excess electricity and dispatch later when congestion is relieved. In addition to such services, storages also provide reactive power control and voltage regulation, enhance hosting capacity of distribution feeders, and thus avoid or defer investment in distribution equipment [34].

For both the medium and high deployment cases proposed in this Roadmap, the establishment of large-scale energy storages have been recommended when the share of grid-tied solar PV would surpass the threshold of 10% of the total installed capacity. This would be an essential measure owing to the variable and uncertain nature of solar PV as a VRE power source as these features pose serious technical challenges to balance the supply and demand, and consequently increasing the need for system flexibility. The following regulatory measures are recommended for the effective utilization of large-scale storages in the future:

- Any restrictions preventing storages to participate in the energy capacity and ancillary services markets should be eliminated (e.g., reserve duration requirement, minimum capacity limit to the ancillary service market);
- Removal of any technology-based discrimination in the ancillary service market;
- Attempts should be taken to make the utilities and system operators to use a least-cost and standardized method that would compare storages providing a full range of stacked services against incumbent technologies, etc.

Large-scale storage implementation must be preceded by separate technical and financial study. IRENA has developed and launched a storage valuation framework and tool to guide policymakers in this regard [34]. Such resources can also be consulted to gain preliminary insights.

7.11 AMI & SCADA in Distribution Utility

To ensure the successful implementation of a large quantity of distributed generation sources (e.g., net metering, SIP integration, small IPP, etc.), the Automatic Metering Infrastructure (AMI) and Supervisory Control and Data Acquisition (SCADA) are essential at the distribution utility level. It can reduce the billing complexity and monitoring can be done in a smarter way. Integration of net metering facility in prepaid meters can also promote rooftop solar in larger capacity residential consumers. It can be also helpful for demand-supply assumption, quality electricity supply, assumption of storage demands, and communication with the National Load Dispatching Center (NLDC)/ISO.

7.12 Transmission Network

A significant portion of the targets set forth in this Roadmap directly calls for consulting the Power Grid Company of Bangladesh Limited's (PGCB) transmission grid extension and upgradation plans. PGCB's long-term grid extension plan (up to 2041) should take into account the proposed large-scale solar parks and power hubs to be developed at the suggested locations. Very brief overviews of some of PGCB's relevant grid extension and system upgradation projects are as follows:

- **Implementation of smart grid:** The current SCADA system is nearly 10 years old and some of the functions are currently not active due to various reasons. The PGCB has already signed an MOU with a foreign company to develop and implement the 'Grand design/architecture or future control and monitoring structure of Bangladesh power system and future smart grid compatible SCADA system' [118]. If implemented successfully, the system can be expected to be able to handle integration of a high share of variable solar PV electricity into the national grid. Figure 7.6 shows an indicative outline of the future SCADA system [118].

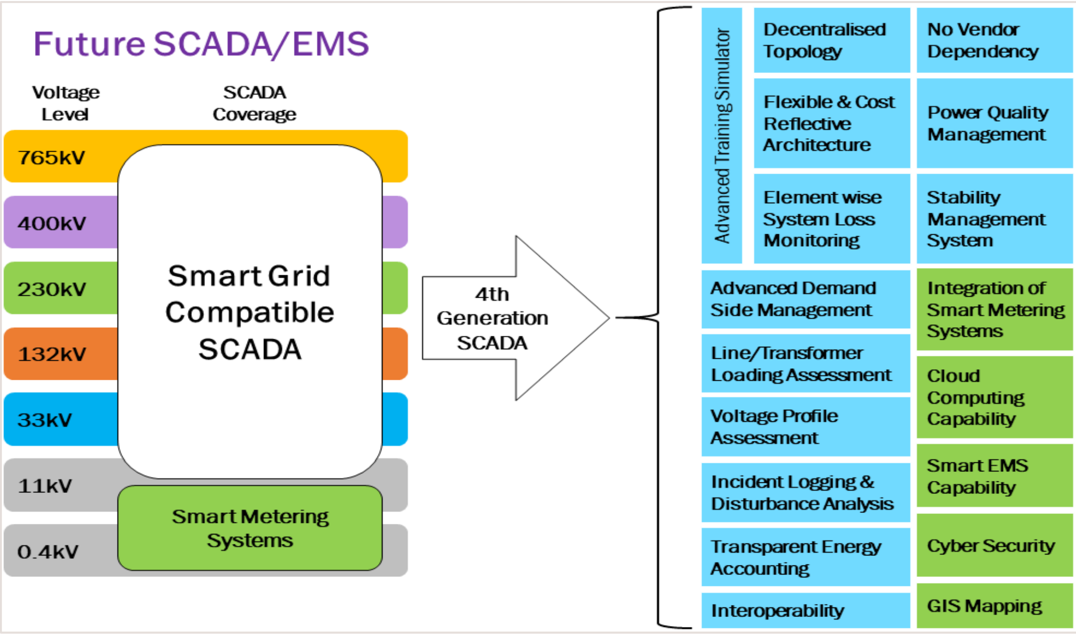


Figure 7.6: Indicative Outline of Future SCADA System (Source: PGCB [118]).

- **Infrastructure development:** PGCB is on the way to formulate its long-term plan of transmission infrastructure development up to the year 2041. A tentative future scenario is shown in **Table 7.4**. However, PGCB's planning and strategy document also rightly notes that it is rather unwise to formulate details of all the transmission projects beyond a decade except for the backbone of the grid, since the future is ever-changing. Therefore, PGCB has published its grid extension plan up to the year 2025, which is depicted in **Figure 7.7**. It is important that further extension plans of PGCB's infrastructure development should be aligned with this Roadmap. On the other hand, the transmission network should be planned in a way that can cover the proposed solar parks and power hubs.

Table 7.4: PGCB's Infrastructure Development Scenario up to 2041 [118].

Indicators	2021	2025	2030	2041
Overall Grid MVA	87,577	1,40,294	1,81,943	2,59,714
Dispatch Capacity (MW)	39,211	63,040	83,738	138,043
Line Length (Ckt. km)	16,242	23,659	28,507	37,057
Number of Infrastructure Projects	25	12	Under Study	
Number of Reliability Projects	01	-		
Total Number of Transmission Projects	26	12		

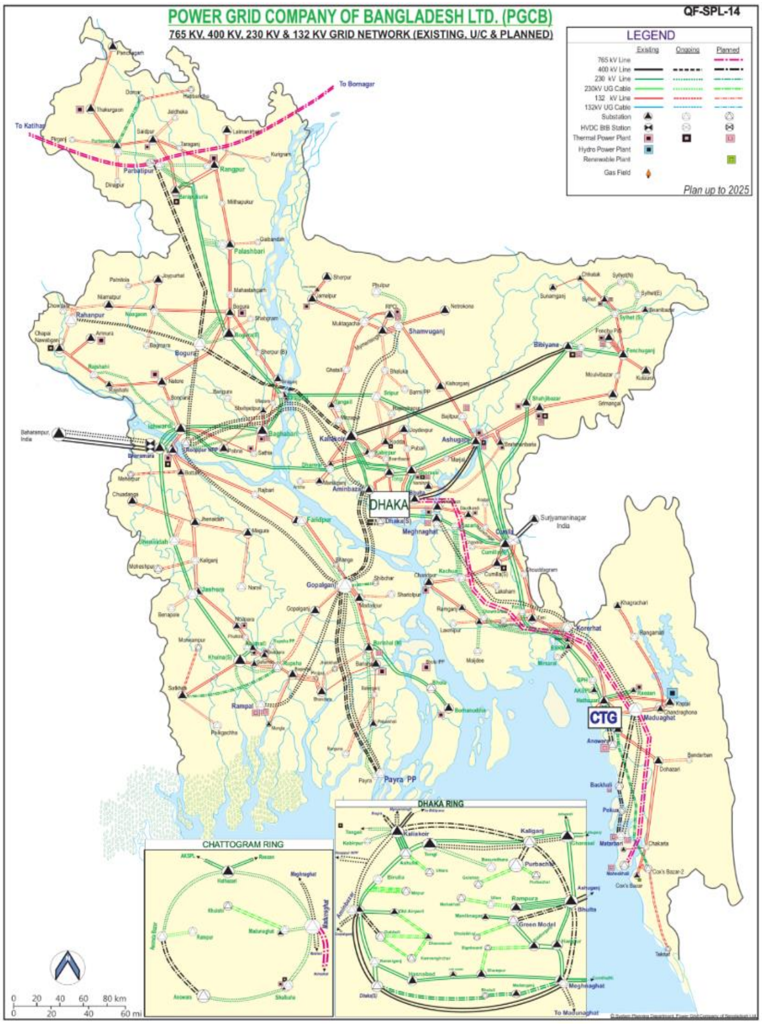


Figure 7.7: PGCB's Grid Extension Plan up to 2025 [118].

7.13 Solar Heating, Cooling and Other Applications

Solar energy applications like the solar heating, cooling, air conditioning and other minor applications are unlikely to contribute to significant degree in near future energy scenario of Bangladesh, unless they implemented on a massive-scale or adopted by the industrial sector. The main reason behind such dim prospect of solar thermal project is their comparatively high upfront cost. For instance, the global weighted average LCOE and total installed cost for CSP plants commissioned in 2019 have been USD0.182/kWh and USD5,774/kW [19]. These values are nearly 3 and 6 times higher than those of large-scale solar PV projects.

In the countries with cold climatic conditions, the heat energy requirement makes the residential sector a significant end user of energy. Since Bangladesh is located within the warm climate region, the residential heat energy demand is insignificant. So, understandably, solar heating technologies will hardly have any significance for Bangladesh in near future.

Still a few of other solar energy technologies may secure some feasible practical applications on a limited scale and thus offer some capacity additions. It is highly probable that the implementation of such applications of solar energy will be driven by factors like social, environmental, public health benefits, etc. rather than by purely economic drive. The following applications briefly discussed below may be considered for remote and off-grid areas with special requirements:

- ***Solar drinking water*** **or** ***solar desalination systems*** can be promoted in the coastal regions or natural disaster-prone areas. Such systems can be very useful during post-disaster rehabilitation phases as well.

  Until now, solar-powered drinking water systems of 1.6 MW capacity has been implemented in Bangladesh. After the Cidr cyclone hit the coastal area of Bangladesh in 2010, there was an acute shortage of safe drinking water. During that time GIZ installed a total of 143 solar powered drinking water systems in those affected areas. Among those systems 3 employ reverse osmosis technique for purifying water. The task was accomplished in cooperation with the Comprehensive Disaster Management Programme (CDMP) of the Bangladesh Ministry of Disaster Management and Relief [88]. By January 2019, a total of 400 solar drinking water system have been installed by GIZ in the coastal region and Department of Public Health Engineering (DPHE) has installed 32 systems in various remote areas [89].

  As mentioned above, future deployment of solar drinking water systems on a large-scale will require such active liaison between the public authorities like the Ministry of Disaster Management and Relief, the DPHE, etc. and various development partners who are currently working to ensure safe drinking water supply across the country. Specially the development partners can play decisive roles in this regard.

- ***Solar crop dryers*** have the potential to secure a more than niche market in Bangladesh, if the apparently simple and cheap technology can be adequately promoted among the farmers and small-scale rural entrepreneurs. The Ministry of Agriculture can become an important stakeholder in this regard. The government can provide some research fund to local universities or research institute to develop weather proof and modular solar dryers, which may find its way even into rural households.

- ***Solar cooking stoves*** is another solar energy technology that may attract a more than niche market in Bangladesh in the long-run. SREDA already has a robust clean cooking stove program. Steps may be taken to investigate the potential to merge solar energy into the broader framework of the current program. Any success in this regard may lead to mention-worthy solar capacity addition.
- ***Solar micro-chilling and solar ice manufacturing plants*** may be promoted among the rural, small-scale entrepreneurs, off-grid hospitals, pharmacies,

etc. The potential consumers-base should be made aware of the co-benefits of such units, such as, the surplus power that may be available from the panels.

As a general step, financial institutions like IDCOL and other banks should be engaged in developing attractive and feasible business models for parties interested in investing in projects or businesses based on the above-mentioned solar energy technologies.

8 Limitations, Challenges, and Way Forward

This chapter is aimed at discussing the limitations of the study as well as the barriers that lie ahead in the path of implementing the targets specified in the Roadmap. Part of it will focus on the possible ways to move forward.

8.1 Limitations of the study

One of the major limitations of this study is that it does not rigorously follow any prior policies or targets. This is partly due to the reasons explained at the end of **Chapter 4**. It is worthwhile to reiterate the discussion here as well. The review of the energy policy landscape of Bangladesh revealed that none of the long-term planning or policy documents are in clear and concise agreement. As a result, any policy formulation effort or process is bound to suffer from the absence of a singular and concrete vision and target set for the sector. The current document is no exception.

The BAU case described in **Section 5.2** is based on particulars as specified in Chapter 13 of the *PSMP 2016* only to a certain extent. The Section 13.4 on Renewable Energy Potential in Bangladesh clearly states that the 3,700 MW of overall RE potential of the country was based on the studies and data available until that point of time (2016). This partly explains the discrepancy between listed potential in PSMP 2016 and the RE deployment plans of the GOB until 2020. It also states that there is scope for updates.

According to the *PSMP 2016*, the 1,400 MW potential capacity to come from solar parks was estimated considering the ‘non-agricultural land use policy’. In the present study, a significant portion of the capacity (high deployment case), if materialized, is proposed to be developed on the reclaimed stretches of land along the main rivers as indicated in the *Bangladesh Delta Plan* [101]. Even though this possible solution has the potential to resolve the land issue to a considerable degree. At the same time, the proposal of deploying huge chunks of power capacity on reclaimed or accreted land indicates an important aspect of uncertainty of the current study, i.e., the issue of land availability.

8.2 Impending Barriers of Solar PV Target Implementation

As apprehensible from the discussion of the current implementation status of Solar PV technology presented in **Chapter 3**, there are still significant barriers that are hindering the development of solar PV projects in Bangladesh on a massive scale. Such obstacles can be linked with (a) the lack and difficulty in obtaining suitable land, (b) weather and climatic conditions, (c) under-developed local equipment market, (d) the lack of well-established technical standards and codes, (e) lack of favorable policy environment and incentives, (f) lack of sufficient project implementation experience and expertise, (g) the lack of robust financial and business models, (h) absence of an adequately aware consumer base, (i) under-developed human resource, etc. To ease the purpose of analysis, the challenges are tabulated in a few major categories as presented in **Table 8.1**.

Table 8.1: Summary of Impending Barriers of Solar PV Target Implementation in Bangladesh.

Category	Components in detail
a) Land related barriers	• **Scarcity of suitable lands**: Large-scale solar PV projects, such as solar parks or mega-grids require vast stretches of land. Being agriculture dominated economy; GOB understandably preserves agricultural lands from being used for solar PV project development. As a result, there are very little non-agricultural lands that lie mostly in the north eastern part of the country, in the river banks and islands, sand bars and in coastal regions. Again, these areas are far away from the national grid facilities or limited by the grid capacity. • **Ownership of land**: The population density is very high in Bangladesh and very often it is found that the ownership of suitable lands for solar PV projects is distributed among several hundred individuals. The legal acquisition of land from several hundred owners requires a considerable amount of time. Moreover, it has also been found very often that the transfer of lands through deeds was not properly conducted in the past, which also delays the project implementation period and thus incurs cost. Until the ownerships of the lands are not clear the project financial closure cannot be achieved. • **Land development**: Having a flat terrain, Bangladesh is prone to flooding and majority of the suitable land for solar PV project development are on the banks of rivers. Most of the land available for solar PV projects, therefore, needs to be backfilled, which adds an additional cost to the project. • **Erosion protection**: Some of the mighty rivers flow through Bangladesh. Suitable lands on the banks of these rivers need an erosion protection scheme, which increases the project cost and thus the tariff.
b) Challenges weather & climatic conditions	• **Weather conditions**: Very often, Bangladesh experiences cyclones in the southern region due to its geographical location. This creates the need for special precaution in the form of mounting structure design and also the assembly, thus increasing the project cost. • **Low irradiance**: Solar irradiation is moderate in Bangladesh, about 4.5 kWh (GHI) per m^2 per day. This average value is also not available all through the year. During the long

Category	Components in detail
	monsoon, the generation is highly variable due to the frequent overcast sky. • **Dust**: Dust accumulation on the solar panels is much higher in Bangladesh compared to other countries, which results in higher O&M cost for the plants. Therefore, a higher maintenance cost needs to be allocated in the project O&M budget, which also increases the cost of electricity from solar PV projects. • **Longer implementation period**: During the monsoon, most of the country's land is inundated and it is difficult to work in the rainy season, which also delays project implementation time and thus increases cost.
c) Challenges arising from gaps in supply chain	• **Insufficient local human resources:** There is a lack of human resources with sufficient technical knowledge of solar PV project development in Bangladesh. So far, the country has six grid-connected solar PV projects (3.28 MWp at Jamalpur, 28 MWp at Cox's bazar, 7.4 MWp at Kaptai and 10.3 MWp at Panchagarh, 74 MWp at Mymensingh and 45 MWp at Manikganj). The system design and EPC contractors are needed to be hired from outside/ foreign countries. The construction environment for them is rather new as we are yet to have a sufficient number of solar PV projects to gain the experience. • **Economies of scale:** So far, the implemented solar PV projects in Bangladesh are rather moderate in size and we are yet to know the real challenges of implementing larger projects. • **Limited information on available services:** Lack of information on relevant services, such as supply chain companies, finance, developers, and relevant standards affects and delays important design related decisions. • **Long downtime:** Unless there is a stable local market, component failure or damage can lead to long periods of system downtime due to the lack of local expertise and/or access to replacement parts.
d) Existing power infrastructure & technical standards related challenges	• **Weak grid**: Renewable power is intermittent in nature. Our national grid is still not robust and reliable enough to absorb intermittent power beyond a certain capacity. This necessitates a rigours and effective grid integration study. Again, at present the country does not have the local capacity to conduct thorough study on the impact of intermittent power injection into the national grid. So, if the investors see some risks, they have to conduct such studies by their own.

Category	Components in detail
	• **The right of way for transmission network**: Generally, the selected solar PV power plants are far away from the grid substation. Getting right of way for the evacuation line construction and transmission tower installation is also a challenging work, as the concerned land owners generally do not want to provide permission to erect transmission towers on their land. Obtaining the right of way for transmission lines is time consuming and sometimes exceeds the estimated cost considering the population density of the country. • **Insufficient transmission infrastructure**: The capacity of the power transmission network also hinders the development of solar PV projects on a broad scale. According to the government policy, most of the suitable lands for solar project developments are in the north-western and southern part of Bangladesh, but the transmission line capacity limits the progress of solar project development in those areas. Also, for the other regions, the limited transmission line capacity is one of the main obstacles for larger solar PV project development. • **Inadequate technical standards:** There is a lack of nationally recognized and well-defined technical standards, codes for solar PV projects. Unless these codes and standards are developed with proper emphasize on the local context, the developers have to either conduct studies by themselves or depend on some assumptions. These compel them to take risks and the risks results in risk premiums.
e) Policy and regulations	• **Inadequate and unharmonious policy framework:** Bangladesh is yet to formulate policies and regulations to address various aspects of the solar energy sector development. For instance, large-scale projects, private investments, etc. demand a dedicated policy and regulatory framework. Moreover, a review of the existing policies reveals a sort of incongruity among them (see **Chapter 4** for details). A clear-cut, firm and stimulating policy and regulatory framework is of foremost importance for any sector to develop and thrive. • **No regulated tariff/incentive:** There is still an absence of regulated tariff structure for solar projects in Bangladesh. • **Considerable administrative overheads:** At present, an independent solar PV project developer needs to organize more than 30 permits and acquiring such permits is quite a challenging task in Bangladesh. Therefore, such challenges and obstacles need to be converted into transparent and quantifiable cost components.

Category	Components in detail
	• **Too long a lock in period:** The lock in period for the investor (The lead partner) and operating partner is for at least up to the 6th year of operation of the plant. This hinders many developers from being interested to invest in Bangladesh. Many of the developers or investors are interested to develop the project and they want to sell it to potential buyers after the CoD. • **Stringent Qualification Criteria for the developer: The o**perations and maintenance of solar PV projects is easy and many solar PV projects worldwide are observed to be unmanned. The requirement of operating experience is hindering local investors from developing large scale grid connected solar PV projects. It takes time to select and appoint an operating partner and negotiate terms with them (the operating partner needs to hold at least 20% of equity share holding), as so far none of the local business entities has experience of operating solar PV projects. • **Solar PV waste disposable policy:** Currently, there is no policy addressing the waste disposal arrangements after the project life of solar PV power plants in Bangladesh. Given the state of rapid progression of the sector, it is imperative to formulate an appropriate regulation addressing this issue.
f) Financing and business models	• **Absence of capacity payment**: Unlike the conventional IPP projects, capacity payment is absent in the solar IPP project. So, the financial model needs to be adjusted to cover the risks. Solar plants usually operate at 17–19% plant utilization factor. So, without capacity payments, all O&M, returns and debt services needs to be covered from the sale of electricity from solar PV Power. • **Risk investment**: The credit rating of Bangladesh is BB- (Standard & Poor's). It is not very encouraging for foreign investors. So, if the return is not high enough the foreign investors are not encouraged to invest. The lack of project realization related information, knowledge and also guidance relating to policy and regulatory compliance obligations for solar PV projects forces the developers to take risks.

8.3 Way Forward

For any long-term plan or policy to be consequential the government of the country, among all the stakeholders, has to play the most crucial and defining role. The materialization of the solar PV capacity targets set forth in this Roadmap is no different. But certainly, there are other important influencing factors as well that have been identified and discussed wherever appropriate. One of the most important is the uncertainty stemming from the issue of land availability. Since the high solar PV deployment case has been recommended for adoption in the Roadmap, the issue of land deserves some additional discussion.

Since Bangladesh is an agriculture dominated economy, the competition over land will remain a reality in the coming decades. For solar PV projects developed by the IPPs or the public utilities, the land factor will be still manageable as there are pockets of non-agricultural land scattered within the country that can be acquired, developed, and utilised by these entities themselves. The Roadmap identified and proposed ways out for another very important capacity component that are the solar PV rooftop systems under NEM. There will be hardly any conflict with agricultural land usage. Policy incentives and legal mandates for industries will be more influential in this case. But the scenario is drastically different when it comes to the large-scale solar power hubs.

The prospect of future land accretion along the banks of the main rivers of the country and land reclamation at the Meghna Estuary as per the *Bangladesh Delta Plan* will be one of the most important factors. It has been mentioned that around 5% of the potential reclaimed land would be sufficient to implement the proposed large-scale solar power hubs. This estimation is based on a few crucial presumptions. First and foremost is the actual realization of the Delta Plan. Moreover, the mere reclamation or accretion of land by itself will not prove to be sufficient. The subsequent land development and disaster (erosion, flood, etc.) protection measures will play equally important roles.

As mentioned earlier, the competition over land will remain in future as well. So, a lot will depend on the decision by the government. Also, all the prospective land reclamation and accretion will occur essentially in the off-grid regions. Therefore, the government will have to organize and support the electrical infrastructure development as well. The solar power hubs will have to declared as special zones, similar to the EPZs.

9 Conclusion

The National Solar Energy Roadmap has been prepared as a part of the Development of Sustainable Renewable Energy Power Generation (SREPGen) project of SREDA with support from the GEF and UNDP. The document should be considered as a preliminary guideline for the relevant stakeholders of the solar energy sector of Bangladesh. It should be kept in mind that the actions recommended here should be further analyzed in detail for actual implementation. The Roadmap should be revised and updated every five years. The scenarios developed in this report are based on existing and developing technologies which are known today and do not consider the possibility of entirely new or unknown technologies emerging.

It is crucial for Bangladesh to prepare for a future when the reserves of fossil fuels will be on the verge of depletion all over the world and climate change will pose an extreme threat to lives and livelihoods. This future is also likely to see the cost of renewable energy decrease and technological efficiency increase. As one of the most susceptible countries to the ravages of climate change, Bangladesh should invest in a future which is environmentally and economically sustainable. Despite limited land availability for the deployment of solar energy, the government through appropriate policies can still use the available land effectively to meet the energy needs. Land use efficiency can be increased by the use of agro-photovoltaics or by creating multilayer uses of solar installations, like raising the height of the solar panels, and using the land below for low radiation agriculture, or grazing pasture for livestock, or planting the land with flowering plants for apiaries or developing pisciculture.

The global scenario is rapidly changing, and the share of renewables in the energy mix across the world is increasing. Renewables are securing more annual investment when compared to fossil fuel capacity. The reasons are obvious—the pressing need for energy security and the risk posed by climate change. Already, renewable energy sources specially the solar photovoltaic, have become financially competitive with fossil fuels in many jurisdictions, and in the future, will become cheaper than any fossil fuel-based energy. Cheaper power from renewables will be the chief driving force in the energy industry. Therefore, like many other countries, Bangladesh should also adopt ambitious renewable energy targets. Since the country has a rationed amount of land, the decisions about land allocation should be prudent. Accordingly, special emphasis should be put on the solar rooftops and the solar irrigation sector.

In this study, three scenarios are presented for the future of solar energy in Bangladesh, i.e., the BAU case, the medium, and the high deployment scenario. In the BAU case, future solar capacity is estimated to be 6 GW; for the mid and high deployment cases, the estimations are 20 GW and 30GW respectively till 2041.

It is recommended that Bangladesh should aim for the high deployment scenario. In this case, the installed capacity of the solar PV systems will be half (50%) of the projected generation capacity of the country under the condition of high economic growth and with EE&C measures. The capacity utilization factor of the solar PV power plants in Bangladesh for a fixed tilt topology is less than 20% and by the year 2041 the energy generation demand of the country will be 240,000 GWh (PSMP 2016: approximating with EE&C measures). In the high deployment scenario, the energy generation from the solar PV systems will be around 47,000 GWh per year, which means that the solar PV systems will provide nearly 20% of the total electric energy demand of the country by the year 2041 in high deployment scenario.

In order to execute the high deployment scenario, the government should undertake several important and timely steps. According to the *Bangladesh Delta Plan 2100*, there will be more than 3,800 square kilometers of new reclaimed land in the near future. If around 5% of this reclaimed new land is used for solar power projects, and the government undertakes the necessary land and transmission infrastructure development, these projects can be built and operated by either the government utilities or the private sector through competitive bidding of IPP projects or by both. Such measures can be expected to bring down the tariff. 40% of the targeted 30 GW capacity can be implemented on the reclaimed lands along the major river banks and Meghna estuary. However, in that case, care must be taken to formulate long-term grid network expansion plan in consultation with the Roadmap. There is a great scope for solar rooftop projects under the net metering policy in Bangladesh. Bangladesh Government is planning to develop 100 Economic Zones (EZ) all over the country and make them operational by the year 2035, The industry sheds and other rooftops in all the EZs and other suitable buildings (public or private, industrial, commercial or residential) should be brought under rooftop solar systems. By 2041, approximately 12 GW of capacity can be added on the cumulative rooftop areas. Thus, another 40% of the targeted 30 GW capacity can be implemented on the rooftops. There is also a vast prospect for capacity addition in the solar irrigation sector. Currently, there are approximately 1.34 million diesel pumps operating in the agriculture sector. By converting a significant portion of these pumps into solar PV-powered irrigation pumps, an additional capacity of approximately 1.2 GW can be easily added to the mix. All these solar irrigation units can be converted to grid-tied units in the future, so that they can contribute to the national grid when there is low demand for irrigation power.

Bangladesh is a riverine country and it has a lot of irrigation canals, low-lying lands, haors, baors (wetlands). Floating Solar PV systems can be developed in the water bodies of these areas. Till now there is no nationwide consolidated study on the feasibility of developing floating solar PV systems. After rigorous study, the nationwide potential of floating solar PV systems should be identified and can be incorporated in the future versions of this roadmap.

A more ambitious solar energy target can be set by using more reclaimed land (ref. Bangladesh Delta Plan) and identifying more feasible areas for floating solar PV systems.

To make the energy transition possible, further policies should be devised to promote the renewables and adequate financing sources must be tapped. The public should be educated about the transition to a renewable-heavy energy future and there should be adequate opportunities for the private households and small businesses to play their roles as prosumers.

Since renewables, and especially solar energy, are intermittent sources, with increasing share of renewables in the system, the grid may become vulnerable. The higher penetration of variable renewables will pose threats to the stability of the grid. At comparatively earlier stages of variable RE penetration, measures such as modifying grid operation practices, enhancing system flexibility, and matching demand with supply by shifting the demand curve may prove to be sufficient. But at more advanced implementation stages, large-scale storage along with reliable forecasting facilities are more suitable and tend to be economically viable. Solar PV power plants with integrated storage systems can diminish the variability quite effectively, and thus they can be utilized to supply the base load.

Since renewable sources should supply the base load starting from the end of the first decade and throughout the second decade, it will be imperative to install large-scale storage facilities. The Roadmap recommends that once the variable renewable power generation capacity surpass 10% of the national base load (grid), each new VRE plant must integrate storage facilities to neutralize (or, reduce the ramp rate at an acceptable limit) the variability on the generation side. It can be anticipated to occur sometime in second half of the first decade. Beyond this stage, VREs with integrated storage facilities can be expected to supply the country's base load. The transportations sector should also be modernized, and EVs should be made available to absorb surplus generation, acting as a storage for the grid according to the daily load profile.

The qualification criteria for the development of large-scale solar PV projects in Bangladesh should be made more flexible and hassle-free. Solar PV power plants are relatively easy to operate. At present, requirements like having operating experience and the operating partner to own a 20% share in the project until the 6th year of CoD, etc. are preventing local developers from developing projects. The operating experience can be relaxed by imposing O&M contracts with an experienced O&M contractor. At present, the lock-in period for the investor (the lead partner) and operating partner is at least until the 6th year of operation of the plant. This hinders many developers from being interested to invest in Bangladesh. Typically, the developers or investors are interested to develop a project and immediately after the CoD, to sell it to potential buyers. So, the lock-in period should be relaxed and the exit policy for the investors or project developers should be made easier.

The approval process of grid connected solar PV projects in Bangladesh is too lengthy. The approval processing time should be reduced. The cost of solar PV technology is gradually reducing. The tariff should be linked with the CoD achievement time. The delay in CoD achievement should follow with a reduced tariff.

Finally, the policy for the energy sector must become comprehensive and well-coordinated, so that the various objectives of energy generation, such as universal electricity access, clean energy transition, and the smart grid transformation plan, all work in tandem. The capacity addition in solar energy should be coordinated with the capacity addition or retirement of fossil fuel plants in order to avoid duplication or wastage of resources. Provisions must be made for the monitoring of projects over the entire lifetime, so that stranded assets are not created due to technological obsolescence of long-lasting projects in a highly technologically evolving industry.

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Appendices

Appendix A: Scope of the Roadmap

The specific scopes of the *National Solar Energy Roadmap* include the following aspects:

- To set the new objective and targets of SREDA in terms of RE power generation to be achieved by 2041. Existing policies shall be reviewed and, if found necessary, revisions will be recommended.
- To know the future RE scenario of the country, the global perspective, potential financing sources and markets, policy requirements, technological support and impending barriers in the RE sector.
- Solar Mini-/Micro-/Nano-grid: Provide direction for installation of the Mini/Micro/Nano-grids as per set target by 2041.
- Solar-powered Irrigation: To focus on the challenges of achieving the existing target, ways to bring the solar PV powered irrigation pumps under grid integration, the policy requirements, etc.
- Rooftop Solar Program - Net Metering: Discuss the current scenario, future prospects, ways to attain the set target by 2041, ways of creating public awareness, capacity building, aligning concessional financing, etc.
- Rooftop Solar Program - Others (including new connections): To guide the ways to achieve the set target by 2041.
- Solar Street Light: To shed some light on how to install systems with 2.7 MW installed capacity within 2020 and more as per the set target by 2041. This target may be achieved through the TR-KABIKHA/KABITA project.
- Others (Vehicle, Aquaculture, Boat, Pico systems): Set the installation target up to 2041. To provide guidance regarding how to bring an electrical vehicle system under commercial operation, how to popularize solar boats and make them economically viable etc.
- In accordance to the RE Roadmap, the current solar energy roadmap will devise targets for 2030 and 2041. It should also comment on how that target will be met with necessary details.

All the future scenarios will be based on an acceptable methodology.

Appendix B: Large-scale grid connected solar PV project status

The following table is the list showing detailed status of various large-scale grid connected solar PV projects:

#	Sponsor	Location	Capacity (MW)	Tariff (USD/kWh)	Date of LOI issuance	Remarks
1	Concord Progatti Consortium Ltd.	Sharishabari, Jamalpur	3	0.189	15.02.15	COD: August, 2017
2	Joules Power Ltd.	Cox's Bazaar	20	0.139	19.05.16	COD: Sept., 2018
3	JV of Paragon Poultry Ltd. & Parasol Energy Ltd. (Bangladesh) and Symbior Solar Siam Ltd. (Hongkong)	Panchagarh	8	0.13	22.04.17	COD: May, 2019
4	Bangladesh Power Development Board	Rangamati	7.4	--		CoD: May, 19
5	North-West Power Generation Company Ltd.	Sirajganj	7.8	--		Expected CoD: 2020
6	Hetat-Ditrolic-IFDC Solar (HDFC Sinpower Ltd.)	Sutiakhali, Mymensingh	50	0.17	21.12.15	Expected CoD: 2020
7	Consortium of Spectra Engineers Ltd. & Shunfeng Investment Ltd.	Manikganj	35	0.139	29.08.17	Expected CoD: 2020
8	SunEdision Energy Holding Private Ltd.	Teknaf, Cox's Bazaar	200	0.17	21.10.15	Cancelled
9	Edisun- Power Point & Haor Bangla-Korea Green Energy	Dharmapasha, Sunamganj	32	0.17	17.12.15	PPA signed
10	Intraco CNG Ltd. & Juli New Energy Co. Ltd.	Gangachora, Rangpur	30	0.16	18.04.16	PPA signed
11	Beximco Power Co. Ltd. & TBEA XinJiang SunOasis Co. Ltd.	Gaibandha	200	0.15	05.09.16	PPA signed
12	Eiki Shoji Co. Ltd. (Japan) & Sun Solar Power Plant Ltd.	Goainghat, Sylhet	5	0.139	06.09.16	PPA signed
13	Green Housing & Energy Ltd.	Paatgram, Lalmonirhat	5	0.125	22.11.16	PPA signed
14	Beximco Power Co. Ltd. & Jiangsu Zhongtian Technology Co. Ltd. (China)	Panchagarh	30	0.139	15.01.17	PPA signed
15	Zhejiang Dunan New Energy Co. Ltd. (China) & National Machinery Import & Export Corporation, Solar Tech Power Ltd. & Amity Solar Limited	Nilphamari & Lalmonirhat	100	0.14	05.04.17	PPA signed
16	Consortium of Hanwha 63 City Co. Ltd., BJ Power Co. Ltd. & Solar City Bangladesh Ltd.	Porabari, Tangail	50	0.13	09.04.17	LOI cancelled

#	Sponsor	Location	Capacity (MW)	Tariff (USD/kWh)	Date of LOI issuance	Remarks
17	Energon Technologies FZE (UAE) & China Sunergy Co. Ltd. (CSUN)	Bagerhat	100	0.138	12.04.17	Vetting in progress
18	8minutenergy Singapore Holdings 2 Pvt. Ltd.	Panchagarch	50	0.133	20.08.17	LoI issued
19	Shapoorji Pallonji Infrastructure Capital Co. Pvt. Ltd. (India)	Pabna	100	0.1195	31.12.17	LoI issued
20	Consortium of China Energy Engineering Corporation and Sunland Holding Co. Ltd.	Trishal, Mymensingh	200	0.11	27.11.18	LoI issued
21	Consortium of IBV, MVV and Fu-Wang Bowling & Services Ltd.	Panchagarch	47	0.1125		LoI issued
22	Joint Venture Company of CREC, China and BPDB-RPCL Powergen Ltd. Bangladesh	Madarganj, Jamalpur	100	0.1105		LoI issued
23	Scatec Solar ASA, Norway	Nilphamari	50	0.1120		LoI issued
24	Symbior Solar Siam & Holland Construction	Moulvibazar	10	0.115		LoI issued
25	Consortium of IBV-MVV- SS Agro Complex Ltd	Dhamrai, Dhaka	50	0.1075		LoI issued
26	Rahimafrooz-Shunfeng	Panchagarh	20	0.1075		LoI issued
27	IBV-AG Agro Consortium	Chittagong	50	0.1094		LoI issued
28	Metito Utilities - JInko Power – Al Jomaih Eneergy Consortium	Rangamati	50	0.0749		LoI Issued
		Total Capacity	**1610**			

Appendix C: Decade-wise General Recommendations

C.1 Recommended Actions for 2021-2030

Type	Policy and regulations

1. **Action:** Revise policy documents and set new RE target, especially a solar Energy target

Rationale: A national target essentially directs a high-priority signal towards all the relevant parties of any sector. Therefore, it is important to revise the previous targets and set a new and unambiguous target immediately.

Details: Bangladesh's RE policy has been developed back in the year 2008. Over the last 10 years, both the global and local power sector has undergone significant changes. A few scientific and experimental undertakings have revealed results that encourage revisiting the country's RE potential altogether [106, 8]. Therefore, the RE policy along with other relevant documents shall be revised and aligned accordingly. A more realistic yet slightly optimistic target can be considered reflecting these changes. **Chapter 5** of this Roadmap recommends decade-wise and sector-wise solar PV targets. These targets can be discussed among all the stakeholders and tailored accordingly if necessary. A set of doable actions are listed below:

- Organize multiple stakeholder meetings to communicate and discuss the possibilities as well as hurdles lying on the path of achieving the set target.
- Upon reaching unanimous agreement, proceed with declaring a nation-wide target and take steps to update all the relevant documents, such as the *Renewable Energy Policy*, *Power System Master Plan,* etc.
- Keep a provision for target revision at a regular interval, i.e., 5 years.

Expected outcome: Setting a long-term target immediately will allow the stakeholders necessary time to prepare themselves for adopting respective roles.

Stakeholders: Power Division, SREDA, BERC, MoF, MoEFCC, ERD, Planning Commission, NBR, LGED, Utilities, PGCB, commercial IPPs, research institutes, development partners, financial organizations including IDCOL, BIFFL, commercial banks, consumers, etc.

2. **Action:** Devise regulatory and pricing policies for incentivizing large-scale solar PV projects

Rationale: A careful study of solar PV sector development in neighboring countries, such as China and India, reveal that they are putting rigorous effort in reaping the benefits of economies of scale. Bangladesh is yet to follow the same path due to some obvious reasons, such as the prevailing conception of limited land availability, insufficient grid infrastructure, absence of local equipment market, lack of skilled manpower, etc. Planning large-scale deployment of solar PV power automatically tends to address these issues and offer market based and economically viable solutions that benefit the entire sector. However, a robust regulatory and policy framework acts the essential foundation.

Details: Favorable regulations shall be developed specially for incentivizing large-scale solar IPPs (e.g. for solar IPP projects). Such regulations can include provisions for site selection, land acquisition and development support, one-window and streamlined process to acquire necessary permits, power evacuation and transmission facilities, obligatory PPA with utilities, etc. However, the measures presented below can be considered:

- Prepare and articulate a dedicated policy document particularizing various incentives for large-scale solar project deployment.
- Organize an open and transparent auction/bidding system with adequate facilities to regulate the price. Many countries have experienced very competitive tariff by adapting reverse auction-based model, Bangladesh can also follow the method.
- Mandate generation utilities to enter into, at least limited, PPAs with large-scale solar IPPs. In that case, the current single buyer model may be revised.
- Regulate the streamlining procedure to reduce implementation time, etc.

Expected outcome: A clear and favorable guideline will facilitate the accelerated development of large-scale grid-tied solar power projects. Open and transparent auction/bidding system can effectively bring down project costs as well as the electricity prices.

Stakeholders: Power Division, SREDA, BERC, IDCOL, utilities, large-scale solar IPPs, etc.

3. **Action:** Formulate a clear and definite main grid-extension related policy

Rationale: It is only common knowledge that power sector's goals shall be met by achieving a crucial balance between the off- and on-grid sectors. So, government's plan of grid expansion shall be well-devised and clearly articulated among the interested investors. The Government of Bangladesh has committed to provide affordable and quality electricity for all. This responsibility should be shared by all the electricity distribution utilities. Electricity distribution utilities need to establish a clear policy distinguishing among areas where electrification is possible by grid expansion and where electrification will be done by RE, especially by solar.

Details: Power Division has decided that commanding areas of each electricity distribution utility including off-grid areas will be electrified by the respective electricity distribution utility by grid expansion or RE/solar projects. People will get electricity at grid tariff. Furthermore, existing mini-grid entrepreneurs will have a safe exit plan after the arrival of the utility electricity. So, now each electricity distribution utility has taken initiatives to make a clear policy where electrification is possible through grid connection by sub-marine cables and where there is the need to use solar/RE technology.

The selection of grid-quality electricity supply systems, like solar mini-grids, micro-grids, nano-grids or pico-grids, etc., is an immediate and essential procedure for the respective electricity distribution utilities, which must conduct the required feasibility studies. Solar Home Systems (SHSs) will not be a viable solution to provide quality electricity to people living in the off-grid areas. The quality of access should be assessed in terms of capacity, availability, reliability, quality (voltage), affordability of use, legality of connection, health and safety, etc. and also over the areas of energy use such as, households, productive usage and community facilities [119]. It is undeniable that the SHSs programme has greatly expanded the energy access frontier in Bangladesh. But in majority of the cases, the 'energy accesses' of households via SHSs resulted into household electrification only for lighting.

Expected outcome: This step is essential to mitigate the risk of private investment in the off-grid sector and to provide quality and affordable electricity to the off-grid area people.

Stakeholders: Power Division, SREDA, electricity distribution utilities, PGCB, IDCOL, existing mini-grid entrepreneurs, etc.

4. **Action:** Expand the policy implementation scope for incentivizing distributed generation

Rationale: The potential of distributed generation should be tapped properly. The small-scale yet numerous interested power producers should be sufficiently incentivized by formulating favorable policies.

Details: GOB has already launched the net metering guidelines and incorporated an OPEX model in the first revision. Payment security of the OPEX investor is mentioned in it, but it can be made more effective in terms of the regulatory bindings. NEM OPEX investors, i.e., any RE generating plants licensing waiver ceiling capacity may be increased up to 10 MW. Also, central electronic application procedure, processing, permission, and contract signing, etc. can be introduced for all the electricity distribution utilities. Billing software of each distribution utility can be developed accordingly and be connected with an automated meter reading facility. Financial models can be made more investor friendly. These actions can make the program more stakeholder-friendly and can yield better results.

Expected outcome: Extending the scope for rooftop systems will help extract the benefit from the most lucrative solar PV option for Bangladesh that is not constrained by land requirement.

Stakeholders: Power Division, SREDA, BERC, electricity distribution utilities, Bangladesh Bank, IDCOL, BIFFL, commercial banks, RE associations, CAB, Consumers, OPEX investors, etc.

5. **Action:** Develop necessary plan of electricity distribution utilities to reduce the generation cost of electricity by adding solar PV in diesel-based electricity supplied off-grid areas

Rationale: Liquid fuel transmission is risky, and may lead to environmental pollution. Also, the generated cost of electricity is higher than the electricity produced by solar PV. There is the need to have a policy at the electricity distribution utility level to incorporate PV with Diesel generator by Fuel Save Controller.

Details: The diesel generator-based electricity supply system is run by the electricity distribution utilities in some off-grid areas. Monpura and Hatiya are examples for this. A clear grid expansion policy is needed as mentioned in the Action no. 3. In areas where off-grid modalities are to continue with the existing diesel-based system, hybridization with solar PV can reduce the generation cost of electricity drastically. The demand on liquid fuel transportation will be reduced, which will in turn bring down the risk of contamination.

Expected outcome: It can provide economic benefit to the distribution utilities as well as reduce the risk of environmental pollution.

Stakeholders: Power Division, SREDA, electricity distribution utilities, etc.

6. **Action:** Formulate policy for the implementation of smart grid to address the variability of generation

Rationale: Timely formulation of adequate and well-developed policy measures and guidelines to implement smart grids is vital to achieve greater flexibility of the overall power system at a more advanced stage of VRE penetration.

Details: Smart grids are computerized, two-way communication network that can meet the increasing demand for flexibility, accessibility, reliability, and power supply quality. Such features of the power systems become essential with increasing share of variable renewable power into the grid. Smart grids are capable of integrating distributed and variable power generators, storage units, efficient energy management, inclusion of ICT and smart metering-based automation, etc.

Policy intervention to implement this at both the distribution utility level and national grid level is essential.

Expected outcome: Smart grid regulations will guide policymakers, system operators, large-scale power, and variable power producers to prepare and plan for a smoother energy transition well ahead of time.

Stakeholders: Power Division, SREDA, BERC, utilities, IPPs, system operators, project developers, power engineers, ICT experts, etc.

7. **Action:** Introducing policy for industrial storage systems for peak shifting and shaving of load and variable RE generation

Rationale: A robust policy framework shall assist the implementation of large-scale solutions like grid-capacity storage units in a well-planned and effective manner.

Details: Large-scale storage units are one of the major and effective strategies when it comes to peak load shaving and accepting greater input of VRE power. Energy storages are still expensive solutions. For grid-scale storage systems, the expenses and the required operational expertise may become proportionately greater. However, the large-scale Battery Energy Storage Systems or BESSs are mention-worthy exceptions in terms of operational expertise requirement, since they come fully automated. But then again, the associated expenses are still substantial. Deployment of industrial storages must be justified by considerable saving from peak-shaving and/or reducing reliance on spinning reserve. Thus, a well-grounded policy framework and proper planning is indispensable when it comes to implementing such solutions.

Expected outcome: A well-developed policy for introducing grid-scale energy storages will help create low-risk environment to encourage investors, help the stakeholders to adapt to the technology, and guide technical experts as well.

Stakeholders: Power Division, SREDA, utilities, foreign investors, system operators, IPPs, project developers, power engineers, ICT experts, etc.

Type	Technical aspects

8. **Action:** Develop and update the Bangladesh Standards (BDS) of solar accessories, related power quality and technical installation suited to the local context

Rationale: At the early stage of solar PV sector, the main goal should be to ensure that the local PV systems affect the grid power quality at its minimum. A few guiding documents recommend that technical study of the grid interconnection point, establishment of equipment and interconnection standards and their adequate enforcement are sufficient at the early stage of solar PV deployment [107].

Details: Preparation of entirely new equipment and connection standards usually takes a long time, involving various stakeholders, such as research laboratories, manufacturer and end users [120]. In Bangladesh such entities are yet to develop their full potential as active participants of such discussion. Also, it is not uncommon that international standards can be sometimes over-demanding compared to the local capabilities. So, a more reasonable step would be to modify the prevailing international standards to suit the local atmospheric conditions and comply with the national grid codes and other regulatory requirements, power systems characteristics and practices, etc.

A few Bangladesh Standards of Solar Accessories i.e., solar module, Inverter, charge controller and battery, have been developed by adapting the IEC standards without any deviation. The IEC standards are updated from time to time, but the BDS is not updated on a regular basis. Similarly, more standards related to solar equipment, power quality and technical installation procedures are needed to develop the solar sector. A list of doable actions in this regard is proposed below:

- Form a national technical committee dedicatedly for solar technology consisting of technical standard experts, engineers, researchers, technical personnel from SREDA, BERC, BSTI, Utilities and PGCB, suppliers, local manufacturers, etc.
- Review the existing Bangladesh Standards and develop up gradation, modification, amendment or withdrawn plan, when required. The committee shall oversee the current status of international standards regularly.
- Review the existing international standards related to PV and propose suggestions of necessary customization, if needed.

Expected outcome: This will ensure the identification of the product, installation, power quality, safety and longevity of the installed system that can bring success to the program.

Stakeholders: Power Division, SREDA, BERC, BSTI, suppliers, manufacturers, universities & research institutes, testing laboratories, individual experts, IDCOL, utilities, PGCB, solar IPPs, SPPs, etc.

9. **Action:** Review national grid code and, if necessary, upgrade accordingly yielding only minimum cost

Rationale: The existing grid codes shall be reviewed and revised for timely risk detection and corrective measures. The present distribution grid code, for instance, contains neither any guideline on RE-based distributed generation sources, nor any grid-interconnection guideline for the solar IPPs.

Details: Modern solar PV plant utilizes power electronics to connect to the grid. The setting that controls the behavior of the systems should be aligned with the local grid condition and be able to accommodate future changes. Grid codes are documents that guide such technicalities of interconnections. So, with the increasing share of variable renewable power sources, national grid and distribution codes should be reviewed at regular basis. Since Bangladesh's existing power structure is highly centralized, the review process should include independent technical experts, allow feedback from the solar PV manufacturers and developers, and include knowledge about the latest international experience, etc.

Expected outcome: This will help to create a level-playing ground for solar PV project developers and ensure power system stability in the future without much incurred cost.

Stakeholders: Power Division, BERC, SREDA, utilities, PGCB, independent power sector experts, etc.

10. **Action:** Achieve higher power system flexibility by introducing RE ancillary services

Rationale: With increasing share of variable solar PV power, enhancing flexibility of the system and utilizing flexible resources in a timely manner can assist in saving costs and improve reliability.

Details: There are several ways of increasing overall system flexibility. Typically, dispatchable generators (powered by gas or other forms of fossil fuel like diesel) help to attain power system flexibility. As in most countries, currently gas-powered units provide significant share of electricity in Bangladesh. The projected natural gas scarcity in future Bangladesh and the obvious unsustainable qualities of diesel may eventually lead to increasing share of uncertain and variable solar PV plants as dispatchable generators. If the forecasting capabilities are strong enough, sometimes solar PV plants can also provide flexibility at least to some extent. However, this may lead to increased solar tariff.

Expected outcome: Proper investment and management of dispatchable power units can offer higher system stability by reducing or even shutting down completely when solar PV power injection is high, or the other way around.

Stakeholders: Power Division, BERC, SREDA, utilities, IPPs, etc.

11. **Action:** Modify system operation practices to include variable solar PV plants

Rationale: Since existing system operation protocols are typically based on years of experience, they may sometime hinder the integration of newer technology into the system.

Details: Bangladesh's existing power system is very much traditional and centralized. So, with increasing share of power input from large-scale solar plants with priority access (to generate the maximum from solar), changes may be required in the operational procedure in future. Plant scheduling, management of operating reserves and interconnections, guaranteed visibility as well as the solar PV power production and demand forecast must be improved. It should be kept in mind that such changes typically demand sufficient time and effort.

Expected outcome: Upgrading system operation protocol will allow higher system flexibility and reliability with high shares of solar PV power.

Stakeholders: Power Division, BERC, SREDA, power generation, transmission and distribution utilities, system operators, solar IPPs, etc.

12. **Action:** Upgradation of the transmission network

Rationale: The existing grid infrastructure, especially the transmission network must be upgraded for the future energy transition that may add a considerable portion of VRE into the grid.

Details: It is common that resource-rich sites for solar PV projects are located in places where either the transmission grid has insufficient capacity or is simply non-existent. A study should be undertaken to assess the status of transmission network at the proposed sites for Solar Power Hubs in this Roadmap. Building new transmission lines take more time than solar PV project implementation. Therefore, options to upgrade the existing structure such as 'dynamic line rating, flexible AC transmission systems, line repowering etc. should be investigated as these measures sometimes prove to be sufficient [107]. In other words, solar PV sector planning shall be synchronized with grid-enhancement and extension planning.

Expected outcome: This step has the potential to reduce the cost of infrastructural development.

Stakeholders: Power Division, PGCB, SREDA, utilities, distribution companies, etc.

13. **Action:** Match demand with the variable solar PV supply via demand side management etc.

Rationale: The most common practice in this regard is to shift the peak demand to better match with the timing of peak generation. This can be done by creating new demand at these times, through measures known as 'sector-coupling', introducing automation in different sectors for demand side management. For example, industrial consumers can be mandated to align their energy-intensive activities during hours of peak solar power production.

Details: The *Power System Master Plan* (2016) has already indicated and forecasted a possible shift of daily demand curve with the progression of industrialization in Bangladesh. The following figures show typical daily load curves during summer and winter season of 2018 and projected ones for 2041. **Figure** Error! No text of specified style in document.**-1** shows that in both seasons the peak demand occurs in the evening, i.e., at 8 pm in summer and at 7 pm in winter [121]. According to the *PSMP 2016*, the peak demand shall gradually shift to occur earlier in the day by 2041, as shown in **Error! Reference source not found.**. As discussed in **Section** Error! Reference so urce not found., the difference in peak demand values are also noticeable. The shift becomes more apparent when compared on the same graph after applying normalization as shown in **Error! Reference source not found.**.

Expected outcome: This will ensure higher shares of solar PV power utilization without the need of expensive energy storage options.

Stakeholders: Power Division, SREDA, utilities, industries, all consumer categories, stakeholders from other sectors, etc.

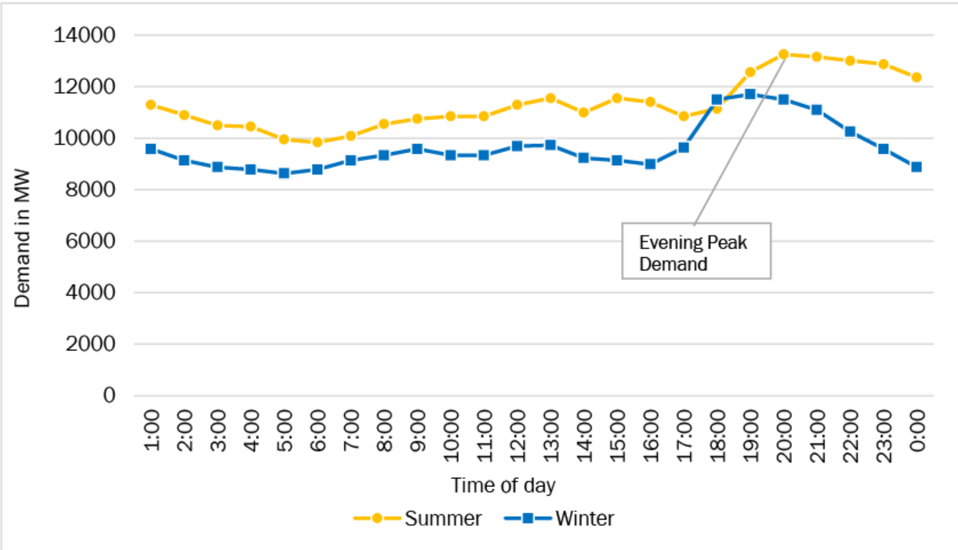

Figure **Error! No text of specified style in document.**-1: Typical Daily Load Curves in 2018 **[97].**

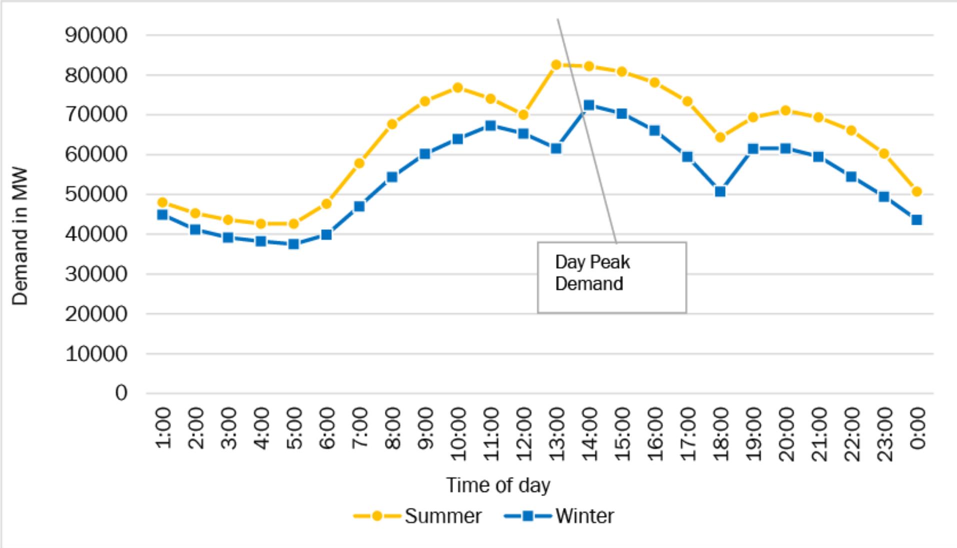

Figure **Error! No text of specified style in document.**-2: Typical Daily Load Curves in Industry 2041 **[97]**.

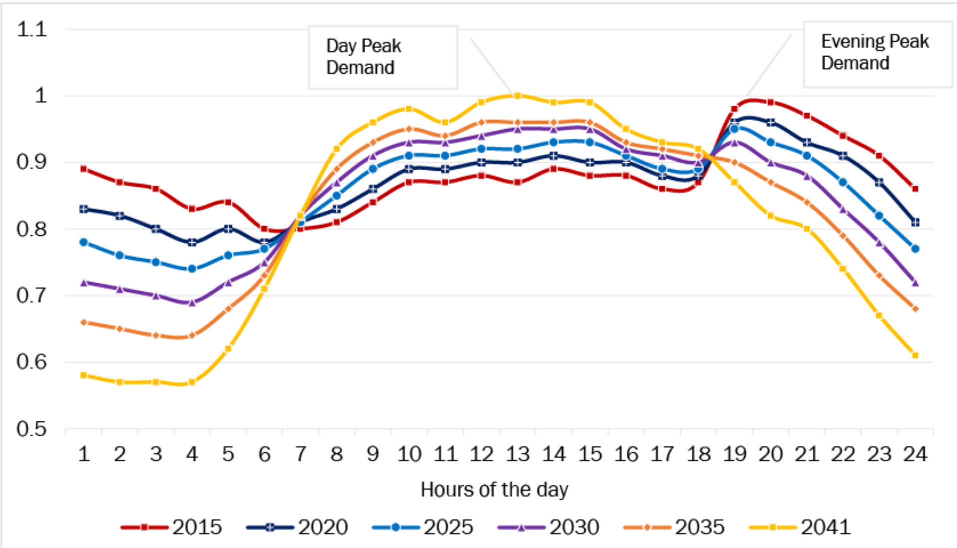

Figure **Error! No text of specified style in document.**-3: Gradual shift of Daily Load Curve from 2015 until 2041 **[97]**.

Type	Supply chain

14. **Action:** Program wise implementation of national standards of solar appliances

Rationale: Success of each solar program depends on the use of quality products. Also, quality power interchange with the grid, and grid stability effects on consumers' load and supply side equipment may be affected due to the use of bellow standard products.

Details: One of the major reasons of success of off-grid programs of IDCOL is ensuring the use of quality appliances and their ensuring mechanism. But in open programs like mandatory rooftop solar for new electricity connection, first phase of solar projects under TR/KABIKHA program etc. are failed to achieve the success due to the lack of standard implementation, no quality control mechanism and also no viable financial returns. Initially verification could be done based on the test report and certificate of accredited laboratory and certification body. Time to time it could be crosschecked by the project/program implementers from the local laboratories, when needed. SREDA already have taken initiative to implement the standard for Net metering program. Similarly, other programs can follow this. However, the following actions can be considered to enable it further:

- SREDA introduced NOC of solar accessories for net metering program based on the certificate and test report of verified accredited laboratories and certification bodies. Solar product suppliers or manufacturers are applying for NOC through online platforms. A technical committee is working to review the applications. Similar NOC can be introduced for utility scale projects and other programs.
- Introduce incentives to encourage suppliers, e.g., acknowledging improving qualities through awards, 'future business guarantees and sharing achieved cost saving' [122].
- Introduce training programs for suppliers and increase industry's interest in supporting such programs.
- Punishment to the below standard suppliers or manufacturers, if discovered during cross checking.

Expected outcome: It can bring about success of the program from technical aspects.

Stakeholders: Power Division, SREDA, utilities, suppliers, manufacturers, testing laboratories, project implementers, etc.

15. **Action:** Setting up of accepted laboratory criteria

Rationale: The laboratory or certification body is an important entity in ensuring standards. Therefore, the service quality of the laboratory or certification body is an important factor.

Details: SREDA has set laboratory selection criteria by consulting with the Bangladesh Accreditation Board (BAB). According to this, the laboratory needs to be accredited according to ISO/IEC 17025 by any MRA signatory accreditation body of International Laboratory Accreditation Cooperation (ILAC). The certification body needs to be accredited according to ISO/IEC 17065 by any MLA signatory accreditation body of International Accreditation Forum (IAF). Respective accreditation body will be responsible to ensure the testing and certification quality as agreed with ILAC/IAF. An interested laboratory or certification body can apply to SREDA to get its name in the accepted list. Listed laboratories and certification bodies are responsible for verifying their issued test reports and certificates. From time to time, the process and conditions can be reviewed with the current situation and experience.

Expected outcome: Testing quality will be ensured and responsibility assigned.

Stakeholders: SREDA, BAB, technical experts, relevant stakeholder, etc.

16. **Action:** Capacity development of local laboratories for local verification

Rationale: Local testing laboratories' capacity development is essential for the confirmation of the quality of solar appliances. It will be helpful to conduct some random sampling and cross checking of products from a project. Also, it will be helpful to implement the mandatory provision of standards during import.

Details: BSTI, BCSIR and Engineering Universities have some testing facilities. The facility could be increased to test a product fully according to an international standard, i.e., IEC 61215:2016. After achieving the testing capability, the testing facilities need to go for accreditation. The technology is changing very fast and the investment cost of testing equipment the main barrier to successful operations. However, if partial testing is carried out for cross checking, the capacity of the local laboratory will be increased day to day and human resource will be developed in the testing and research field. Capacity and human resource development support can be provided from SREDA, as needed.

Expected outcome: Local testing capacity will be developed and product quality cross checking with certificate/foreign laboratory test report will be ensured.

Stakeholders: Power Division, SREDA, BAB, local laboratories, program/project implementers, suppliers and installers, etc.

17. **Action:** Development of installation standards, capacity building of quality designers and installers

Rationale: In addition to product quality, installation quality is an important factor. The formation of installation standards and training human resource development on it is essential.

Details: The net metering guideline mentioned some installation standards, which can be helpful for system designers and installers. Those standards are also conducive to achieving the expected power output, ensuring quality installation, achieving the expected lifetime, reducing the risk, and increasing the safety level. Most of the small and medium scale designers and installers didn't follow the installation standards due to the lack of knowledge, awareness and training. Installation standards and their implementation are mostly helpful for open access solar programs but can also be supportive for utility scale projects. The following activities can be taken:

- The dedicated technical committee for solar as mentioned in action-8 or specific program wise technical committee can be formed to review the requirement of installation standards.
- SREDA can take the necessary steps to add the implementation standards to the program policy document. Some technical installation standards might be mandatory and some might be voluntary based on the situation.
- Training program can be arranged by SREDA to generate quality designer or installer in the market. Initially SREDA can start directly and later on it can be arranged by several training institute, engineering universities with the supervision of SREDA when training demand will be increased.
- Adding to the course curriculum in diploma and vocational level regarding solar design and installation standards.

Expected outcome: Quality installation and manpower will be developed.

Stakeholders: Power Division, SREDA, DTE, utilities, training institutes, engineering universities, technical experts, etc.

18. **Action:** Incorporating the provision of mandatory Bangladesh Standard during import

Rationale: At present, both good- and poor-quality products are imported into our country. There are no restrictions on it. This creates market distortions and hampers the reputation of the solar sector.

Details: From time to time, SREDA can monitor the situation and propose some solar equipment standards and make them mandatory during the import phase. Initially the standards can be based on those by accredited laboratory or CB reports. Then once capacity of the local laboratories will be adequate, those can be gradually converted to the local ones. Laboratory and CB criteria are mentioned in Action no. 15 & 16. Through the formal procedure of BSTI and the Ministry of Industries and Ministry of Commerce, mandatory standard provision of proposed solar standards can be added to the 'Import Policy Order' published by the Ministry of Commerce.

Expected outcome: It can restrict the poor-quality solar products being imported into Bangladesh.

Stakeholders: Power Division, SREDA, Ministry of Commerce, Ministry of Industries, BSTI, NBR, Customs, CC&IE, testing laboratories, etc.

19. **Action:** Facilitate the development of the local manufacturing industry and easier access to export to the other countries

Rationale: Important parts of solar systems are now import dependent. Local manufacturing facilities need to be developed to reduce dependency as well as create employment. Those items may also be exported to suitable countries.

Details: Quality solar products and relevant appliances are mostly import dependent. Local module assembly companies have been developed to some extent, but they are facing tough competition against the imported products. Also, some good quality system accessories should be manufactured locally. Gradually local manufacturing capability needs to be developed alongside easy export facility.

Expected outcome: It can reduce the dependency on import as well as employment generation.

Stakeholders: Power Division, SREDA, Ministry of Commerce, Ministry of Industries, NBR, Customs, CC&IE, etc.

20. **Action:** Create a comprehensive information hub and introducing National Solar Helpdesk service

Rationale: It is important for large-scale project developers as well as for individual interested consumers to have access to a platform or source containing detailed information regarding various aspects of solar PV projects.

Details: Creation of an information hub can be considered as a complementary action. SREDA has already introduced the 'National Database of Renewable Energy' and 'RE Stakeholder Database', including a list of RE focal persons of all government organizations, who are important parts of the information hub. 'Solar E-service Desk', 'Net metering calculator', 'Solar Inter-Row-Spacing Calculator', etc. are also proving to helpful tools for the interested parties. These information platforms can be further enriched to disseminate more information in many other ways. A few recommendations are provided below:

- A comprehensive collection of information about the national and international supply chain companies, financial institutions, and latest updates on available technologies and technical standards can be made available online, accessible via websites of relevant government bodies like the MPEMR, SREDA or financing bodies like IDCOL.
- A reliable and accessible local solar resource data and forecast system must be developed.
- Handbooks/Guidebooks can be developed and widely circulated to reach even the lowest administrative levels.
- 'National Solar Help Desk' could be introduced at SREDA with Physical service, Hotline, Email and Video conferencing medium. A dedicated helpdesk web, a digital record book

and customer feedback could be introduced to ensure the service quality and sustainability of the service.

- Utility officers can be trained up for initial guidance and further information, they can refer to the 'National Solar Help Desk'.

Expected outcome: Comprehensive reserve of information will enable project developers and prosumers to make informed business decisions and investments.

Stakeholders: Power Division, SREDA, BERC, utilities, IDCOL, development partners, solar associations, private developers, technical experts, prosumers, etc.

21. **Action:** Solar PV waste disposal plan

Rationale: Each solar appliance has a labelled life time. After that lifetime, the appliances need to be disposed in proper ways, i.e., in ways that will be safe for the environment. Reduce, Reuse, Recycle or, in short, the 3Rs can be handled in a better way if the processes are made technically and financially viable.

Details: The average lifetime of solar module is around 20—30 years, and of inverters is around 10–15 years. Charge controllers, batteries and related appliances have similar a lifetime. An exit plan for those solar products needs to be under planning before the lifetime ends. This can avoid environmental pollution.

Expected outcome: Solar PV waste will be disposed in a planned, safe and environment-friendly way.

Stakeholders: Power Division, SREDA, DoE, utilities, suppliers, manufacturers, etc.

Type	Financial environment

22. **Action:** Availability of long term and concessionary financing through commercial financial institutes

Rationale: Finance is undoubtedly one of the major concerns when it comes to achieving any energy related targets. The availability of low-cost financing therefore may play vital role in the sector development and achieving targets set in this Roadmap.

Details: At present only IDCOL is playing the important role of organizing and channeling of the RE funds in Bangladesh. Capacity of the commercial financial institutions should be enhanced for handling long term concessionary financing, especially for the RE projects. Commercial financial institutes can have the organizational model similar to IDCOL. Such organizations could be made responsible for securing international grants, attracting foreign investments, distributing funds among local project developers, streamlining low-cost financing etc. Each of the commercial financial organization should have sufficient technical manpower to evaluate the solar projects.

Expected outcome: Financial organizations will secure the financial landscape essential for the solar PV sector development.

Stakeholders: MoF, Power Division, Bangladesh Bank, IDCOL, BIFFL, commercial banks and other financial organizations, development partners, etc.

Type	Market Enhancement and capacity building

23. **Action:** Launch nation-wide awareness programs

Rationale: An informed and devoted customer base helps to develop and sustain any industry and solar PV industry is no exception. Therefore, citizens should be made aware of the economic, environmental and social benefits of RE technology, with special focus on solar PVs. This will assist not only in expanding and securing the solar power market, but also other solar-powered products.

Details: A country-wide solar PV promotional campaign can be designed, launched and sustained. Industries or companies that either produce or sell solar PV related products and service should be encouraged to join force. Especially various development partners can play important role in this regard. Ways should be devised to merge or align solar promotional program with other awareness programs led by the government, such as safe drinking water program etc.

Expected outcome: Such programs will encourage the consumers to opt for solar PV power and thus help securing revenues for the industry.

Stakeholders: SREDA, IDCOL, development partners, other relevant ministries, etc.

24. **Action:** Introduce and expand educational and training programs

Rationale: Educational and training programs are essential to enhance the capacity of existing workforce and to develop the future human resource capital that will serve the solar sector in coming decades.

Details: The existing human resource pool should be trained to the needs of emerging markets and advanced technologies. But it is also important that the future generation develops a deeper and contextual understanding of issues related to climate change, environment, sustainability and their connection with RE technologies. Therefore, while professional training programs should be initiated immediately, it will be beneficial to integrate traditional academic bodies into the discipline in the long-run. A few doable and relevant actions are prescribed in the list below:

- The curricula can be revised to include topics related to sustainability, climate change, green economy and growth, RE etc., starting from primary to higher education, including the applied and vocational studies.
- Students' research projects can be funded to encourage local innovation.
- 'Solar laboratories' can be established in schools and colleges to create learning opportunities for young students.
- Existing solar PV project sites can be used as educational platforms, e.g. by allowing excursions, internship programs etc.
- Award-based competitions at all educational levels can be organized.
- Steps should be taken to facilitate the interaction between academia and industry. Establishment of a public funded research institute might be helpful in this regard.
- Form liaison with the private sector and the industries, if possible, at different levels of educational and training programs.

Expected outcome: Educational and training programs will not only help build a skilled and motivated human resource pool to serve the local solar sector, but also develop generations of future consumers who are likely to make educated energy consumption choices as responsible citizens.

Stakeholders: MPEMR, SREDA, Ministry of Education, all educational institutes, development partners involved in the education sector, industries, etc.

25. Action: Initiating and expanding solar PV research and development efforts

Rationale: In the long-run, it will be both feasible and reasonable to build local research and innovation capabilities to serve the solar PV industry.

Details: A local base of researchers and innovators will be certainly desirable in the long-run and at a more mature stage of solar PV development. To achieve this several steps can be considered:

- Enter into active collaboration with various international research organizations.
- Allocate part of national budget to fund solar PV related research projects and scholarships.
- Encourage and support universities to establish research facilities and to organize conferences for knowledge sharing etc.
- Establishment of a dedicated research institute will be of much value in this regard.
- Local industries should be encouraged and allowed to fund local research projects.

Expected outcome: These actions will help to develop a pool of local researchers, form and maintain a strong international network of collaborators. This will not only accelerate the process of technological catch-up, but also allow and ease the contextualization of such technologies to meet the local needs.

Stakeholders: MPEMR, SREDA, Ministry of Science and Technology, universities, research and testing laboratories, international academic and industrial collaborators, etc.

26. Action: Create attractive 'solar jobs'

Rationale: Due heed should be paid to create sufficient job opportunities for the skilled candidates to serve the solar PV industry.

Details: IRENA reports that in 2017 the number of jobs in the solar PV industry has increased by 8.7% to reach a total of nearly 3.37 million [123]. In 2018, the total employment in the solar PV sector summed up to 3.6 million, including 372,000 off-grid jobs in South Asia and parts of Africa [124]. It also indicates that the solar PV jobs are still geographically concentrated in a few countries. However, it is challenging to create jobs in Bangladesh for various reasons. But this aspect nevertheless demands proper and timely attention.

- It can be speculated that with the industrialization of the solar PV sector, numerous jobs will be automatically created. Still, apart from the creation of new positions, ways can be devised to re-brand the existing opportunities as 'solar jobs.'
- Public as well as private sector companies operating in the solar PV industry can be guided to modify their job requirements at least to some extent to appeal to or incentivize candidates with educational background or specialized trainings on solar PV technologies, project management, financing etc.

Expected outcome: Attractive job opportunities are likely to encourage and increase the participation of professional citizenry in the solar PV industry.

Stakeholders: Power division, SREDA, Ministry of Labour and Employment, public and private companies involved in the solar PV sector, etc.

C.2 Recommended Actions for 2031-2041

Type	Policy and Regulations

1. **Action:** Introduce and cascade down RE/solar PV quotas and obligations to either administrative regions or even to various companies operating in the sector

Rationale: Distributed target and obligations help reducing the pressure lying on the central public authority and ensures active participation of many stakeholders involved in the sector.

Details: The national targets can be distributed and channeled down to various entities such as local administration, the suppliers, manufacturers, power producers and even consumers as RE Purchase Obligations (RPOs). Such practices exist in nearly 100 jurisdictions across the world, including in countries like India (26 states), US (29 states), UK, Korea, UAE, etc. [107]. The design of such quota systems varies widely and expensive penalties for non-compliance is important for effective implementation.

Expected outcome: The responsibility will be distributed among the players of the energy domain instead of lying only on the shoulder of central governing bodies.

Stakeholders: MPEMR, SREDA, IDCOL, utilities, all private and public business companies, consumers, etc.

2. **Action:** Establish and regulate a tradable RE/solar PV certificate mechanism

Rationale: The main aim of this action is to introduce a market-based scheme as an effective tool to acceleration solar PV deployment.

Details: It is not uncommon for countries with obligatory electricity quota systems to establish a tradable REC market (30 countries have by 2017) [107]. RECs are typically awarded for each MWh of RE and market players can trade such RECs to meet their annual RPO target. There are numerous studies and reports which present comprehensive discussions on such REC markets. For example, Shrimali and Tirumalachetty have reviewed the REC markets prevailing in various Indian states in details [125].

Expected outcome: This market-based scheme can generate and mobilize internal sources of funding and, if properly exploited, in the long run can help significantly to meet the national RE/solar targets.

Stakeholders: Power Division, MoF, SREDA, IDCOL, utilities, all private and public business companies, consumers, etc.

Type	Technical aspects

3. **Action:** Establish large electricity storage capacity

Rationale: Currently in Bangladesh, the peak demand occurs between 6 to 10 pm, while the solar PV power systems generate only during day hours. With industrialization and proper demand-side management, it can be expected that the demand curve will tend to be smoother over the years and that the peak demand will occur earlier as discussed previously. However, at a more mature phase when Solar Power Hubs of GW capacities will be in operation, there might be excess generation during daytime even after supplying the peak load. Large-scale energy storage will have the ability to absorb this excess generation and offset demand, thereby providing greater power system flexibility. Cost of storage might be decreased significantly within that time.

Details: Typically, deployment of mega-scale energy storage systems are adopted at a comparatively mature stage of solar PV sector development due to the high investment cost associated with them. In this Roadmap, the grid-scale storages are recommended for the later decade, i.e., 2031–2041. But if the solar PV power sector undergoes rapid development, or in other words high share of VRE (more than 20% of total installed capacity) is achieved at an early period may call for storage deployment much earlier. Therefore, the sector's development should be closely monitored, which will enable assessing the large-scale storage requirement at the optimum stage. The choice of appropriate storage technology and sizing shall be dictated by factors such as the future technological development, share of solar PV in the power system, etc.

Expected outcome: Large-scale energy storage deployment will ensure better system flexibility and reliability with a higher share of variable solar PV power.

Stakeholders: Power Division, BERC, SREDA, IDCOL, utilities, private investor, national and international storage experts and companies, etc.

Appendix D: Prospect of NEM System Development in the Economic Zones

The Government of Bangladesh has taken up an ambitious plan to develop 100 new economic zones (EZs) over the next 15 years to expand the export sector and accelerate economic development in the comparatively lagging regions. Bangladesh Economic Zone Authority (BEZA)—being an accessible, committed and capable partner to private investors—is acting as the key agency behind this elaborate development program. As of September 2020, BEZA has already acquired approval to develop 88 out of these 100 EZs; 59 of which are government-owned and the rest are under private ownership.

The following table contains available details of 67 of these EZs [126].

#	Name	Upazila	District	Land area (acres)
1	Mongla EZ	Mongla	Bagerhat	205.00
2	Mongla EZ	Mongla,	Bagerhat	110.15
3	Rampal EZ	Rampal	Bagerhat	300.00
4	Sundarban Tourism Park	Shoronkhola	Bagerhat	1546.35
5	Agailjhara EZ	Agailjhara	Barisal	300.00
6	Bhola sadar EZ	Bhola Sadar	Bhola	304.07
7	Bogra EZ -1	Ushajahanpur	Bogra	251.43
8	Ashugonj EZ	Ashugonj	Brahmanbaria	328.61
9	Anawra -2 (CEIZ)	Anawra	Chittagong	774.48
10	Anwara EZ	Gahira, Anwara	Chittagong	503.70
11	Mirsarai EZ	Mirsarai	Chittagong	30,000.00
12	Patiya EZ	Patiya	Chittagong	774.48
13	Comilla EZ	Meghna	Comilla	272.00
14	Cox's Bazar Special EZ	Moheshkhali	Cox's Bazar	8784.77
15	Jaliardip Economic Zone EZ	Taknaf	Cox's Bazar	271.93
16	Moheshkhali -1 EZ	Moheshkhali	Cox's Bazar	1438.52
17	Moheshkhali -2 EZ	Moheshkhali	Cox's Bazar	827.31
18	Moheshkhali -3 EZ	Dholghata	Cox's Bazar	1501.04
19	Moheshkhali Special Economic Zone	Ghotibagha	Cox's Bazar	1000.00
20	Moheshkhali Special Economic Zone Cox's Bazar	Ghotibagha and Sonadiya, Moheshkhali	Cox's Bazar	12962.22
21	Moheshkhali Special Economic Zone Kalamarchora	Moheshkhali	Cox's Bazar	3980.07
22	Sabrang, Tourism SEZ	Tacknaf	Cox's Bazar	1027.56
23	Dhaka EZ	Dhohar	Dhaka	316.35
24	Dhaka SEZ	Karanigonj	Dhaka	105.00
25	Feni Economic Zone	Sonagazi	Feni	7219.79
26	Shreepur EZ	(Nayanpur), Shreepur	Gazipur	510.00
27	Sreepur EZ	Sreepur	Gazipur	510.00
28	Gopalganj EZ	Kotalipara	Gopalganj	201.83
29	Gopalganj EZ - 2	Gopalganj Sadar	Gopalganj	200.00
30	Habigonj EZ	Chunurughat	Habigong	511.83
31	Jamalpur EZ -2	Jamalpur Sadar	Jamalpur	263.25
32	Jamalpur EZ	Jamalpur sadar	Jamalpur	457.77
33	Khulna EZ -1	Boiyaghata	Khulna	519.52
34	Khulna EZ -2	Terkhada	Khulna	509.64
35	Kustia EZ	Bheramara	Kustia	506.77

#	Name	Upazila	District	Land area (acres)
36	Manikgnnj EZ	(BIWTA old Aricha Ferighat), Shibaloy	Manikganj	300.00
37	Shrihatta EZ	Sherpur	Moulavibazar	352.12
38	Munshiganj Gazaria EZ	Gazaria	Munshiganj	97.98
39	Mymensingh EZ	Mymensingh	Mymensingh	487.77
40	Mymensingh EZ	Mymensingh Sadar	Mymensingh	494.00
41	Araihazar -2 Economic Zone	Araihazar	Narayanganj	400.00
42	Araihazar Economic Zone	Araihazar	Narayanganj	1010.90
43	Narayanganj EZ	Bandar & Sonarga	Narayanganj	875.65
44	Narsingdi EZ	Narsingdi Sadar	Narsingdi	690.20
45	Nator Economic Zone	Lalpur	Nator	3220.00
46	Netrokona EZ -1	Netrokona Sadar	Netrokona	266.76
47	Nilphamarai EZ	Nilphamari Sadar	Nilphamari	357.76
48	Panchghar EZ	Debiganj	Panchghar	595.01
49	Rajshahi Economic Zone	Paba	Rajshahi	204.06
50	Rajshai EZ	Poba	Rajshai	204.60
51	Shariatpur Economic Zone	Jajira	Shariatpur	525.27
52	Shariatpur Economic Zone	Gosharhat	Shariatpur	750.00
53	Sherpur Economic Zone	Sherpur	Sherpur	361.08
54	Narayanganj EZ Sonargaon	Sonargaon	Sonargaon	1000.00
55	Sylhet Special EZ, Gowainghat	Gowainghat	Sylhet	255.83
	Total area of approved govt. owned EZs			**108,627.42**
1	A K Khan PEZ	Polash	Narshindi	200.00
2	Megna Industrial Economic Zone PEZ	Sonargaon	Narayangonj	245.00
3	Megna Economic Zone PEZ	Sonargaon	Narayangonj	68.00
4	Aman Private EZ	Sonargaon	Narayangonj	150.00
5	Abdul Monem PEZ,	Gojaria	Munsigonj	500.00
6	Bay Private EZ	Gazipur	Gazipur	65.00
7	United City IT Park Ltd.	Badda and Vatara	Dhaka	2.43
8	Arisha Private EZ	Keranigonj, Savar	Dhaka	84.95
9	East-West Special EZ	Keranigonj	Dahaka	54.00
10	Bosundhora Special EZ	Keranigonj	Dahaka	56.00
11	Sirajganj EZ	(Adjacent to Bangabandhu Bridge), Sirajganj Sadar & Belkuchi	Sirajganj	1041.43
12	City Economic Zone	Narayanganj		120
	Total area of approved private EZs			**2,586.81**
	Total area of all the approved EZs			**111,212.23**

According to the data presented in the table above (total 67 Economic zones)., the total area covered by the already approved EZs is 111,212.81 acres or nearly 450 km^2. If all the planned 100 Economic zones are in operation by the year 2035 (According to the plan of Bangladesh Government). Then around 670 km^2 land will be under the economic zones. If we consider around 15% of this area to be industrial sheds, parking sheds and other sheds that are suitable for solar PV system installation then around 10 GW of rooftop solar PV system can be installed in the economic zones only.

Currently, BEZA is particularly focusing on development of existing Mirsarai EZ to around 40,000 acres as “Bangabandhu Sheikh Mujib Shilpa Nagar (BSMSN)”. As part of the BSMSN masterplan, BEZA is planning to improve the EZ's strategic quality, and in particular move toward smart, green and resilient developments to attract the most internationally reputed developers and investors using various financial models including the PPP model, wherever feasible. Very recently, SREDA has signed a Memorandum of Understanding with BEZA in this regard. The organisations intends to join forces to ensure implementation of renewable energy and energy efficiency measures at all the EZs including BSMSN [127].

Short biography of the consultant

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Education & Employment
Shahriar Ahmed Chowdhury obtained his B.Sc. in Electrical and Electronic Engineering from Bangladesh University of Engineering and Technology (BUET) in 1997 and M.Sc. in Renewable Energy from University of Oldenburg, Germany in 2006 with the highest marks in the graduating class. He worked in Bangladesh power sector for a decade (In system control & grid circle of DESA and planning & design in BPDB). He is the founding director of Centre for Energy Research at United International University (UIU). He has teaching and research experience in the UK and Germany.

Research Achievements and Awards
Shahriar has invented a novel dry fabrication process for CIGS thin film solar cell with one of the highest efficiency at the time (2006) in Centre for Solar Energy and Hydrogen Research at Stuttgart, Germany. In 2016 one of his research project “Peer-to-Peer Smart Village Grid” won the “UN Momentum for Change” award in UNFCCC CoP 22 in Marrakesh, Morocco and “Intersolar Award” in Munich, Germany. In June, 2018 he received the “Education Leadership Award” from “World Education Congress, 2018” in Mumbai, India for his contribution in Education, Leadership and Teaching in the Renewable Energy sector. In 2019 he has received the “Asian Photovoltaic Industry Association Award” in Shanghai, China for his academic contribution to the Solar PV industry. He was the supervisor of the finalist student project for the IEEE International Future Energy Challenge, 2009 in Illinois Institute of Technology, Chicago, USA. His Research projects “Smart Solar Irrigation System” and “Demand Response Enabled Smart Grid” won the “Inter University Innovation Award” at Power and Energy Week 2016 & 2018 respectively, organized by the Ministry of Power, Energy and Mineral Resources of Bangladesh.

Works and Affiliations
Mr. Chowdhury has drafted several National Policy documents like, the Net Metering Guidelines for Bangladesh, Guidelines for Integration of Solar Irrigation pumps into National grid, Bangladesh Delta plan (Part 4: Power). As a team leader he has performed the first two technical auditing of the Solar Home Systems installed all over Bangladesh under IDCOL program. He is extensively involved in developments of grid connected and off-grid solar PV systems. He is the designer of the first ever utility-scale grid connected solar PV project of Bangladesh (Engreen Sharishabari 3.3 MWp, came into operation in August, 2017). He was also involved in designing the Kaptai 7.4 MW (BPDB) and Sirajganj 7.6 MWp (NWPGCL) solar PV projects (The first two solar PV projects of Bangladesh in public sector). So far, he has also designed 23 solar diesel hybrid mini-grids (100kW ~ 3 MW) for rural off-grid area electrification in Bangladesh. He is also involved in designing large grid tied rooftop solar PV systems (Ranging from few kW to several MW).

As a power & energy sector expert he was involved in projects like Bangladesh Energy and Emission Modeling 2050, Supporting implementation of *Bangladesh Climate Change Strategy and Action Plan (BCCSAP)*, Bangladesh off grid energy sector assessment, etc. He has working experience in projects funded by the World Bank, ADB, UNDP, UNEP, DFID, EPSRC, DECC, GIZ, kfW, JICA, GoB, IDCOL, etc. He has developed a solar PV mini-grid laboratory at his University by the grant support from the World Bank. Mr. Chowdhury has jointly initiated a bi-yearly International Conference on Renewable Energy (ICDRET), this is first conference of its kind in Bangladesh [So far successfully organized 5 events]. He has designed and initiated a course in Renewable Energy for the first time in Bangladesh for the undergraduate students of EEE department in 2007. He is the author of more than 45 book articles, journal papers and conference proceedings. He has working and project experience in Bangladesh, Germany, UK, Kenya and Nigeria.