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Yield enhancement analysis of installed solar power projects in the country: An assessment for productive utilization of the power through Repowering

[1]Shilpa Urhekar, [1]Madhu Sharma, [2]Someshwer Dutt Sharma, [3]Radhey Shyam Meena

[1]School of Engineering, University of Petroleum and Energy Studies, Uttarakhand, India.
[2] Solar Expert, AES India, Gurgaon, Haryana, India.
[3] National Solar Mission Division, Ministry of New & Renewable Energy, India.

Abstract

The paper's main focus is on an assessment of the country's established solar power plants and techniques for their efficient usage through yield development in favor of customers and power producers, taking into account future aims and attainment through various government schemes. This study also examines current policies for renewable energy development, capacity addition, tariff patterns in various technologies in the sector, specific achievements, and comparisons for future growth, all of which will eventually help to redefine policy for the country's RE sector. Endogenous technical progress, cheap tariffs, and widespread renewables adaption are among the findings of the study, all of which will contribute to the country's low-carbon target and economic gains.

Keywords: Solar capacity development, Yield analysis, Solar policies in India, SECI, Renewable energy in India, Tariff trends.

1. Introduction of Development in India's Renewable Energy Sector

To meet the energy demand for its fast-growing economy, India will require a secure supply of energy that is more than double the current total energy expended. One of the best ways to meet the increasing demand is to use energy from diverse renewable technologies. Renewable energy now accounts for almost 38% of India's primary energy consumption. The energy sector is extremely important for a country's economic prosperity. India's power sector is broad, ranging from traditional sources like coal, oil, natural gas, and hydro to unconventional ones like solar, wind, and biowaste. Electricity demand has risen dramatically in recent years and is likely to continue to rise in the future. Intending to bring power to every home in the country, the government continues to increase capacity expansion across the country. India ranks third in the world in terms of primary energy consumption, after China and the United States, with 162-kilowatt hours of electricity consumed per capita [1]. India's energy demand is rising to meet the country's current economic development ambitions. The provision of growing amounts of energy is a necessary condition for a country's economic progress [2]. The Ministry of Power's National Electricity Plan [NEP] [3] has developed a 10-year detailed action plan with the goal of providing electricity across the country, as well as a second plan to ensure that power is delivered to citizens effectively and at a reasonable cost. Coal, oil, and natural gas, which are used to generate power, account for one-third of worldwide greenhouse gas emissions. It is critical to improving people's living standards by delivering cleaner and more reliable electricity [4]. According to the World Resource Institute Report 2017 [5, 6], India is responsible for about 6.65% of global carbon emissions, ranking fourth after China (26.83%), the United States (14.36%), and the European Union (14.36%). (9.66 percent). Climate change has the potential to disrupt the world's ecological balance. The United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement has received Intended Nationally Determined Contributions (INDCs). The latter intended to achieve the goal of keeping global warming well below 2 degrees Celsius [7, 8].

Indians are on their way to increasing investments and sustainable energy installations as a result of the Copenhagen and Paris climate agreements. India has great plans for renewable energy. The fast-growing country, which has a population of about 1.4 billion people, is undergoing an energy shift that is critical to global decarbonization. Global electricity demand will peak in 2030, according to the World Energy Council. India is one of the world's largest coal consumers and imports expensive fossil fuels [9].The Indian government has placed a greater emphasis on environmental monitoring in recent years and has set ambitious renewable energy goals for the coming decade. In 2015, the Indian government, led by Honorable Prime Minister Mr. Narendra Modi, declared a short-term goal of 175 GW (GW) of renewable energy capacity by 2022, with solar accounting for 100 GW, wind for 60 GW, bio waste for 10 GW, and hydropower for 5 GW [10]. Long-term, the country has set a goal of 450 GW of renewable energy by 2030 [11]. With a goal of 100 GW of solar power by 2022, the country has experienced a substantial increase in the recent decade, with central and state governments auctioning tenders to build large-scale solar projects. In the Energy Budget 2020, the government offered an impetus of INR 220 billion for the power renewable energy sector, which drew a favorable response from power sector players [12]. Renewable energy sources are critical for ensuring long-term energy security with lower emissions [13].
The year 2070 was chosen as the aim for achieving Net-Zero. (Source: Press Information Bureau, November 1, 2021.) Solar and wind power capacity in India has developed significantly, with solar power installed capacity increasing from 3.7 MW in 2005 to almost 4060 MW in 2015, a CAGR of over 100% over the decade. Similarly, the installed capacity of wind power in India increased from 1716.17 MW in 2005 to 3471.95 MW in 2015 (India's INDC, 2015). India had the fastest growth in renewable energy capacity addition among major economies from 2015 to 2021, with renewable energy capacity increasing by more than 2.5 times and solar energy increasing by up to 15 times. Although renewable energy has grown rapidly in recent years (see Table 1), considerable economic, financial, technological, and institutional impediments must be overcome to reach generating and installation targets. One of India's major commitments, as part of its Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC), is to achieve about 40% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030 through technology and financial transfers (India's INDC, 2015).As of December 2022, the share of renewable energy in installed capacity has already reached around 40 % (including Hydro and Nuclear) even though its share in the generation is only over 26%.Figure 1 shows the Share of RE in the installed capacity of Power Sector in India.

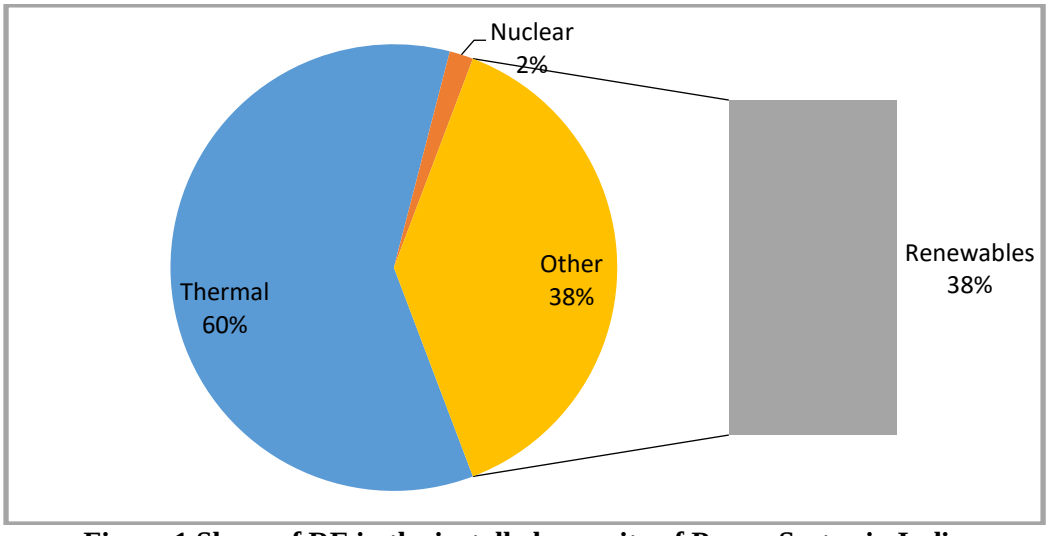

Figure 1 Share of RE in the installed capacity of Power Sector in India

(As of 31-12-2022, *Source: Ministry of Power*)

To meet the government's lofty targets of generating 450 GW of renewable energy by 2030, 330,000 additional jobs and livelihood possibilities are required [14, 15]. The growth of renewable energy technology should be aided by a combination of push policies and pull mechanisms, as well as specific initiatives. Technology advancements, appropriate regulatory policies [16], tax deductions, and efforts to improve efficiency through research and development (R&D) [17] are some of the pathways to energy and environmental conservation that should ensure that renewable resource bases are used in a cost-effective and timely manner.As a result, initiatives to encourage investment in the renewable energy sector as well as jobs for unskilled people, technicians, and contractors are considered. The government's technological and financial initiatives [18], policy and regulatory framework, as well as training and educational programs [19, 20] for the growth and development of renewable energy sources are all detailed in this article. The advancement of renewable technologies has run across clear roadblocks, necessitating a discussion of these roadblocks. Furthermore, it is critical to identify potential ways to overcome these barriers, and as a result, appropriate recommendations for the steady growth of renewable energy have been proposed [21–23]. Given the country's tremendous renewable energy potential, consistent legislative measures and an investor-friendly administration may be the most important factors.

Renewable energy plays an important part in resolving a country's energy crisis and advancing it toward the status of a country that can meet its own energy needs [24]. A rising number of researchers are examining the significance of carbon price in meeting climate/renewable energy goals. With Indian governments increasing their support for renewable energy, the problem of Indian renewable energy has gotten a lot of attention from academics all over the world. The study's available content focuses on development history [25],policy evolution [26], sociological viewpoints [27], and a variety of other topics. There are two types of studies: qualitative research and quantitative research.

This qualitative study summarizes India's current renewable energy adaptation situation and other government initiatives to support the development of renewable energy sources in the international environment [28]. The link between India's renewable energy usage and factors including economic growth [29], household income [30], and pollutant emissions [31] may be studied using correlation analysis. There are also other studies that concentrated on the creation of new technology or the formation of specific practical policies [32],[33]. The emission reduction potential of renewable energy [34], the performance of renewable energy policies [35], renewable energy technologies [36], and types of renewable energy [37] can all be ranked using assessment models to create corresponding assessment indicators, allowing the effectiveness of renewable energy to be determined. Since 2009, the research paper examines the state of solar energy development in the Indian context. Various papers/reports and other literature surveys were evaluated in this part to provide a flow for the present work. The expansion achieved in the RE sector thus far with the help of various policy frameworks is examined in the next section.

2. Growth in RE Capacity vis-à-vis policy addition

India has a wide range of renewable energy options, including solar, wind, small hydro, and bio power, among others. The government realizes that harnessing these resources is critical for economic and climatic growth, and as a result, it has adopted a number of measures that encourage the construction of renewable energy sources. India was the first country to establish a full-fledged ministry devoted to the development of renewable and alternative energy sources. The Ministry of New and Renewable Energy (MNRE) of the Government of India estimates that commercially exploitable renewable energy sources such as wind (695.51 GW at 120 meters), small hydro (211.33 GW), bio-energy (44.85 GW), and solar energy have a total potential of roughly 1700.68 GW (748.99 GW assuming 3 percent wasteland).Figure 2 Installed Capacity in India for Renewable Energy Sector in last 10 years.

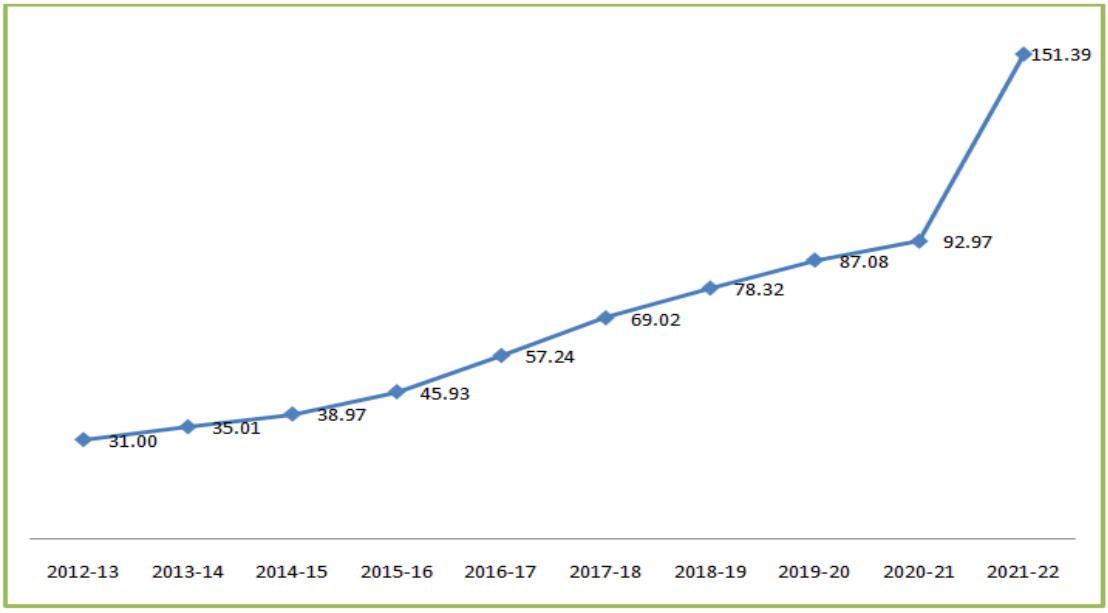

Figure 2 Installed Capacity in India for Renewable Energy Sector in last 10 years

(In MW, Source: MNRE Annual Reports & Website)

India receives excellent sun irradiation, ranging from 3 to 7.5 kWh/m2 per day, due to its geographical location. It has an average of 250-300 bright sunshine days per year, and studies show that merely 0.1 percent of land deployment can meet energy demand and close the energy gap. Other Renewable Energy Sources (RES), such as hydro, wind, and biomass, have significant potential for generating clean electricity in India. This potential has been acknowledged, demonstrating India's awareness of the need to reduce its carbon footprint as a developing country.

The planning was done by the Indian government using the Five Year Plan technique. The plan wise

- India's energy generation mix, which was primarily coal, oil, and hydro, was assessed in the first and second Five Year Plans (1950-55) and the second FYP (1956-60). India had a total installed capacity of 2300MW in 1950, and by 1960, it had expanded to 5700MW.
- Solar energy as a method for energy generation was initially discussed in the 3rd FYP (1961-66). The total installed energy generation capacity was 31GW by the end of the 5th FYP (1974-79).
- Solar energy was mentioned prominently in the 6th FYP (1980-85) as a means of meeting the energy demands of decentralized rural areas and prospective industrial uses. The Department of Non-Conventional Energy Sources (DNES) was established as a unit under the Ministry of New & Renewable Energy on September 6, 1982.
- 7th FYP (1985–90) saw an important development of Amorphous Silicon Solar Cell (ASSC) technology. BHEL was given the responsibility to execute a plant with a capacity to manufacture 500kW of modules per annum and to achieve the cell efficiency of13–15% at the laboratory level.
- IREDA was established on March 11, 1987, with the primary goal of promoting, developing and providing financial support for renewable energy and energy efficiency/conservation projects.
- 10,000 villages were proposed to be powered utilizing decentralized and non-conventional energy sources such as solar photovoltaic in the 8th FYP (1992-97).
- The government of India supported private sector participation in energy generation, transmission, and distribution in the 9th FYP (1997-2002). Under this initiative, the Independent Renewable Power Producers (IRPP) were given the authority to sell (renewable) power to any

third party in the country using existing transmission lines of the State Electricity Boards (SEBs) in exchange for acceptable fees. To encourage IRPPs to contribute to the promotion of power generation from non-conventional energy sources, all obstacles in this regard required to be overcome. Private developers were allowed to build power plants of any size and type under the policy (wind or solar).

- The Government of India planned to build a 140MW Integrated Solar Combined Cycle Plant at Mathania, Rajasthan, during the 10th FYP (2002-07), but it was postponed due to viability difficulties and gas supply. Several solar PV pumps were constructed across villages with government subsidies ranging from 66% to 90%. During this time, significant R&D progress was made, which was rewarded during the 6th FYP.
- During the 11thFYP (2007-12), solar energy was given due importance for attaining clean energy independence and Jawaharlal Nehru National Solar Mission was launched. The 12thand last FYP (2012-17) has kept its focus on research and development of new energy technologies to make them a better success.
- The Jawaharlal Nehru National Solar Mission (JNNSM), one of the eight missions within the National Action Plan on Climate Change (NAPCC–2008), was launched by the Indian government in January 11, 2010, in an effort to promote clean energy. 'National Five Year Plans' were used to meet national energy needs prior to JNNSM.

In the early years of JNNSM, projects were awarded to IPPs with a typical cap of 5MW, and project awards were made in phases and batches, which was necessary because this technology was new in the country and few organizations had prior experience working on such projects. In truth, design engineering was outsourced to some European companies for a number of projects. Certain aspects of efficiency are improving like tracking systems were introduced almost 5 years after the start of the mission. The first batch of Solar PV plants was commissioned in 2011 which is more than a decade now. In this section, the various major and policies since 1950 have been described and key achievements have been noted. After the announcement of 8 major missions in India, the Government also give a boost to various technologies of RE. In the upcoming section, one of the missions "Jawaharlal Nehru National Solar Mission" has been discussed in detail.

3. Jawaharlal Nehru National Solar Mission

The Jawaharlal Nehru National Solar Mission (NSM) is a major government of India project aimed at promoting environmentally sustainable growth and addressing the country's energy security challenges. The NSM is one of the National Action Plan on Climate Change's eight missions (NAPCC). The strategy paper elaborates on a novel approach to reducing the stress of climate change, illustrating its point using the poverty-growth relationship. The NAPCC also mentions the following: "India is a tropical country where the sun shines for longer periods of time and with greater intensity. As a result, solar energy has a lot of potential as a future energy source. It also has the benefit of allowing for decentralized energy distribution, which empowers people at the grassroots level ". Recognizing the potential of solar energy to contribute to India's energy security, the government of India launched the National Solar Mission (NSM) on January 11, 2010, with the goal of establishing India as a global leader in solar energy by establishing the policy conditions for its rapid adoption across the country. By 2022, the National Solar Mission (NSM), dubbed "Solar India," aimed to build 20 GW of grid-connected and 2 GW of off-grid capacity. The Mission will be implemented in three phases: Phase-I will cover the 11th Plan and the first year of the 12th Plan (up to 2012-13), Phase-II will cover the next four years of the 12th Plan (2013-17), and Phase-III will cover the 13th Plan (2017-22) as Phase-III.

The mission's policy framework aims to establish the appropriate environment for industry and project developers to invest in solar power generation research, local manufacturing, and development, resulting in a critical mass for the domestic solar industry. The Mission's immediate goal was to focus on creating a

conducive environment for solar technology penetration throughout the country, both centralized and decentralized. The first phase (from 2010 to 2013) concentrated on catching the low-hanging fruit in solar, pushing off-grid solutions to serve populations without access to commercial electricity, and adding modest capacity to grid-based systems. After taking into account the previous years' experience, capacity was aggressively ramped up in the second phase to provide the necessary circumstances. India, in its Intended Nationally Determined Contributions (INDC), announced to increase the share of installed electric power capacity from non-fossil-fuel-based energy resources by 2030 to 40% and to reduce the emission intensity of its GDP from 33 to 35% by 2030 [4]. In consideration of the above, the Government of India in June 2015 scaled up the target for setting up grid-connected solar power capacity from 20,000 MW to 1,00,000 MW by 2022 under the NSM. The above capacity is proposed to be achieved through the deployment of 40,000 MW of rooftop solar projects and 60,000 MW medium& large-scale solar projects. To harness the solar potential efficiently and to achieve the objectives of NSM, it was required to develop State level Infrastructure solely dedicated to promoting solar power generation. One of the ways of achieving that was the development of solar parks in a focused manner across different parts of the country. In the next section the various policies, scheme, and requirements of RPOs which was taken up by the Government have been discussed.

4. Policies Encouraging the development of Solar Power

The Electricity Act of 2003 paved the way for renewable energy generation and mandated the State Electricity Regulatory Commissions (SERC) to promote cogeneration and renewable energy generation by providing suitable measures for grid connectivity and sale of electricity to any person, as well as specify a percentage of total electricity consumption in the area for the purchase of electricity from such sources. Following that, the Government of India notified the Tariff Policy, 2006, which, in addition to mentioning the provision mandated in the Electricity Act, also stated that, within the percentage so made applicable, the SERCs shall also reserve a minimum percentage for the purchase of solar energy, which will go up to 0.25% by the end of 2012-2013 and further up to 3% by 2022.

Further, as per the amended Tariff Policy issued vide order in January 2016, the SERCs are required to reserve a minimum percentage for purchase of solar energy such that it reaches 8% of the total consumption of energy, excluding Hydro Power, by March 2022 or as notified by the Central Government from time to time. Ministry of Power vide its further order dated 22.07.2016 has notified the Long Term growth trajectory of Renewable Purchase Obligations (RPOs) for Non-Solar as well as Solar, uniformly for all States/Union Territories, initially for three years from 2016-17 to 2018-19.

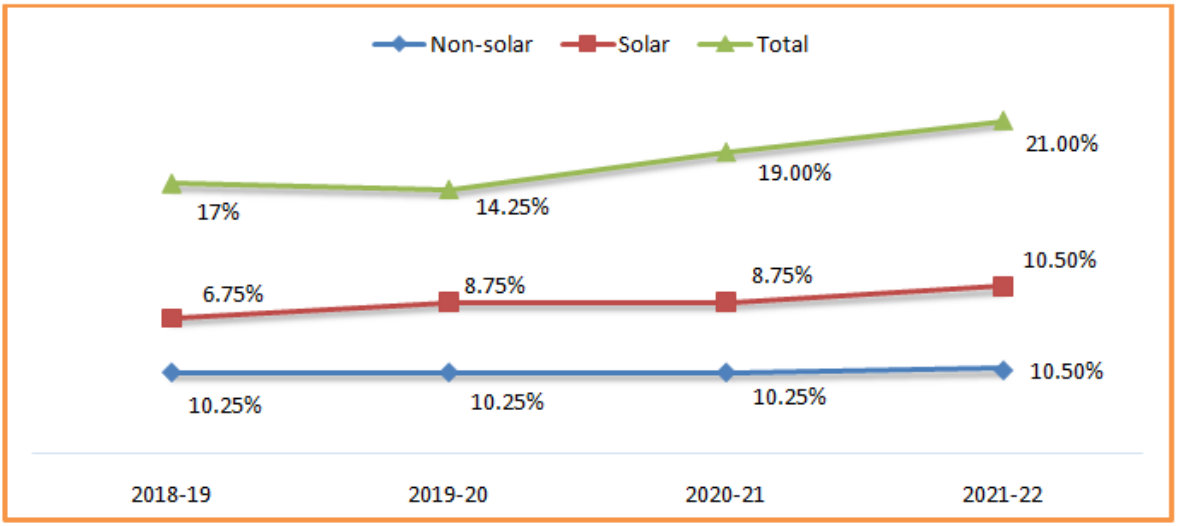

Figure 3 Year-wise Renewable Purchase Obligation (RPO) trajectory

(*Source: Ministry of Power*)

In the above Figure , the annual RPO target set by the Ministry of Power is shown, as per the RPO, in the Year 2018-19, the States to achieve the RPO targets of 17 %, which includes 10.25 % in Solar and 6.75 % in Non-Solar Category. Further, the year-wise targets up to 2029-30 are also calculated to achieve the targets of 450 GW by 2030. If the States operate in a parallel active mode, the 175 GW RE Power goals can be conveniently met by 2022 by meeting RPO requirements and installing RE capacity in the States. Figure 4 depicts India's proposed combined solar and non-solar potential beyond 2022 by state.

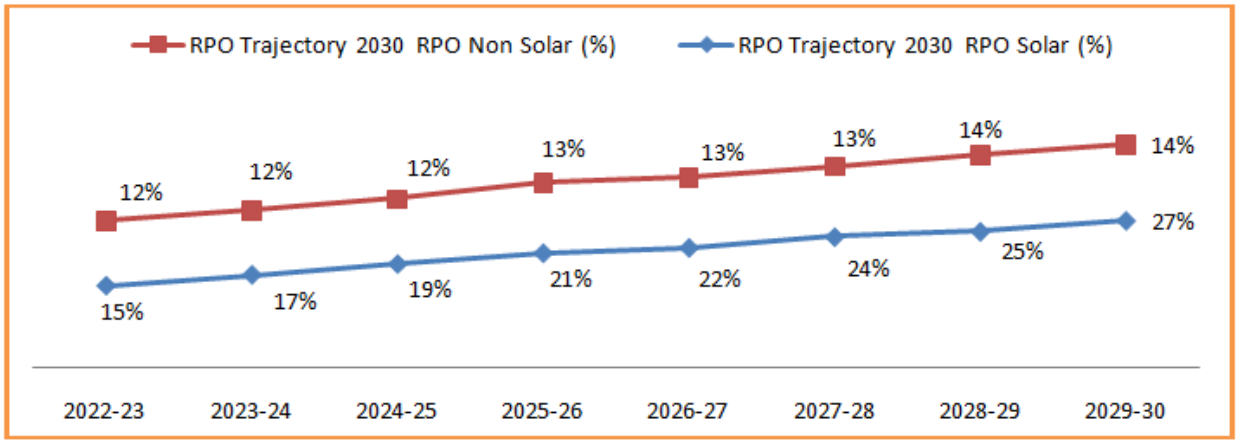

Figure 4 Solar & Non-Solar RPO trajectory(*Source: Ministry of Power*)

As per the provisions of the Electricity Act, 2003, the SERCs are required to notify RPO for their respective States in line with the aforesaid uniform RPO trajectory. Due to this RPO requirement, States are expected to come forward to enhance the capacity installation through the various schemes. The major achievement in this section has been discussed which also helps repowering the sector through various innovative models.

5. Major Achievements

A. Renewable Energy

The country's renewable energy potential from solar, wind, small hydro, and biomass is estimated to be roughly 16,36,043 MW, with a significant portion suitable for grid uses. India's power sector has traditionally relied on fossil fuels to create energy, with the majority of the coal used is generated locally. Since independence, the country has been quickly expanding its generating capacity, owing to economic growth, population growth, and fast urbanization, all of which have increased demand. As of December 2021, India's utility electrical sector had one National Grid with a total installed capacity of 393.39 GW. India is the world's third-largest producer of electricity and fourth-largest user. Despite India's lower electricity tariffs, per capita, electricity consumption is modest in comparison to many other countries.The contribution of power from renewable energy sources contributes about 38% and that of solar power is more than 12 % in the overall energy mix.

With capacity addition, grid renewable power has grown by roughly 90%, with a cumulative installed capacity of 160GW at the end of December 2022, accounting for 38% of grid renewable power installed capacity from all resources, including large hydro. Figure 5 shows the percent share of various technologies in total installed capacity, which includes 13 percent hydro and 12 percent solar. Figure 6 also shows the year-on-year increase in the share of renewable energy in terms of installed capacity compared to total installed capacity.

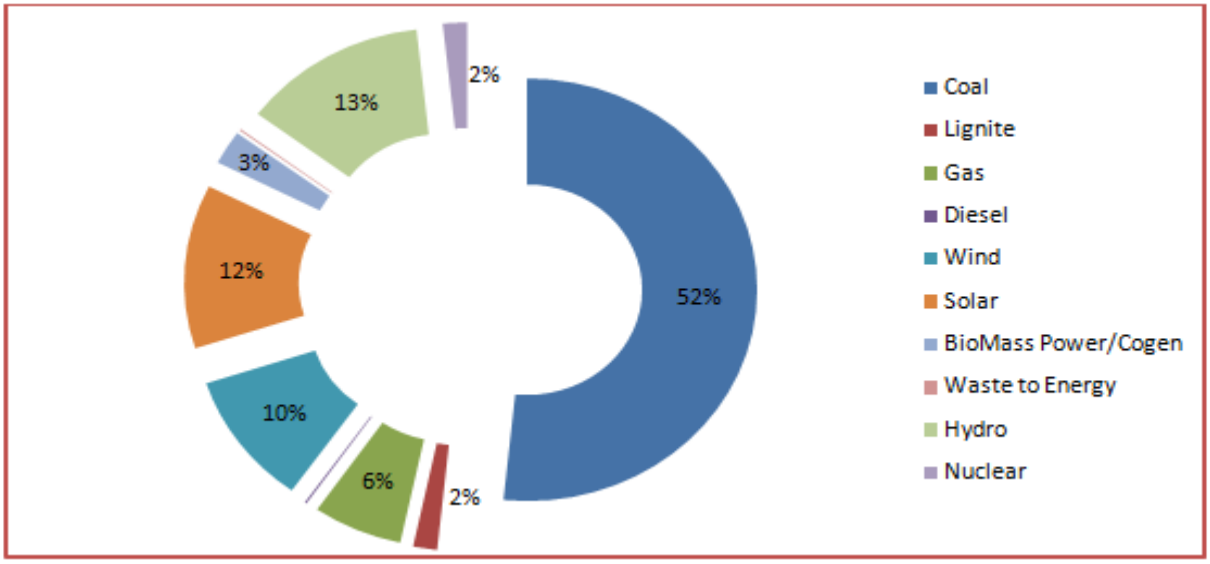

Figure 5 Installed Capacity in India for different sector
(As of 31-12-2022, Source: MNRE Website)

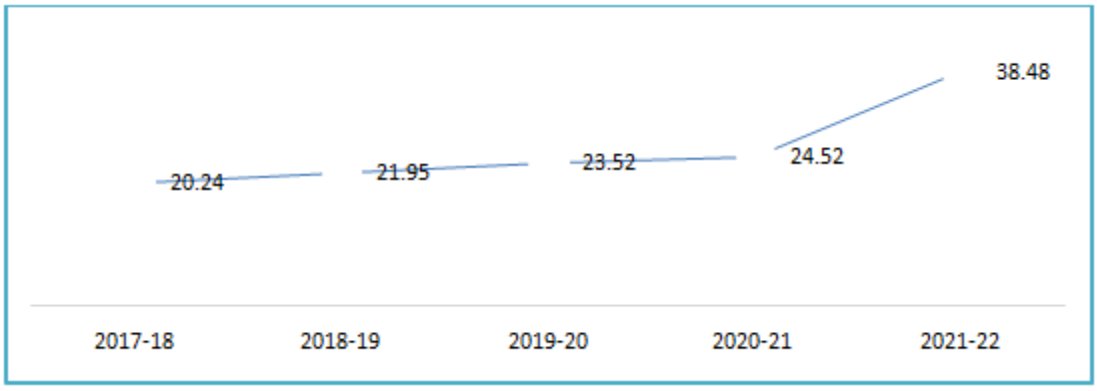

Figure 6% Share of RE in total Installed Capacity in last 5 years
(Source: MNRE Annual Reports & Website)

The key obstacles in traditional power generating, on the other hand, include decreasing coal supplies in India, difficulty obtaining imported coal, and long gestation periods for coal-based power plants. India, with its vast population and quickly expanding economy, requires access to clean, affordable, and dependable energy sources. India is located in a region with high solar insolation and large solar energy potential, with most of the nation receiving around 300 days of sunshine per year with daily solar radiation ranging from 4 to 6 kWh per square meter of surface area depending on location and time of year.

The Indian government has made renewable energy a point of faith, setting a goal of 175 GW of installed renewable capacity by 2022. Solar energy is expected to provide 1,00,000 MW of the total 1,75,000 MW. The Indian government has also been driving a strong renewable energy program aimed at ensuring energy security, energy availability, and lowering the country's carbon impact. This is following India's obligations under the 2015 Paris Agreement to reduce emissions intensity by 33 to 35 percent by 2020, compared to 2005 baseline levels, and to expand non-fossil fuel-based power to 40 percent by 2030.

The following panchamrits were stated by the Hon'ble Prime Minister in his statement at the COP26 Summit in Glasgow as an unprecedented contribution of India to climate action. First, India's non-fossil

energy capacity will reach 500 GW by 2030. Second, by 2030, India will have met 50% of its energy needs with renewable energy. Third, from now until 2030, India will reduce overall anticipated carbon emissions by one billion tonnes. Fourth, by 2030, India's economy will have reduced its carbon intensity by less than 45 percent. And, finally, by 2070, India would have achieved its Net Zero goal.

B. Growth of Solar Capacity

Solar energy is being promoted by the government through fiscal and promotional incentives such as a capital subsidy, a generation-based incentive, accelerated depreciation, viability gap funding (VGF), financing solar rooftop systems as part of a home loan, concessional custom duty, excise duty exemption, and foreign direct investment up to 100% under the automatic route, among other things. Because foreign direct investment is permissible via the automatic route in India, there is a huge possibility for foreign investment in the solar sector. Renewable energy, particularly solar energy, has been designated as a priority sector by the Reserve Bank of India (RBI). Banks will be able to lend up to Rs 150 million to renewable energy borrowers as a result of this. India has launched yet another effort to establish an International Solar Alliance (ISA).It will be a group of about 120 countries working on solar energy development and promotion. India, as the alliance's founding member, has offered to host its secretariat and has also pledged financial support.

Only 11 MW of solar capacity had been constructed before the commencement of the National Solar Mission. Solar capacity developed rapidly after the NSM and other state programs favoring solar energy generation were implemented. Total solar capacity installed of about 1 GW was added up to the 11th Plan Period and about 9 GW were added in the 12thPlan Period. Solar energy has increased at a remarkable rate in the previous ten years. The installed capacity of solar installations is depicted in Figure 7, which has increased from 1.6 GW to 48 GW. As of now in the Jan 2023, the capacity reached to 63 GW from earlier 48 GW.

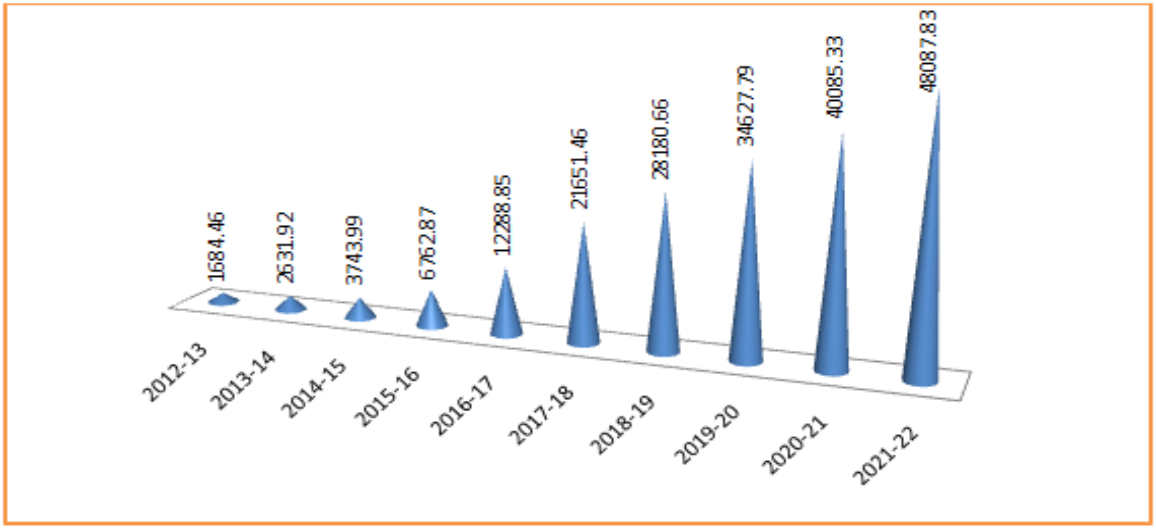

Figure 7 Cumulative Installed capacity (in MW, Source: MNRE website)

In Figure 8, the graph has been designed for the top 10 states in the installed solar capacity in the country so far, Rajasthan is on the top with a cumulative capacity of around 16 GW.

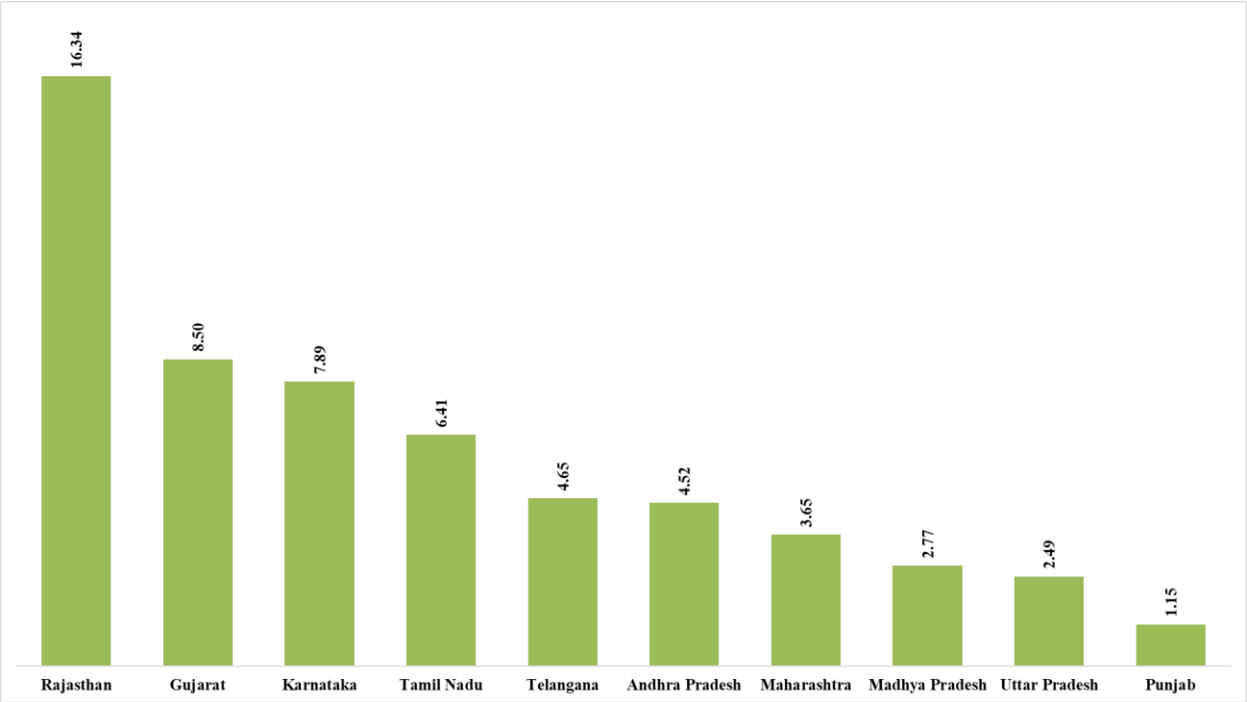

Figure 8 Top ten states in Solar Capacity (in MW, as of 31-12-2022, Source: MNRE website)

C. The trend of Solar Tariff

Location, solar irradiance in the state, availability of supportive State policy for solar, availability of land, cost of financing and business climate, willingness of DISCOMS to purchase solar electricity, power evacuation infrastructure, and other factors all influence tariff calculation. The solar projects that are being set up under the State Scheme are generally selected through a tariff-based competitive bidding and reverse auction procedure, as a result of successful bidding of solar projects under the NSM. This method of selection has resulted in a significant reduction in the solar average bid rate discovered in bidding/auctions, from Rs. 17.91 per kWh in December 2010 to around Rs.1.99 per kWh in the financial year 2020-21.Tariffs in the Indian solar market changed regularly as shown in Figures that the weighted average tariff varies from Rs. 17.91 per unit to Rs. 2.14 per unit. The declining trend of solar power tariff during the period from 2009-10 to 2021-22 is shown below in Figure 9.

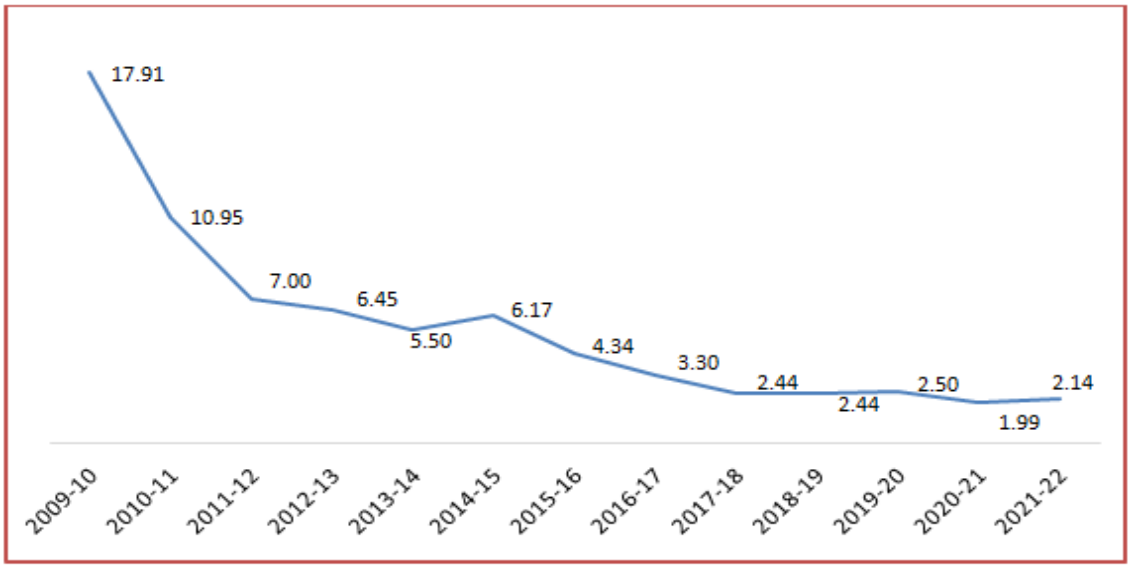

Figure 9 Year-wise lowest solar tariff (in Rs. /kWh, Source: Various Date collected from various sources/website/news and complied by author)

The recent downward trends in solar tariff may be attributed to the factors such as economies of scale, assured availability of land, and power evacuation systems under the various schemes.

6. Case Study and analysis

In this section, the tariff discovered in the solar projects set up in central as well as state-specific schemes has been analyzed for the last 5 years. Due to competitive biddings and various factors of Electricity Act and supporting policy, the capacity addition in the respective years also enhanced which ultimately give a boost in the repowering India's economy of the solar sector and over all renewable sector. Factors that led to lower tariffs and accelerated RE capacity addition is Renewable Purchase Obligation trajectory issued till 2021-22; Standard Bidding Guidelines; Electricity Act 2003, Section-6; Payment Security with Demand Aggregation; Bids by intermediary procurers (primarily SECI) on behalf of States; Inter-State Transmission (ISTS) Charges waiver till June 2025; FIT, Accelerated Depreciation, GBI; Central subsidy; Concessional Custom Duty and lower GST.

A. Tariff analysis for last five years

Calculation of tariff depends on various factors that include location, solar irradiance in the State, availability of conducive State policy for solar, availability of land, the cost of financing and business environment, the willingness of DISCOMS to purchase the solar power, power evacuation infrastructure, etc. The year-wise tariff in 2017, 2018, 2019, 2020, and 2021is as given below in Table 1.

Table 1 Tariff last five years

(Data collected from various sources/website/news and complied by author)

S.No	Biding Agency/Location	Scheme	E- Reverse Auction (Month & Year)	Capacity Offer (MW)	Highest Bid (Rs./KWh)	Lowest bid (Rs./KWh)
Tariff Discovered in the year 2017 under various Schemes/Projects						
1	RUMSL - Madhya Pradesh	State Scheme	Feb-17	750	2.979	2.97
2	NTPC - Andhra Pradesh	Bundling Scheme	Apr-17	250	3.15	3.15

S.No	Biding Agency/Location	Scheme	E- Reverse Auction (Month & Year)	Capacity Offer (MW)	Highest Bid (Rs./KWh)	Lowest bid (Rs./KWh)
3	SECI - Rajasthan-Bhadla Ph IV Solar Park	VGF Scheme	May-17	250	2.63	2.62
4	SECI - Rajasthan - Bhadla Ph III Solar Park	VGF Scheme	May-17	500	2.45	2.44
5	TANGEDCO - Tamil Nadu	State Scheme	Jul-17	1500	3.97	3.47
6	GUNL - Gujarat	State Scheme	Aug-17	500	2.67	2.65
8	SECI - Rajahthan - Bhadla Ph IV Solar Park	VGF Scheme	Dec-17	250	2.49	2.48
9	SECI - Rajahthan - Bhadla Ph III Solar Park	VGF Scheme	Dec-17	500	2.48	2.47
Tariff Discovered in the year 2018 under various Schemes/Projects						
10	SECI - Gujarat	State Scheme	Mar-18	500	3.06	2.98
11	KREDL - Karnataka-Pavagda Solar Park	State Scheme	Mar-18	550	2.93	2.91
12	MSEDCL - Maharashtra	State Scheme	May-18	1000	2.72	2.71
13	APDCL - Assam	State Scheme	Jun-18	85	3.7	3.17
14	SECI - Uttar Pradesh - Solar park	VGF Scheme	Jun-18	125	3.38	3.32
15	SECI - Andhra Pradesh -Kadapa Solar Park	VGF Scheme	Jul-18	750	2.71	2.7
16	UPNEDA - Uttar Pradesh	State Scheme	Jul-18	1000	3.55	3.48
17	SECI- Anywhere in India	ISTS -I Biding	Jul-18	2000	2.54	2.44
18	SECI - Anywhere in India	ISTS -II Biding	Jul-18	3000	2.71	2.44
19	KREDL- Karnataka - Pavagada Solar park	State Scheme	Jul-18	500	2.85	2.85
20	SECI - Odisha	State Scheme	Jul-18	200	3.2	2.79
21	NTPC - Anywhere in India	ISTS Biding	Aug-18	2000	2.6	2.59
22	GUVNL - Gujarat	State Scheme	Sep-18	500	2.45	2.44
23	KREDL - Karnataka	State Scheme	Oct-18	150	2.92	2.92
24	UPNEDA - Uttar Pradesh	State Scheme	Oct-18	500	3.23	3.13
25	SECI -Floating in Uttar Pradesh	State Scheme	Nov-18	150	3.29	3.29

S.No	Biding Agency/Location	Scheme	E- Reverse Auction (Month & Year)	Capacity Offer (MW)	Highest Bid (Rs./KWh)	Lowest bid (Rs./KWh)
26	UPNEDA - Uttar Pradesh	State Scheme	Dec-18	550	3.08	3.02
Tariff Discovered in the year 2019 under various Schemes/Projects						
27	GUVNL - Gujarat	State Scheme	Feb-19	500	2.68	2.55
28	MSEDCL -Maharashtra	State Scheme	Feb-19	1000	2.75	2.74
29	GUVNL - Gujarat	State Scheme	Feb-19	700	2.89	2.84
30	SECI - Anywhere in India	ISTS - III Biding	Feb-19	1200	2.61	2.55
31	SECI - Rajasthan Non-Solar Park	State Scheme	Mar-19	750	2.49	2.48
32	SECI - Dondaicha Solar Park Maharashtra	State Scheme	May-19	250	2.91	2.87
33	GUVNL - Gujarat - Raghanesda Solar Park	State Scheme	May-19	500	2.7	2.65
34	GUVNL - Gujarat	State Scheme GUVNL Ph V	May-19	250	2.75	2.75
35	SECI- Anywhere in India	ISTS-IV Biding	Jun-19	1200	2.55	2.54
36	UPNEDA - Uttar Pradesh	State Scheme	Jun-19	500	3.05	3.02
37	SECI- Rajasthan	State Scheme Tranche II	Jun-19	750	2.5	2.5
38	SECI - Anywhere in India	ISTS-V Biding	Aug-19	1200	2.65	2.53
39	HPPC - Haryana	State Scheme	Aug-19	300	2.99	2.82
40	SECI - Anywhere in India	ISTS-VI Biding	Oct-19	1200	2.72	2.71
41	GUVNL - Gujarat	State Scheme GUVNL Ph VI	Oct-19	200	2.65	2.65
42	GUVNL - Gujarat	State Scheme GUVNL Ph VII	Oct-19	750	2.75	2.75
43	MSEDCL -Maharashtra	State Scheme MSEDCL Ph IV	Dec-19	500	2.9	2.89
Tariff Discovered in the year 2020 under various Schemes/Projects						
44	UPNEDA - Uttar Pradesh	State Scheme	Jan-20	500	3.18	3.17
45	SECI - Anywhere in India	ISTS-VIII Biding	Feb-20	1200	2.51	2.5
46	GUVNL - Gujarat	State Scheme GUVNL Ph VIII	Mar-20	750	2.64	2.61
47	MSEDCL -Maharashtra	State Scheme MSEDCL Ph V	Mar-20	500	2.9	2.9

S.No	Biding Agency/Location	Scheme	E- Reverse Auction (Month & Year)	Capacity Offer (MW)	Highest Bid (Rs./KWh)	Lowest bid (Rs./KWh)
48	MSEDCL -Maharashtra	State Scheme MSEDCL Saur Krishi Vahini	Mar-20	1350	3.3	3.28
49	NHPC - Anywhere in India	ISTS Biding	Apr-20	2000	2.61	2.55
50	SECI - Anywhere in India	ISTS-IX Biding	Jun-20	2000	2.38	2.36
51	GUVNL - Gujarat	State Scheme GUVNL Ph IX	Aug-20	700	2.81	2.78
52	GUVNL - Gujarat	State Scheme GUVNL Ph X	Oct-20	100	2.73	2.73
53	KSEB - Kerala	State Scheme	Nov-20	200	2.97	2.97
54	SECI - Rajasthan	State Scheme Tranche III	Nov-20	1070	2.01	2
55	ISTS- Hybrid Anywhere in India	ISTS-Hybrid Biding Tr III	Dec-20	1200	2.42	2.41
56	GUVNL - Gujarat	State Scheme GUVNL Ph XI	Dec-20	500	1.99	1.99
Tariff Discovered in the year 2021 under various Schemes/Projects						
57	GUVNL - Gujarat	State Scheme GUVNL Ph XII	Mar-21	500	2.21	2.2
58	NTPC- Rajasthan	Nokh Solar Park	Mar-21	190	2.25	2.25
59	UPNEDA - Uttar Pradesh Solar Park	State Scheme	Mar-21	200	2.69	2.68
60	MSEDCL - Maharashtra	State Scheme - Hybrid	Jul-21	500	2.62	2.62
61	MSEDCL - Maharashtra	State Scheme MSEDCL Ph V	Jul-21	500	2.43	2.43
62	RUMSL - Madhya Pradesh	State Scheme	Jul-21	550	2.45	2.44
63	RUMSL - Madhya Pradesh	State Scheme	Jul-21	450	2.33	2.35
64	RUMSL - Madhya Pradesh	State Scheme	Aug-21	500	2.15	2.14
65	BREDA - Bihar	State Scheme	Aug-21	250	3.12	3.11
66	SECI - Rajasthan	State Scheme Tranche IV	Dec-21	1785	2.18	2.17

B. Year-wise capacity addition in last five years

Solar energy is projected to provide the bulk of new green energy. Since India has a huge amount of solar irradiance, it can power a large portion of the world, making solar energy an appealing investment opportunity for both developers and financiers. The government has also launched several other initiatives

and projects to encourage investment in the industry. Due to this support and low tariff in these years the capacity addition also enhance as compared to the previous 10 years.

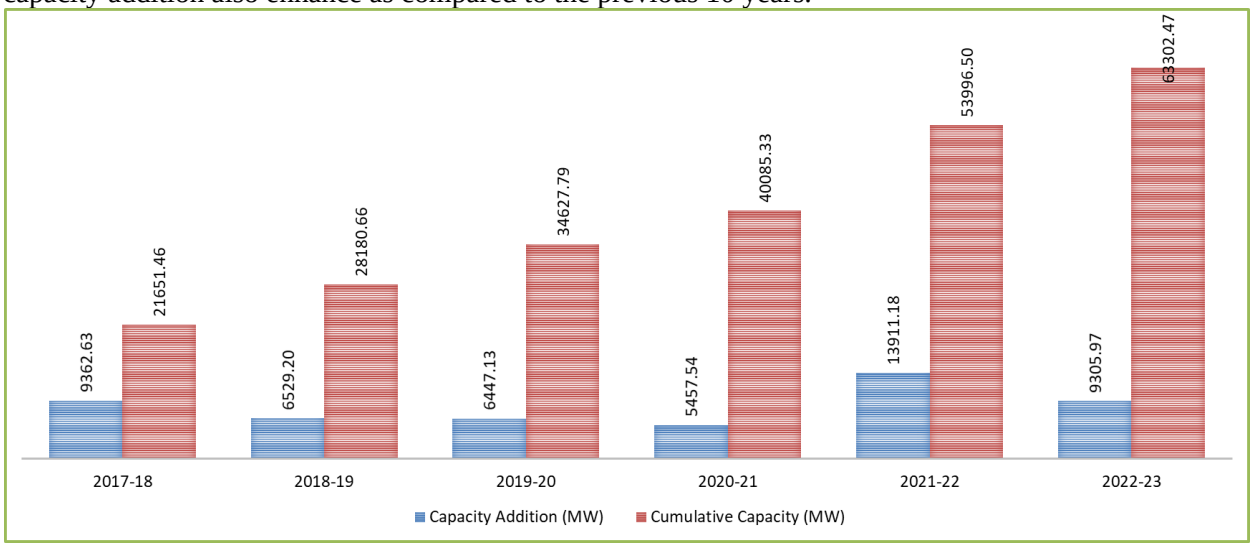

Figure 10 Capacity addition in previous years (in MW, as of 31-12-2022 Source: Date collected from various sources/website/news and complied by author)

From Figure 10 it is very clear that the capacity added in a particular year have an effect of tariff derived in various biddings under the various central and state scheme. In the year 2017-18, a capacity of around 9.3 GW was added as compared to 5.5 GW in the previous year of 2016-17. In the recent year of 2020-21 and 2021-22, the capacity of around 5.4 GW & 8.0 GW was added respectively. Most of these plants built in the latter part of the 2000-2010 decade and early 2010s are occupying regions of high solar potential in the country. Also, these plants are built with technologies available then but have been rendered outdated and inefficient in light of the ever-evolving technological options. With time, the efficiency of solar plants declines to owe to various reasons- environmental factors, sometimes bad initial design decisions, phasing out of key components like inverters, and inherent material characteristics of solar modules[7]. Over the last decade, solar PV technology and the key components like inverters and transformers have made substantial progress and these rapid advancements have not only lowered the capital costs but also the cost of maintenance. Thus repowering of older and/or nonperforming plants with cheaper and more efficient technology options presents itself as an immediate and logical solution. The primary aim is to maximize the productivity of a commercial solar power plant and to increase its longevity, both of which present a strong incentive to the PV plant developers and component manufacturers [11][12].

7. Future Scope and way forward

To achieve the enhanced capacity and to repower the various project through the schemes/program of government, several new Schemes are taken by the various level. Few of them have been studied and the analyses take a view on the future capacity addition plan.

Large Scale Solar Parks

The concept of solar parks has indeed emerged as a powerful tool for the rapid development of solar power projects in India. Assured availability of land and transmission infrastructure are the major benefits of a solar park. The recent downward trends in solar tariff may be attributed to the factors like economies of scale, assured availability of land, and power evacuation systems under the Solar Park Scheme. The capacity of the Solar Park Scheme approved by the Government of India is 40 GW, out of which around 33 GW has been approved in 14 States for setting up of 43 Solar Parks of different capacities. These parks

are at different stages of development. The list of these parks is shown in the table given below. Out of 43 parks, around 37 parks are being developed by Government entities and 6 Solar Parks by Private Entities including JVC of Private & Government

Benefit of ISTS

For the sixth time, the CERC changed the law governing the division of ISTS charges and expenses. Solar and wind energy producers benefited from this legislation. The amendment stated that there will be no transmission charges or damages for solar and wind energy generation using the ISTS network. This will be valid for 25 years following the COD of the plant. This Amendment will aid in the installation of renewable energy in the country since most developers will aim to meet the designated capacity within the time frame (period). This has now been extended to June 20, 2025. To meet the aim of 175 GW, MNRE formed a committee to identify potential wind and solar energy zones across the country. The Committee members consisted of MNRE, CEA, CTU/PGCIL, SECI, and invited NISE and NIWE.

Green Energy Corridors

The Committee identified 66.5 GW of Renewable Energy Zones (REZ) across 7 states (Tamil Nadu, Andhra Pradesh, Karnataka, Gujarat, Maharashtra, Rajasthan, and Madhya Pradesh), with 50 GW of solar and 16.5 GW of wind, and created a complete transmission plan combining these razes.

Scheme for Farmers

In the 2018-19 Budgets, the Pradhan Mantri Kisan Urja Suraksha Evam Utthaan Mahaabhiyan (KUSUM) solar pump distribution system was announced to offer farmers respite from high-cost diesel-powered water pumps and unreliable power supply. Around 1.75 million solar pumps will be deployed in regions where the grid is not available. The Centre intends to subsidize 30% of the bill, while the state would do the same by granting a loan for that amount.

The Scheme's goals are to provide farmers with reliable daytime solar power, increase their income by planting renewable energy plants on their barren land, provide farmers with an additional source of income by selling surplus power, conserve water, reduce carbon emissions, and reduce the burden of subsidies on the agriculture sector.

Way Forward of Repowering

While the past decade has not seen much in solar repowering, the concept has gained momentum in more mature sectors like wind and hydropower. Several business cases merit repowering and retrofitting such as restoring or improving system performance or extending them past their useful lifetime of 20 – 25 years. Repowering of solar systems allows for the production of more electricity while utilizing existing land, interconnection points, and other infrastructure, leading to lower LCOE. From 2020 - to 2030, the potential market for solar repowering sites that have reached 20 years of operation could reach up to 67 GWdc cumulatively. This could be a major boon for asset owners, O&M providers, and solar component manufacturers, to list a few.

8. Conclusion

In this paper, we investigate and interpret the government's numerous recent changes. This hope and desire for the future is mirrored in and included by the National Solar Mission's development (NSM). In this essay, we will examine India's energy security concerns, the NSM's incentive structure for meeting those 2030 targets, and the primary measures for increasing cumulative installed capacity. Solar pricing and capacity increases over the last five years are examined here, project by project.

- The research concluded that the projects established during these years took advantage of lower tariffs and increased the nation's capacity addition as a result of emerging technological advancements and policy factors. Through time and new technologies, these also help boost the overall output of solar projects.

- Furthermore, the study translates the current capacity building and tariff journeys into the requirement for repowering, especially for older facilities situated in areas with abundant solar potential and higher rates.
- Current strategies for the development of renewable energy are also analysed in this study, along with capacity addition, tariff trends in different technologies, and specific achievements that will help to redefine policy for the country's RE sector.
- Findings from the study suggest that the country can achieve its low-carbon target and economic gains through a combination of endogenous technical progress, low tariffs, and widespread adaptation of renewables.

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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