DISCUSSION PAPER

ROADMAP TO INDIA'S 2030 DECARBONIZATION TARGET

Ajay Shankar • A K Saxena • Taruna Idnani

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THE ENERGY AND RESOURCES INSTITUTE
Creating Innovative Solutions for a Sustainable Future

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For more information and suggestions: Contact Authors

Mr Ajay Shankar
Email: ajay.shankar@teri.res.in

Mr A K Saxena
Email: ak.saxena@teri.res.in

Ms Taruna Idnani
Email: taruna.idnani@teri.res.in

Editorial and design

Abhas Mukherjee

Sudeep Pawar

The Energy and Resources Institute (TERI)
Darbari Seth Block, IHC Complex, Lodhi Road, New Delhi 110 003, India
Tel.: +91 11 2468 2100 or 2468 2111 | Fax: +91 11 2468 2144 or 2468 2145
Email: mailbox@teri.res.in | Web: www.teriin.org

FROM THE DESK OF DIRECTOR GENERAL

In India, there is the will to move away from fossil fuels as much and as early as possible. This is clear from the announcements made by Prime Minister, Shri Narendra Modi, at COP26 in Glasgow in November 2021. Today, greenhouse gas emissions have become central to any discussion on energy system choices. Technological progress has brought to the fore a growing number of technologies that can be adopted at a commercial scale. Furthermore, there is urgent need to eliminate the dependence on fossil fuels.

We are pitching for energy transition in international forums and displaying that intent in our domestic policies. India has aimed high, decarbonizing 50% of its energy by 2030. Innovative policies to avoid dependency on fossil fuels and ensure long-term sustainability are required. In addition to this, investment in R&D has to be scaled up. Domestic manufacturing also needs appropriate incentives to become Aatma Nirbhar Bharat.

Energy is at the heart of economic development and perhaps no country is more challenged than India as it strives to create a better life for its population of almost 1.4 billion people. The Discussion Paper makes a constructive contribution to the public debate on the range of issues, which need to be addressed for the achievement of the highly ambitious 2030 goals set by the Prime Minister.

We look forward to engaging closely with multiple stakeholders in the coming years and working towards achieving India's energy ambitions that require an unprecedented scale of transformation along a pathway never followed by other countries of rapidly increasing energy consumption and decarbonizing energy at the same time.

Dr Vibha Dhawan
Director General
The Energy and Resources Institute
(TERI)

PREFACE

The electricity sector in India has undergone rapid transformation in recent decades. The country has successfully electrified all households. There is adequate power generating capacity whose optimal utilization is facilitated by an integrated national grid. The per capita electricity consumption in India stands at 1208 kWh up from 559 kWh in 2001. This would increase at least three times as India's economic development gathers greater momentum and living standards of its citizens rise in the coming decades. Reliable, affordable, quality, round-the-clock power supply to all is the goal to be achieved in the next few years.

India is now committed to the energy transition of decarbonization and achieving a state of net zero emission. India has made remarkable progress in recent years. It now has the 5th largest solar and 4th largest wind power capacity in the world, with their total capacity being over 100 GW. Though the share of renewables in total electricity generation is now over 10%, more than 70% of the country's electricity was still generated by fossil fuels in 2021.[1]

At COP26, India announced the highly ambitious goal of decarbonizing energy to 50% and achieving 500 GW of fossil fuel free generating capacity by 2030. This was a very large increase above its Paris commitments, far more than expected.

This paper examines the challenges in achieving the ambitious 2030 targets and discusses feasible pathways for achieving these.

[1] Details available at https://cea.nic.in/general-review-report/?lang=en

ACKNOWLEDGEMENTS

We would like to express gratitude to Bloomberg Philanthropies for their continued support to TERI's ongoing work on energy transitions. TERI's global partnership with the We Mean Business Coalition, aimed to garner business voices in support of power policy reforms and strengthened advocacy for accelerating corporate climate actions in India, have greatly benefitted putting together this Discussion Paper.

We acknowledge and appreciate the constant support, guidance and encouragement from the TERI team particularly Mr Robin Mazumdar and Mr Girish Sethi, who have been instrumental in providing inputs, valuable suggestions, and thoughtful insights. We are grateful to the editorial and design team at TERI for their contribution.

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LIST OF ABBREVIATIONS AND SYMBOLS

ACC	Advanced Chemistry Cells
AD	Accelerated Depreciation
BCS	Baseline Capacity Scenario
BESS	Battery Energy Storage Systems
CAGR	Compound Annual Growth Rate
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
CSP	Concentrated Solar Power
C&I	Commercial and Industrial
DISCOM	Distribution Company
DPR	Detailed Project Report
DSM	Demand Side Management
GBI	Generation-based Incentives
GSECL	Gujarat State Electricity Corporation Limited
GUVNL	Gujarat Urja Vikas Nigam Limited
GW	Giga Watt
GWEC	Global Wind Energy Council
GWh	Giga Watt-hour
HNI	High Net Worth Individual
HRES	High Renewable Energy Scenario
IEA	International Energy Agency
IISD	International Institute for Sustainable Development
IRENA	The International Renewable Energy Agency
IPP	Independent Power Producer
JNNSM	Jawaharlal Nehru National Solar Mission
KPCL	Karnataka Power Corporation Limited
kW	kilo Watt
kWh	kilo-watt-hour
LBNL	Lawrence Berkeley National Laboratory
LCOE	Levelized Cost of Electricity
LCOS	Levelized Cost of Storage
MENA	Middle East and North Africa
MoP	Ministry of Power
MNRE	Ministry of New and Renewable Energy
MSEDCL	Maharashtra State Electricity Distribution Company Limited

MU	million unit
MW	megawatt
MWh	megawatt hour
NASDAQ	National Association of Securities Dealers Automated Quotations
NBFC	Non-Banking Financial Company
NBR	The National Bureau of Asian Research
NLDC	National Load Dispatch Centre
NVVN	NTPC Vidyut Vyapar Nigam Limited
PFC	Power Finance Corporation
PHS	Pumped Hydro Storage
PLF	Plant Load Factor
PLI	Production Linked Incentives
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan
POSOCO	Power System Operation Corporation
PPA	Power Purchase Agreement
PSP	Pumped Storage Plants
PSPCL	Punjab State Power Corporation Limited
REMCL	Railway Energy Management Company Limited
RE	Renewable Energy
RUMSL	Rewa Ultra Mega Solar Limited
₹	Indian Rupee Symbol
SERC	State Electricity Regulatory Commission
SECI	Solar Energy Corporation of India
STPS	Super Thermal Power Station
TERI	The Energy and Resources Institute
TOU	Time of Use
TPS	Thermal Power Station
VGF	Viability Gap Funding
VRE	Variable Renewable Energy

EXECUTIVE SUMMARY

The highly ambitious goals announced at COP26, Glasgow of having 500 GW of non-fossil fuel capacity and meeting 50% of energy requirements from renewables by 2030 are achievable. However, this would be very challenging. It may well turn out to be a lower cost pathway for meeting growing energy demand and thus, serving the socio-economic imperatives of a developing country.

The pace of installation of renewables, which has been high, would have to be accelerated very rapidly. Larger shares of variable renewable energy (VRE) need greater flexibility and resilience in grid management, creation of large-scale storage would be essential for providing this resilience and also for fully utilizing the huge increase in solar power generation. Fortunately, solar power with storage has now become cheaper than electricity from new thermal power plants.

Achieving India's 2030 Targets:

1. Increase share of decentralized kW range solar power by introducing feed-in-tariff

- ◊ Feed-in-tariff in kW range for solar power would lead to a surge in decentralized capacity addition in rural India through private investment.
- ◊ The feed-in-tariff has to be well above the price bids received for large solar projects as there are higher unit costs in dispersed small installations as well as greater risks.
- ◊ This would reduce distribution company (DISCOM) costs, provide better quality power in villages, and increase farmer's incomes.

2. Increase momentum of wind power growth

- ◊ Reintroduce banking. Banking makes it worthwhile for industrial consumers to set-up captive wind farms.
- ◊ Incentivize repowering of older wind projects at high-resource sites.
- ◊ Commence off-shore wind power development.

3. Introduce Time-of-use (TOU) tariffs

- ◊ Have large difference between peak and off-peak consumer tariffs to incentivize flattening of the demand curve.
- ◊ Distribution companies (DISCOMs) to undertake separate peaking power procurement.
- ◊ DISCOMS to give choice to all consumers, starting with Commercial and Industrial (C&I) consumers to buy carbon free electricity.

4. Undertake detailed system studies and planning on a continuing basis to appropriately assess power system security and stability with high share of VRE in the generation mix.

5. Implement storage projects

- ◊ **Pumped storage plants (PSP):** Prepare Detailed Project Reports (DPRs) of feasible sites in order of priority and include in infrastructure pipeline. Begin execution with long-term debt from the new development financial institution, NBFID (The National Bank for Financing Infrastructure and Development).
- ◊ **Solar thermal with storage:** Invite tariff bids for development of projects at identified sites, with land, and provide solar radiation data. Create a competitive industry structure as in solar power development.

- ◊ **Battery energy storage systems (BESS):** Scale up competitive procurement of BESS – a mature technology with declining costs.
- ◊ **Hydrogen energy storage technologies:** Put up pilot projects using hydrogen – an emerging long-term energy storage option – to meet seasonal demand peaks.

6. Become *Aatma Nirbha*r. Become a globally competitive renewable energy (RE) manufacturing hub

- ◊ Scale-up domestic production to large volumes to devise benefit of economies of scale.
- ◊ Expand Production linked incentive (PLI) scheme to cover full value chain of solar panels, reversible turbines for pumped storage, mirrors for solar thermal, and green hydrogen.
- ◊ Use government procurement for RE manufacturing in India.
- ◊ Achieve energy security.

1. INDIA'S NEW 2030 DECARBONIZATION TARGETS

India has continued to demonstrate climate leadership and a firm commitment for achieving the clean energy transition. At COP26 in Glasgow, the Prime Minister of India announced the five nectar elements or *Panchamrit*—The Gift of Five Elixirs.[2] The four targets to be achieved by the year 2030 included the following:

1. *India will reach its non-fossil energy capacity to 500 GW by 2030.*
2. *India will meet 50% of its energy requirements from renewable energy by 2030.*
3. *India will reduce the total projected carbon emissions by one billion tonnes from now onwards till 2030.*
4. *By 2030, India will reduce the carbon intensity of its economy by less than 45%.*

The fifth target announced at COP26 is India's commitment to net-zero by 2070.

India's Nationally Determined Contributions (NDCs) were announced at COP21 in 2015 in Paris. The year 2015 marked a seminal moment in the low-carbon transition of India's power sector when it committed to increase its non–fossil fuel power-generation capacity to 40% by 2030 and installing 175 gigawatt (GW) of renewable capacity by 2022.

India's total non-fossil fuel capacity, including nuclear, stood at 165 GW in April 2022. It represents 41% of total installed electricity capacity of 401GW[3] (MNRE, 2022). The target of having 40% of non-fossil fuel power capacity by 2030 is already achieved. India had also achieved emission reduction of 28% over 2005 levels and is set to exceed its NDC commitments well before 2030.[4]

India's climate ambition has increased substantially from Paris (COP21) to Glasgow (COP26). A snapshot of India's commitments at COP21 and COP26 is given in Figure 1.

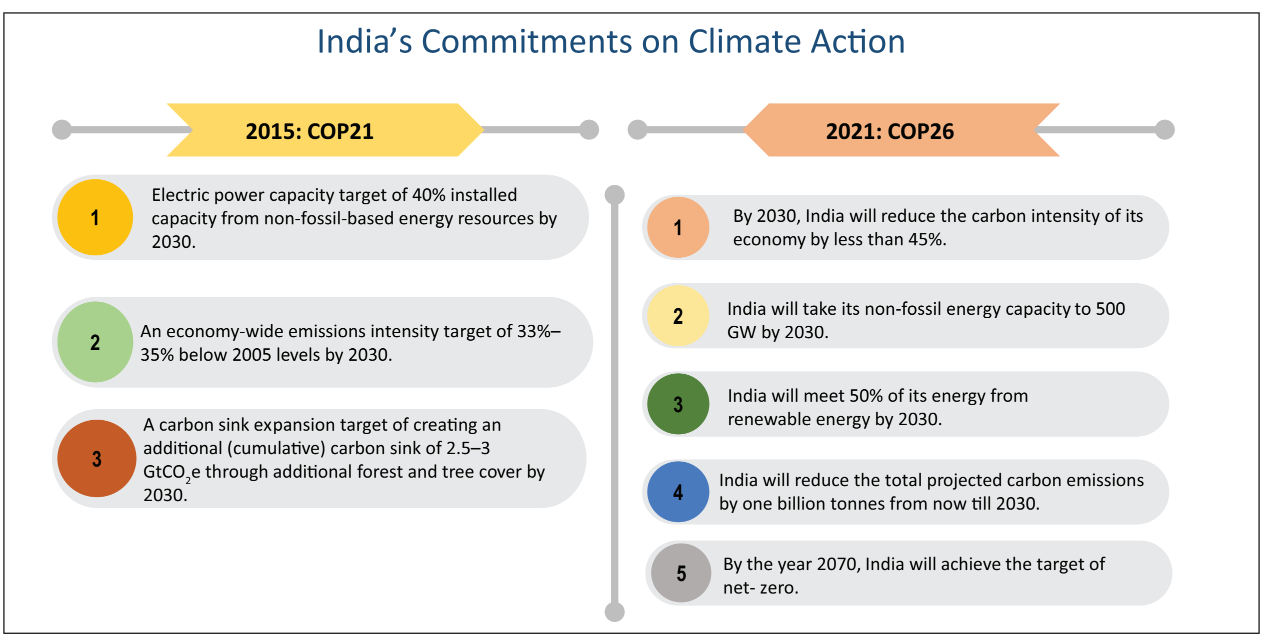

Figure 1: India's commitment to climate ambition at COP21, Paris and COP26, Glasgow

[2] Details available at https://pib.gov.in/PressReleasePage.aspx?PRID=1768712

[3] Details available at https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1785808

[4] Details available at https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1738317

Achieving these ambitious commitments would need deep decarbonization efforts on a gigantic scale. In order to reach India's new 2030 targets, the country would require the installation of an additional 340 GW of non-fossil fuel energy capacity in this decade. India has witnessed the fastest growth rate in renewable energy capacity addition amongst all large major economies in the last seven years.[5] It will need to upscale capacity addition of renewables significantly at an average of approximately 40–43 GW of non-fossil fuel energy capacity per year.

There would be new operational challenges, which would arise as the share of renewables in electricity generation would increase rapidly from their present share of around 10%. This is due to the very nature of renewables where electricity is generated only when the sun shines, and the wind blows. This is variable and intermittent. It needs to be fully utilized. At the same time, the grid has to be stable with supply meeting demand on a continuing real time basis. There is growing understanding globally on how to run power systems efficiently keeping in mind the security and stability of the grid, integrated resource planning of the power with higher share of renewables. India should be able to use this and adapt it to handle the transition smoothly. It would need to undertake system planning with simulation studies on a continuing basis to assess the emerging need for ancillary services and storage.

According to projections of the Central Electricity Authority (CEA), Glasgow announcements of achieving 500 GW of non-fossil fuel energy could be achieved by approximately combining 435 GW from wind, solar and other RE sources; 61 GW from large hydro and 19 GW from nuclear energy capacity (CEA, 2020).

Achieving 500 GW of non-fossil fuel capacity and 50% generation from renewables would not only be feasible but in all probability affordable as well. But achieving these targets would be very challenging. The major challenge would be to increase flexibility of generation sources and deployment of large-scale energy storage capacities. These are needed to ensure smooth functioning of the grid, completely utilize RE capacity, and at the same time meet demand fully on a 24X7 basis with high degree of reliability. Greater focus on increasing decentralized generation from renewable sources would facilitate this transition and at the same time become cost effective in the long run.

The following sections of this paper examine the growth trajectory of renewables in India, the policy and programme initiatives as well as enablers that would be needed for achieving India's new and ambitious 2030 targets announced at COP26.

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[5] PIB (2021). Details available at https://pib.gov.in/PressReleseDetail.aspx?PRID=1785808

2. GROWTH OF RENEWABLES

Renewable energy capacity in India is now over 100 GW. It has grown rapidly in the last decade. This growth has given confidence to all stakeholders. It has been achieved by smart policies. Capacities have been created by private investors and developers in a competitive industry structure. India has been able to take full advantage of the global decline in costs of renewables, which has been phenomenal. Figure 2 shows the growth of RE capacity in the country over the last two decades.

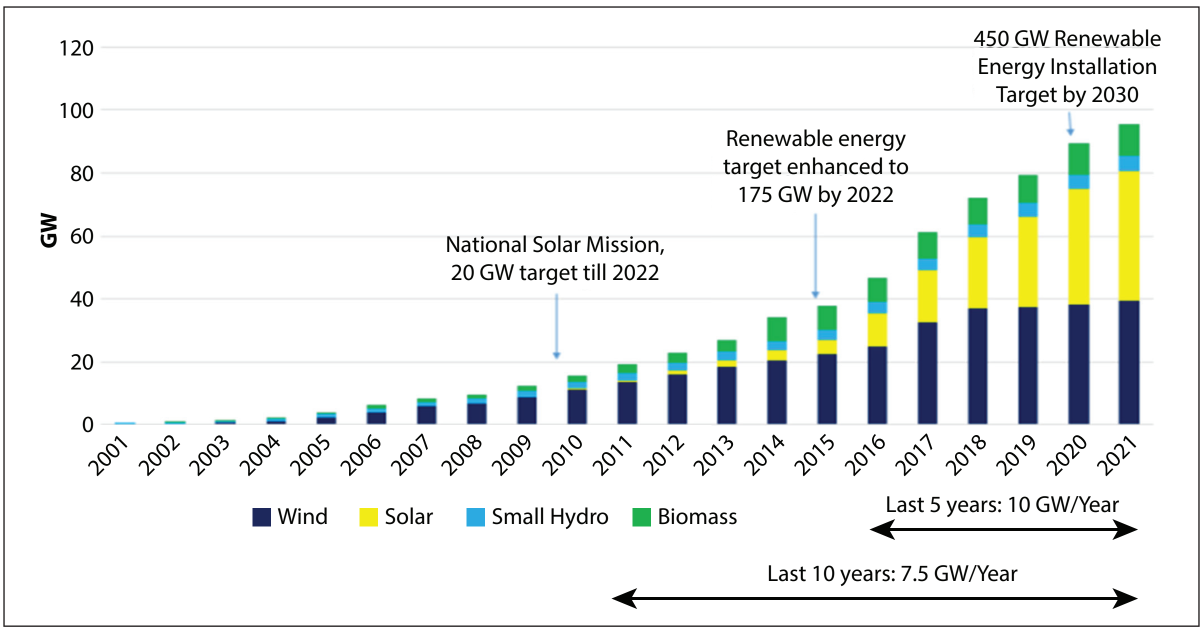

Figure 2: Growth trajectory of renewables in India

Source: TERI's analysis

After the start of the National Solar Mission in 2010, growth has been accelerating especially after India's NDC commitments at Paris. The renewable capacity in India has grown at a CAGR of 10% in the last five years and over 20% during the last decade.

Renewable energy generation costs have fallen sharply over the past decade in the world. This has been the result of remarkable progress in manufacturing technologies, economies of scale, competitive supply chains and greater developer experience (IRENA, 2020). Solar and wind power have transitioned from being an expensive niche, to becoming the cheapest source of electricity when the sun shines or the wind blows. Figure 3 depicts the global decline in levelized costs of electricity (LCOE) from utility scale solar and wind power technologies from 2009 to 2019. There is now a clear commercial case in favour of renewables. For the first time, there is the fortunate convergence between what is the least cost option for meeting growing electricity needs and what is best for rapid decarbonization of the electricity system.

In this section, we examine the trajectory of this remarkable growth of renewables and the policies that were adopted and which made this growth possible.

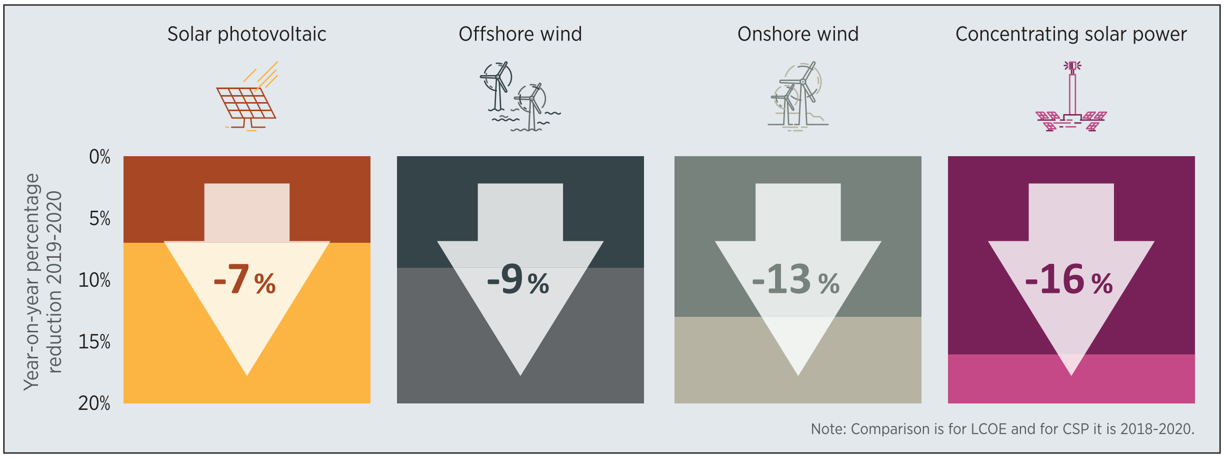

Figure 3: Global weighted-average levelized cost of electricity (LCOE) from newly commissioned, utility scale solar and wind power technologies from 2009 to 2019

2.1 Wind Power

Indian wind industry has achieved remarkable growth through private sector investments from as early as the mid-1990s. This growth was triggered by incentives, fiscal as well as non-fiscal. India was also able to develop a globally competitive wind power manufacturing industry, which was facilitated by the growing domestic market. Table 1 provides the growth of wind power capacity in the country during the last decade.

Table 1: Installed capacity of grid-connected wind power capacity in India

Sl. No.	Period	Wind Capacity addition during period (MW)	Cumulative Wind Capacity (MW)
1	Up to 2010	1,565	11,807
2	2010–11	2,349	14,156
3	2011–12	3,197	17,353
4	2012–13	1,699	19,052
5	2013–14	2,090	21,141
6	2014–15	2,298	23,439
7	2015–16	1,649	25,088
8	2016–17	7,192	32,280
9	2017–18	1,766	34,046
10	2018–19	1,580	35,626
11	2019–20	2,043	37,669
12	2020–21	1,578	39,247
13	2021–22	1,111	40,358

Source: MNRE

The initial fiscal incentive of accelerated depreciation provided by the central government and the provision of the banking mechanism by the state governments made private investment in captive wind farms attractive in the states where there was good wind potential. These two mechanisms propelled the growth of wind sector in the country. Wind power tariffs declined as the investments scaled up. Figure 4 depicts the declining trends of wind power tariffs from 2011 to 2022.

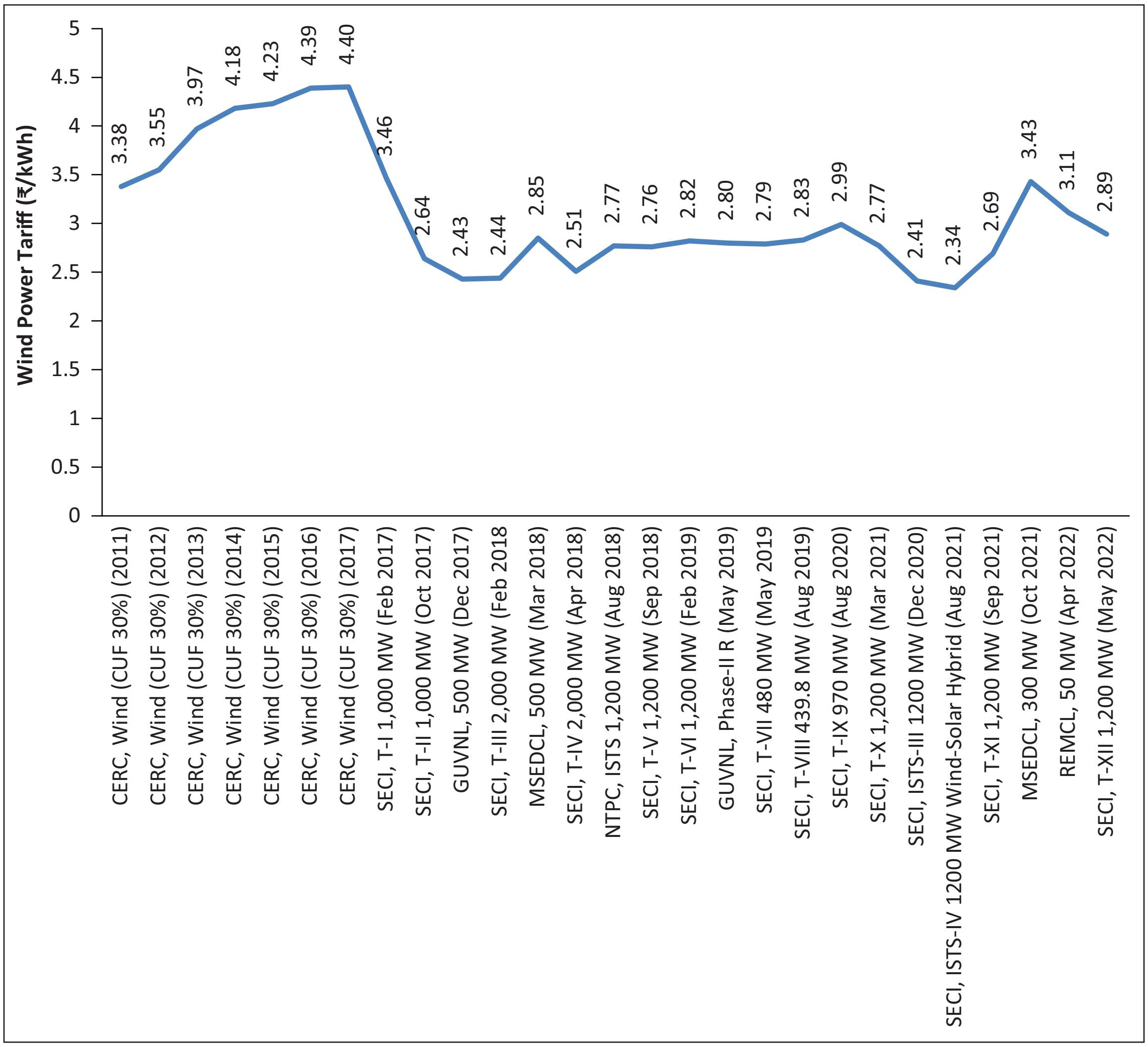

Figure 4: Wind power tariff trend from 2011 to 2022

Source: CERC and Mercom India

2.1.1 Accelerated Depreciation

Accelerated depreciation was introduced as a tax saving mechanism in 1994 for wind energy projects with a depreciation rate of 100%. It did not provide direct financial assistance to wind power projects but gave huge post-tax benefits to the investor. The mechanism attracted investments from high net worth individuals (HNIs), corporations, and small- and medium-sized enterprises (Chaurasiya, *et al*., 2019). Private sector investment in captive wind farms began to surge. These investors harnessed wind energy to meet their captive demand and also used it as an instrument to offset the profits from their other businesses and paid less tax. Private investments created the domestic market for wind turbines, which in turn led to the growth of the manufacturing industry and other allied services. During the initial years, wind power plants were set up primarily for captive consumption. During 2004 to 2014, the wind sector grew at the phenomenal compounded annual growth rate of 24%.

The provision of accelerated depreciation (AD) was withdrawn in 2012 as it was felt that this gave excessive benefits. After a two-year gap, AD was reinstated in 2014.[6] In April 2017, the accelerated depreciation rate was lowered to 40%.[7] Various studies have highlighted how the AD benefits provided the impetus for investment in the high-capital-cost wind energy sector, and withdrawal of the benefit correlates with a fall in capacity additions (IISD, 2015).

2.1.2 Generation-based Incentives to Tariff Bidding

In 2009, the Ministry of New and Renewable Energy (MNRE), Government of India, announced the generation-based incentive (GBI) scheme in parallel to the AD scheme for the period 2009–2012. This scheme was introduced to facilitate the entry of large independent power producers, including foreign direct investors to the wind power sector. Being IPPs and not captive power plants they were not in a position to avail the AD benefit. GBI policy provided an incentive of payment of ₹0.50 per unit of electricity sold to the DISCOM through the grid, over and above the tariff fixed for the power for a period of not less than four years and a maximum period of 10 years.

After it expired in 2012, the GBI scheme was reinstated after a gap of one year in August 2013. The GBI scheme facilitated the creation of 7 GW of the wind power capacity during its operational period up to March 2017. As costs had declined, it was felt that incentives were no longer required for wind power. Guidelines for tariff-based competitive bidding were issued and the process of wind power development through competitive bids began. Figure 5 provides an overview of the somewhat modest wind capacity additions during the period 2019–2020. There is a need to bring back the momentum of wind capacity in order to achieve 2030 targets.

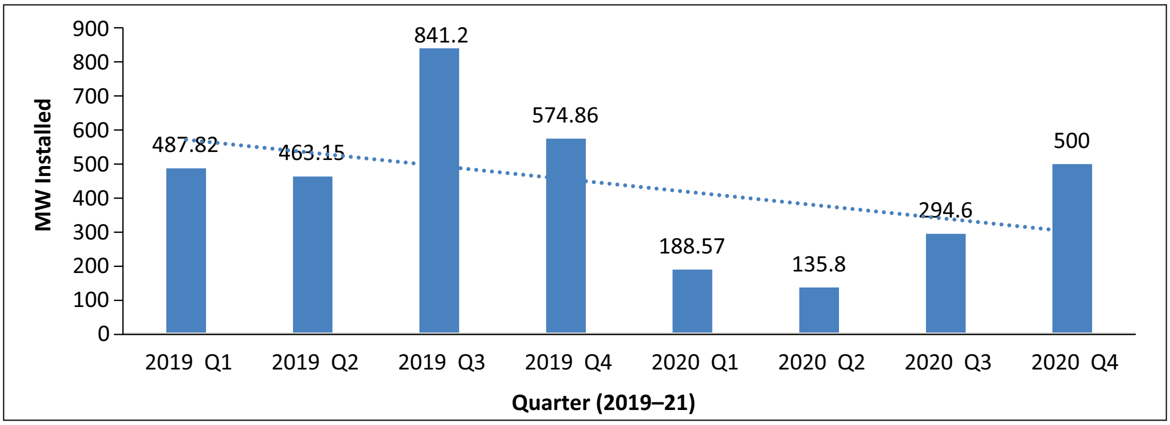

Figure 5: Capacity addition in wind sector

Source: Kumar A, et al., 2022

2.1.3 Banking of Wind Power

The concept of banking was first introduced in the state of Tamil Nadu in 1986.[8] and since then it has been used by several states. The DISCOM took the electricity generated by a captive wind farm of an industrial enterprise located where there was wind power potential and banked it. This banking was notional. The industrial enterprise was billed on a net basis after deducting from its electricity consumption the quantum of wind power it had banked. The industrial enterprise located elsewhere took electricity from the DISCOM to meet its actual electricity needs. The banking mechanism proved to be an attractive option for industrial consumers. The DISCOM tariff for industrial consumers ranged between ₹7–9/kWh. The banking provisions allowed them to avail electricity at a cost of ₹4–5/kWh from their captive wind farm leading to significant savings.

[6] PIB(2014). Details available at Renewable Energy Programmes Gets A New Impetus; Focus on Development of Energy Infrastructure (pib.gov.in)

[7] PIB(2016). Details available at FM: Tax Proposals are aimed at Boosting Economic Growth and Employment Generation (pib.gov.in)

[8] Details available at http://www.tnerc.gov.in/Orders/files/CO-MPNo21%20050820211743.pdf

2.2 National Solar Mission

The Jawaharlal Nehru National Solar Mission (JNNSM) was launched in 2010. The target was to achieve solar power capacity of 20 GW by 2022. The Government of India in June 2015 revised the target of installation of renewable energy capacity to 175 GW till 2022, comprising 100 GW solar capacity, including 40 GW of rooftop solar systems. The National Solar Mission adopted the process of inviting tariff-based bids for grid-connected solar power projects. A series of bids were invited, and projects were awarded to a few bidders in each round to create a new competitive industry structure of solar power developers. The growth of solar power in India has been very rapid after the launch of the National Solar Mission in 2010. And so has been the decline in costs. When the Solar Mission was started, the solar tariff specified by the Central Electricity Regulatory Commission was ₹17.91/kWh in 2010–11.

The Mission was successful in getting tariffs to go down through competition. Solar tariffs declined rapidly from ₹6.48/kWh in March 2013 to ₹1.99/kWh in December 2020 in response to the competitive bid process. Figure 6 depicts the decreasing trend of solar tariffs in India from 2010 to 2022. When the Solar Mission was started, the solar power capacity was 11 MW and capacity of 25 MW was added during 2010–11.

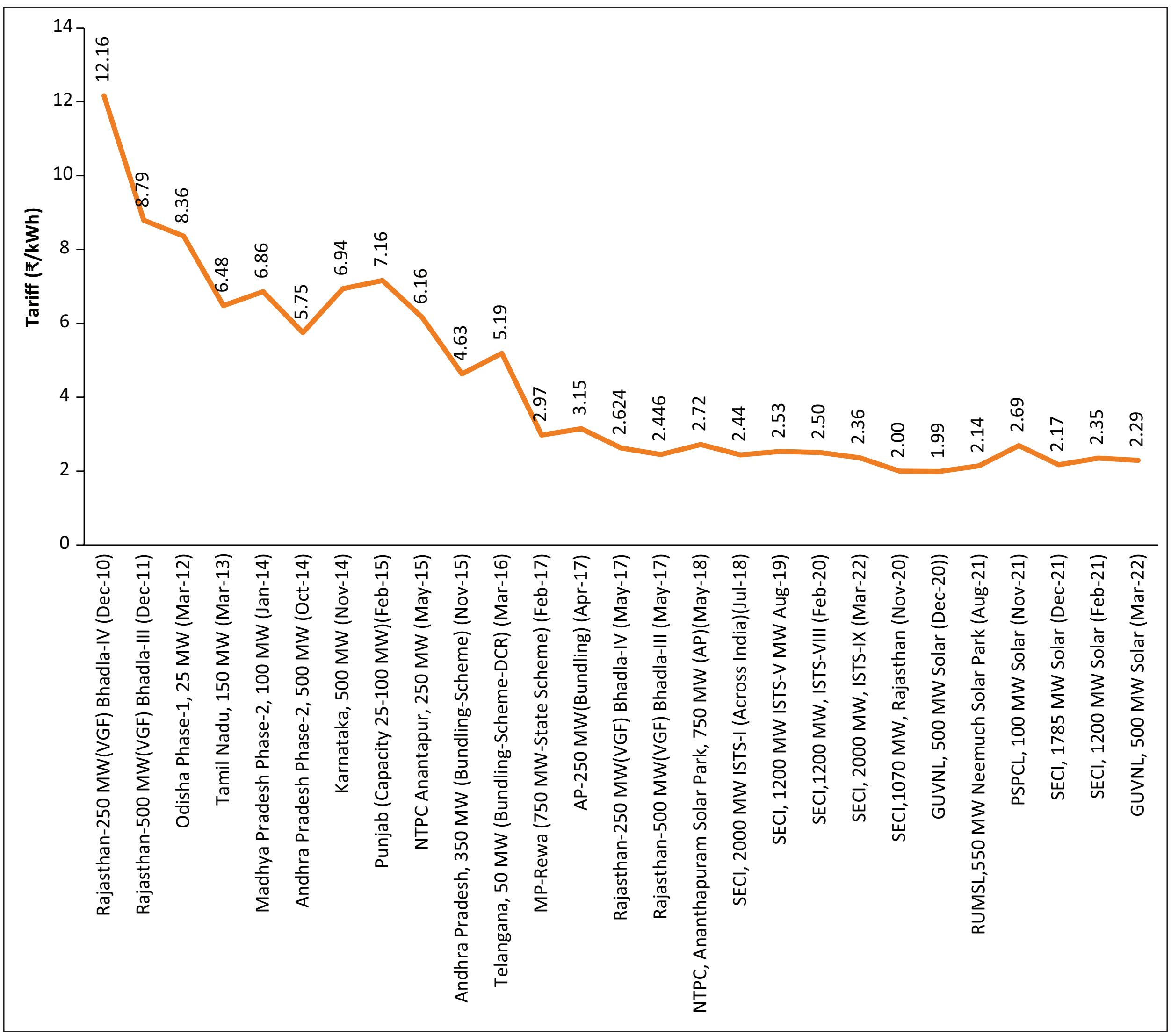

Figure 6: Trend of solar tariffs in India from 2010 to 2022

Source: MNRE, 2021

From being more expensive than thermal power, solar power is now decisively cheaper. Figure 7 depicts rate of sale of power across state-owned coal power stations. Figure 8 shows the rate of sale of power from new coal plants as approved by the Central Electricity Regulatory Commission (CERC) and the State Electricity Regulatory Commissions (SERCs). The sale price of power at new coal plants ranges from ₹4.69–7.4/kWh as depicted in Table 2. This clearly shows the increasing cost of power from new thermal power plants.

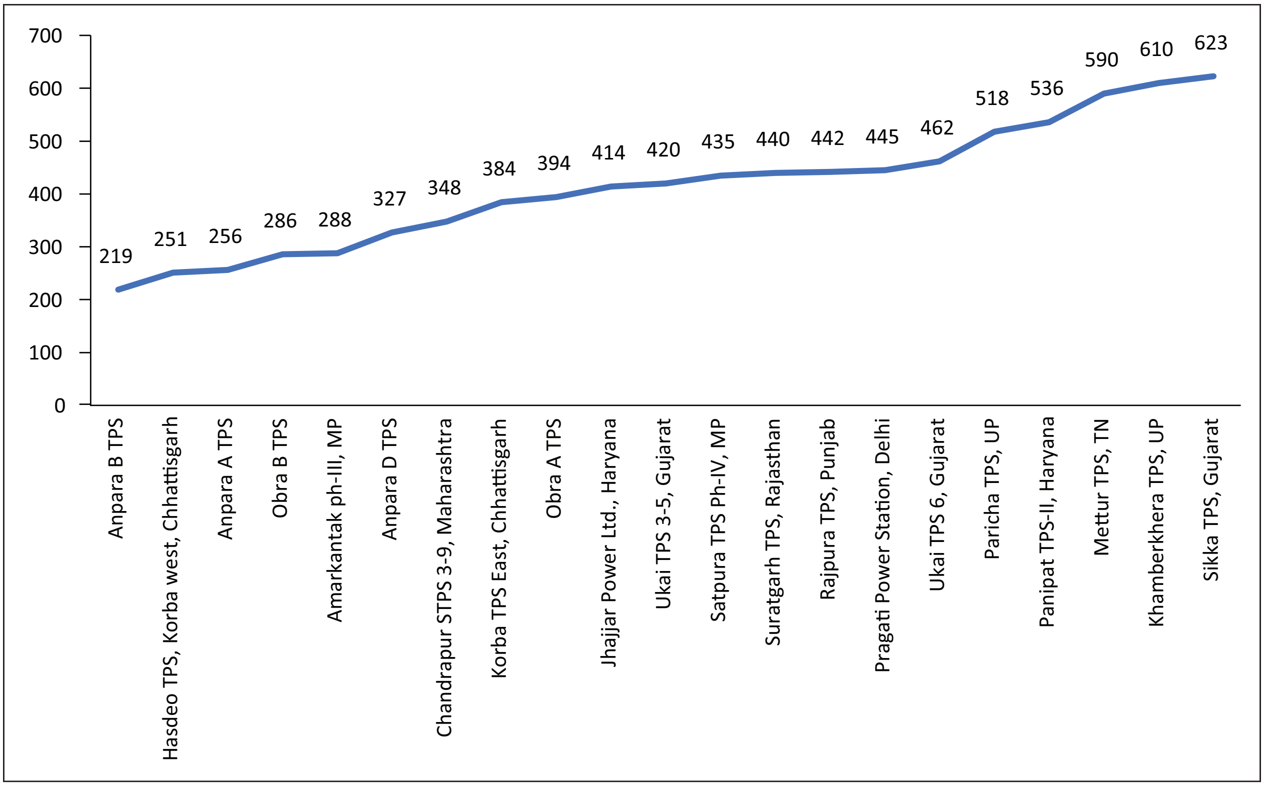

Figure 7: Rate of sale of power from state-owned coal power stations in 2017–18

Source: Executive Summary of Power Sector (March 2020). Central Electricity Authority, Ministry of Power. Details available at https://cea.nic.in/

Table 2: Rate of sale of power from new thermal power stations as approved by CERC/SERC (Paise/kWh) (2019–20)

Utility/Power Station	Rate of Sale as approved by CERC/ SERC (Paise/kWh) (2019–20)	Date of Commissioning
Mouda-II (1320 MW-NTPC)-Maharashtra	469	March, 2017
Khargone (660 MW-NTPC)-Madhya Pradesh	475	August, 2019
Solapur (1320 MW-NTPC)-Maharashtra	514	March, 2019
Gadarwara (800 MW-NTPC)-Madhya Pradesh)	531	March, 2019
Wanakbori TPS 8 (800 MW-GESCL)-Gujarat	634	October, 2019
Meja Urja Nigam Pvt. Ltd. (660 MW)-Uttar Pradesh	684	April, 2018
Bellary TPS-3 (700 MW-KPCL)-Karnataka	743	March, 2016

Source: Executive Summary of Power Sector (April 2022). Central Electricity Authority, Ministry of Power. Details available at https://cea.nic.in/

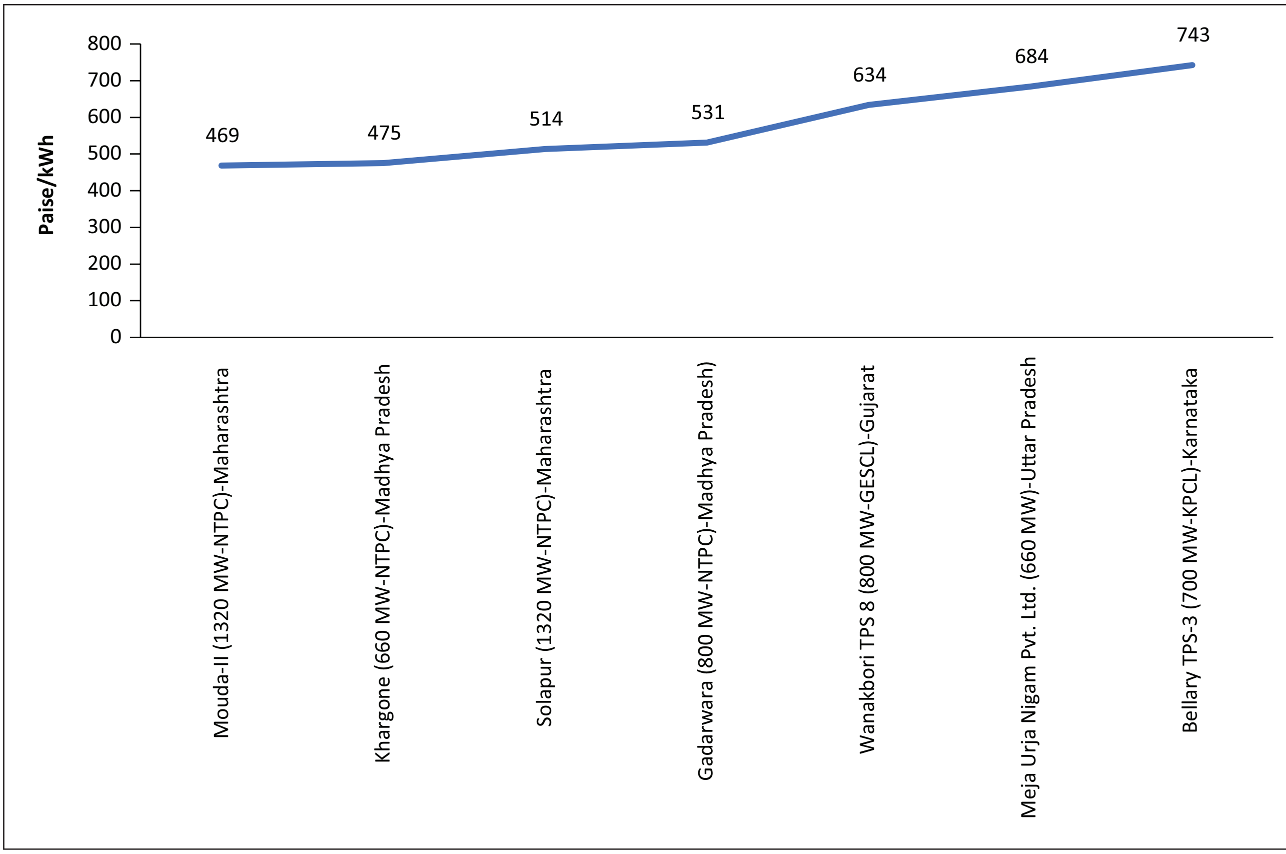

Figure 8: Rate of sale of power approved by the CERC of new coal power plants commissioned between 2016 and 2019

Source: CEA, 2022

2.2.1 Bundling Mechanism

Bundling was an innovative mechanism used to start the National Solar Mission without any budgetary support from government and through private investment. Under this mechanism, costly solar power was bundled with relatively cheap power from coal-based thermal power plants of NTPC, where 15% of the installed capacity was available to the Central government for discretionary allocation. The cost of the bundled power was made comparable to the conventional grid-power from new projects. DISCOMs were therefore willing to buy this power through normal PPAs. In this manner, solar power projects were selected in two batches (batch-I during 2010–11 and batch-II during 2011–12), through a process of competitive tariff-based bidding. The power from the plants was purchased by NTPC Vidyut Vyapar Nigam Limited (NVVN), a wholly owned power trading subsidiary of NTPC, and sold to DISCOMs after bundling with power from thermal power stations of NTPC, out of the unallocated capacity available with the Union Ministry of Power for discretionary allocations, on equal capacity basis, thus effectively reducing the average per unit cost of solar power.

An illustrative example is shown in Table 3 and Table 4 to understand the impact of the bundling mechanism.

Table 3: Solar PV power tariff

Period	Feed-in-tariff determined by CERC (₹ /kWh)	Average tariff after bidding (₹ /kWh)	Effective rate after bundling (₹/kWh)
2010–11	17.91	12.12	4.75
2011–12	15.39	8.77	4.11

Source: MNRE

Table 4: Solar thermal power tariff

Period	Feed-in-tariff determined by CERC (₹/kWh)	Average tariff (₹/kWh)	Effective rate after bundling (₹/kWh)
2010–11	15.31	11.48	4.63

Source: MNRE

Viability Gap Funding

After the success in getting attractive bids from private solar power developers during the initial phase of bundling, the programme needed to be scaled up. The availability of unallocated power from NTPC power stations was limited. Viability gap funding (VGF) was then introduced by the MNRE to take the programme to the next level in 2013. With VGF, the tariffs continued to fall rapidly and did not need financial support anymore. Since then, solar projects have been coming up through competition in the reverse auction process.

The generic tariff determined during the period from 2010–11 to 2016–17 is given in Figure 9.

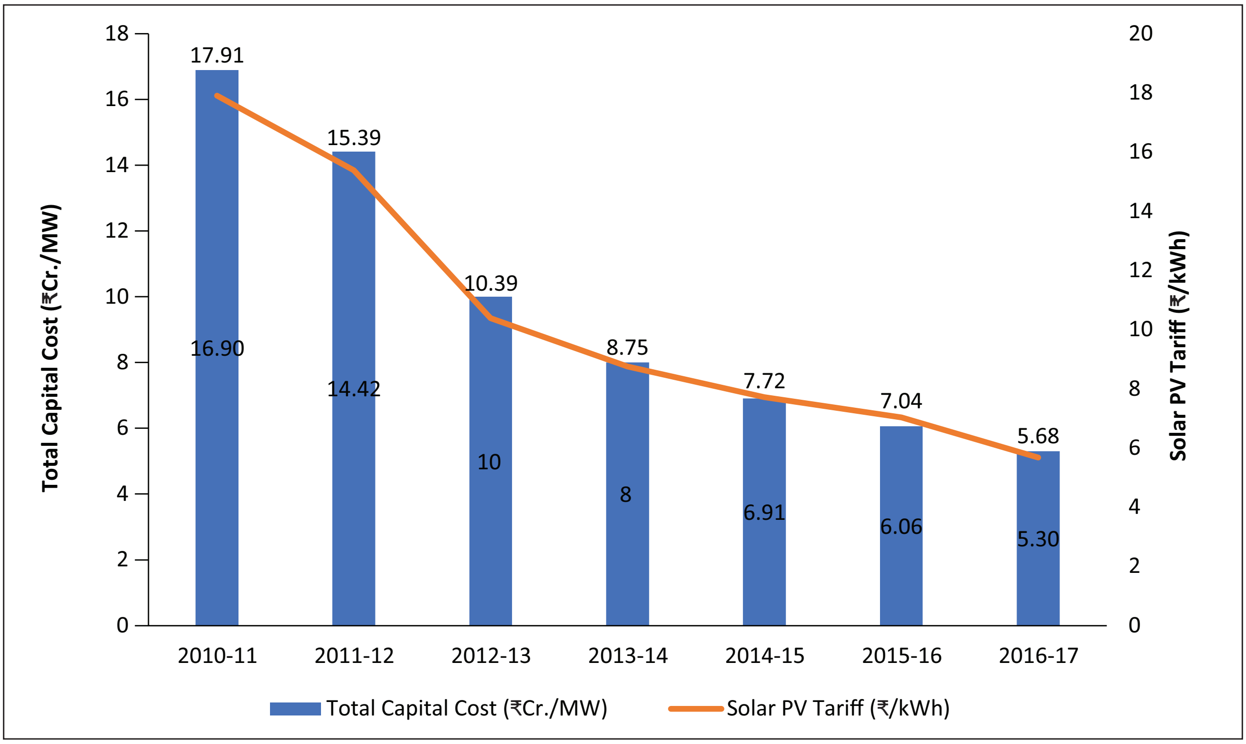

Figure 9: Snapshot of solar PV capital costs and tariff trends

Source: CERC Tariff Regulations 2010–2017

Table 5 captures the growth of grid-connected solar capacity in India in the last decade.

Table 5: Growth of grid-connected solar power capacity since 2010

Period	Solar Capacity Addition (MW)	Cumulative Solar Capacity (MW)
Up to March 2010		11
2010–11	25	36
2011–12	994	1,030
2012–13	656	1,686
2013–14	946	2,632
2014–15	1,112	3,744
2015–16	3,019	6,763
2016–17	5,526	12,289
2017–18	9,363	21,651
2018–19	6,529	28,181
2019–20	6,447	34,628
2020–21	5,458	40,085
2021–22	13,911	53,997

Source: MNRE

India was able to get the full benefit from the global decline in production costs of solar panels through its policy of competitive bidding. A strong competitive private industry structure also emerged in India in this sector.

Many players have been able to access lower-cost, concessional international finance. There has been innovation and cost reduction in installation of solar panels and their maintenance. Indian companies have begun to explore foreign stock exchanges as a source of funds. For example, ReNew Power is listed on NASDAQ. India has become an attractive destination for investment in renewables.

3. SOLAR AND WIND POWER DEVELOPMENT

India has been remarkably successful in the growth of grid-connected large-scale private solar power projects. In the last twelve years, it has installed solar power capacity of 54 GW. In this period, it has added 40 GW of wind power capacity. The annual rate of capacity addition, however, needs to be raised rapidly to achieve the 2030 goal. The 500 GW non-fossil fuel capacity target over the course of the next 8 years is very ambitious and challenging. Capacity addition growth needs to take place at 18.34% CAGR, requiring ~40–43 GW annual addition from the current pace of 9–10 GW per year. This extraordinary pace has to be achieved for the realization of the 2030 targets.

The key challenges for such a massive scale-up appear to be:

1. Finances

India has achieved over 100 GW of renewables capacity with private investment. These projects have come up with financing from the market. Developers have also been accessing global finance. The availability of global finance is increasing. Hence, availability of finances as such may not be a constraint.

The key risk, however, is the financial health of India's electricity distribution companies (DISCOMs). The financial health of DISCOMS has steadily deteriorated, with total accumulated losses doubling between the fiscal years 2013 and 2020, despite bailouts (PFC, 2021). This needs to be set right at the earliest. The Ministry of Power (MoP) has again initiated a fresh set of strong measures to improve the situation. These must yield results and be seen as succeeding in the next two years. Private investments in renewables use finance from the domestic as well as global markets. The sanctity of PPAs and record of timely payments for existing renewable energy projects has facilitated the financing of new projects so far. The implicit state guarantee behind SECI and DISCOMs has helped in reducing risk perceptions in financing RE projects. But markets are fragile. The moment they lose faith, there would be a loss of willingness to finance new renewable energy projects in India. If this happens, the 2030 targets would become unachievable.

2. Land

Availability of adequate land is clearly essential for the accelerated development of renewable power projects to achieve the 2030 targets. For such scaling up, land needs would rise proportionately and so would the challenges related to land assembly. These would need to be addressed. Grid-connected wind and solar projects, for example, require land in excess of 2 hectares per MW (Thapar S, *et al*., 2017). States have been facilitating land assembly for the development of solar power projects. Private developers have developed the ability to assemble land efficiently for their projects. The Government of India is in addition implementing a scheme for setting up of 52 Solar Parks of aggregate capacity 38 GW in 14 states. Solar power projects of an aggregate capacity of around 9.2 GW have already been commissioned in these parks.[9] More such solar parks would need to be set up in the coming years. Work for these may be initiated now.

To the extent captive solar plants are set up by industries and institutions, and the decentralized rural kW range projects with a feed-in tariff gain momentum, the need of land for large projects would get reduced. Further, the beginning that has been made in putting up of solar panels on canals needs to be taken forward with speed. All canals could be covered with solar panels by 2030. This has immense potential, and a minimum of 10 GW capacity could be created on major canal systems of India.[10]

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[9] PIB (2022). Details available at https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1785808

[10] PV Magazine (2021). Details available at https://www.pv-magazine-india.com/2021/03/09/installing-solar-atop-canals/

3. Demand

In the last few years, in some states there was a view that they had already signed PPAs for power in excess of their need and they, therefore, do not need to enter into fresh PPAs. The phrase 'surplus power' in terms of generation capacity gained currency. The overall PLF of thermal power stations in the country came down to less than 60% from a high of over 75%. As the growth rate of the economy moderated, actual demand growth of electricity became lower than projected by the CEA. Further, when demand is fully met and there are no power cuts, the PLF of thermal power stations have to be lower if there are no separate peaking power supply arrangements as the demand curve is not flat.

A natural question is whether demand in 2030 would be large enough for the capacity being envisaged. Demand projections are inherently uncertain. A number of studies have made projections of installed capacities by 2030 (Annexure-I) and how power stations would be able to meet demand by 2030. It can, however, be said that demand growth in the coming years would be higher due to two trends, which are gaining momentum. The first is growing demand for air conditioning and electrical appliances with rising middle class incomes. The second is the breakthrough that may be occurring in the demand of EVs. These would be gaining a substantial market share in the coming years. Promotion of induction cooking could be another end-use, which could boost the demand for the electricity.

3.1 Decentralized Solar Power

The growth of solar power in India has a distortion as the bulk of the capacity creation is taking place through large grid connected solar power projects. Decentralized solar power generation through rooftops is cheaper. No investments in transmission are required. There are no transmission losses. While efforts have been made in recent years to promote solar rooftop power, the results are still modest. Decentralized rooftop solar capacity in India is only 7.6 GW (as on March 31, 2022) against the target of 40 GW. A breakthrough in getting momentum in deployment of decentralized solar power in the kW range is overdue. Such a breakthrough would make it that much easier to attain 2030 targets.

Many states provide subsidized or free electricity for pumping up groundwater for irrigation to get higher yields in agriculture. In 2019, agricultural demand made up 18% of India's electricity consumption. The use of solar power for pumping water for irrigation in agriculture is economical. If the solar panels are located at the pump, then there are no transmission and distributions costs. Solar power when the sun shines is the cheapest source of electricity. The resulting agriculture demand shift to the hours of solar power generation facilitates absorption of variable RE generation at lower costs. It has enabled several states to accommodate high levels of solar and wind power without major system events (IEA, 2021).

PM-KUSUM Scheme

The Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan (PM-KUSUM) scheme is an ambitious scheme designed to support installation of solar pumps for irrigation. The scheme provides assistance to farmers to set up standalone solar pumps, and to solarize their grid-connected pumps. Solar energy projects of capacity 500 kW to 2 MW can be installed under the scheme by farmers, group of farmers, cooperatives, panchayats, and farmer producer organizations. Farmers can install the project on their land and earn by selling power to DISCOM or provide their land on lease to a developer and get lease fee. With solarized grid-connected agriculture pumps, power generated can be used to meet the irrigation needs of the farmer and the excess solar power can be sold to DISCOMs and generate extra income.

States have been designing their own implementation strategies.[11] In Haryana, the State Government is bearing the cost of solarization, besides the Government of India subsidy, and the farmer will get ₹1/kWh for sale of surplus power. In Gujarat, settlement is done on net-metering basis and farmer can feed and draw power from the grid. IEA's Gujarat State Model has predicted that flexibility from agricultural demand response in Gujarat is central to the cost-effective integration of increased solar generation by 2030. The Rajasthan Renewable Energy Corporation allotted 722 MW plants to 623 farmers under the KUSUM scheme, which ensure energy security for farmers, as they could generate revenue from their agriculturally unproductive or barren land (Hindu, 2022). Similarly, Chhattisgarh State Electricity Regulatory Commission (CSERC) has proposed a generic levelized tariff of ₹3.51/kwh for decentralized solar projects with 500 kW to 2 MW capacity. Madhya Pradesh has determined a pre-fixed levelized tariff of ₹3.07/kwh, applicable for projects under PM-KUSUM scheme (Mercom India, 2022).

As of April 2022, under the KUSUM scheme, 42.75 MW of solar capacity, 97,463 off-grid and standalone solar-powered irrigation pumps and 1026 individual pump solar pumps have been installed. It is estimated that full implementation of the KUSUM scheme will lead to reduction in CO_2 emissions by 32 million tonnes annually by replacing 8 million diesel irrigation pumps with solar-powered pumps.[12]

Feed-in-tariff

The KUSUM scheme concept can be taken to the next level by introducing a straightforward feed-in tariff system. The feed-in-tariff was used successfully in Germany. Such a feed-in tariff mechanism for decentralized solar power generation in the kW range is a very attractive option for all. For DISCOMs, the average cost of supply ranges between ₹7 and ₹8/kWh and has been increasing at an approximate average rate of 6% per year (Prayas Energy Group, 2018). They lose around ₹4–5 for every unit of electricity supplied to lower income households (Shankar and Avni, 2020).

For the feed-in-tariff to succeed, it must be attractive for private investment. It needs to be well above the price bids received for large solar projects. This is necessary as there would be higher unit costs in dispersed small installations as well as greater risks. A feed-in tariff between ₹3 and ₹4 would trigger large-scale private investment and at the same time save money for the DISCOMs. The DISCOM, with the approval of SERC, would announce the feed-in tariff for procurement of power in the kW range. The injection points could be indicated where power would be taken on a first-come, first-served basis subject to the technical capacity at that point. The per unit cost savings for DISCOMs would improve their financial health. Additionally, DISCOMs would not have to make substantial investments in transmission infrastructure to absorb solar power unlike in the case of large solar projects. A feed-in tariff would create an attractive large market with minimal transaction costs and risks.

India has approximately 6 lakh villages. Assuming a potential of 1 MW per village, India has a potential of 600 GW. A variety of business models would emerge and compete for this market space. These would range from farmers investing in the solar panels on their own to just leasing space for the panels. Farmers' incomes would rise across the country. Dispersed job creation for installation would take place. Finances would flow through banks and NBFCs. These in turn could access cheaper global green finance.

Further, the expansion of solar power generation in rural areas would enable DISCOMs to supply reliable electricity for agricultural and other productive activities during the daytime and that too at a lower cost. Getting electricity in the day for irrigation would enable farmers to use water more efficiently and conserve water. This in turn would increase productivity and incomes in rural areas.

[11] Details available at http://164.100.47.193/lsscommittee/Energy/17_Energy_17.pdf

[12] Details available at https://mnre.gov.in/img/documents/uploads/file_f-1632204688401.pdf

3.2 Accelerating Momentum of Wind Capacity

The Global Wind Energy Council estimates that the Indian wind sector is expected to add 20.2 GW of wind power capacity between 2020 and 2025. In addition to new wind power projects, repowering of old wind sites, which have been in operation for more than 15 years , needs to be undertaken. These have comparatively low-capacity utilization of 10–15%, compared to more than 30% capacity utilization of modern wind turbines (Kumar, et al., 2022). If these turbines are repowered, the project capacity may be increased by 2–3 times, resulting in a significant increase in annual energy output. Some of the best wind resource sites have <1 MW of turbines, which have a hub height of less than 80 metres. With the development of technologies and innovation, 3.6–4 MW turbines are now installed in India with a hub height of 100 metres.

A pragmatic and viable policy framework for repowering older wind projects at high-resource sites needs to be put in place after stakeholder consultations. This would accelerate India's wind energy development. There is a potential of 4.5 GW for repowering old sites (GWEC, 2021). To accelerate the wind power development further, reintroducing banking would certainly help. It did deliver very good results earlier. Firms would on their own find good sites and put up state-of-the-art wind turbines. With banking they would save money on their electricity bills. At the same time they would be part of the vanguard in decarbonization. DISCOMS are in case providing net metering for RE. This is an extension of the concept as captive generation in wind farms is taking place elsewhere rather than in premises of the C&I consumer. Further, wind power is generated at night also and so needs less storage. Hence, banking for wind power may be introduced through DISCOMS from the central government.

3.3 Start Off-shore Wind Development

According to forecasts, global off-shore wind capacity would exceed 2000 GW by 2050 with the Indian region expected to have 140 GW of this installed capacity (MNRE, 2017). According to the National Institute for Wind Energy, total off-shore wind energy potential is 302 GW at 100 metres and 695.50 GW at 120 metres hub height. Approximately 36 GW of off-shore wind potential exists off the coast in Gujarat and nearly 35 GW exists off the Tamil Nadu coast.

However, there are significant challenges to the deployment of off-shore wind farms. These include subsea cabling, turbine foundation, installation of turbines including logistics, and development of transmission connectivity to the state/national grid (National Offshore Wind Energy Policy).[13] The per mega-watt costs of offshore wind turbines are at least 2–3 times higher than onshore wind turbines, according to the MNRE. However, the price of offshore wind turbines and tariffs are expected to decline as the country begins and increases deployment.[14] As in other sectors, with volumes and competition, costs should decline. Further, with the provision of long-term debt, the tariff from such farms could become lower.

This is the right time to initiate the development of offshore wind in the country. For offshore wind, suitable wind farm sites need to be identified and a few promising ones may be taken up for development. Tariff bids may be invited successively providing wind data and other site details to discover the tariff. The transmission system for evacuation from the off-shore wind farm to the grid would have to be separately developed and provided to synchronize with the commissioning of the offshore wind farm. With price discovery through successive rounds of bidding and development in the next 4–5 years, it would be easier to take a call on the pace at which to scale up offshore wind power development.

[13] Details available at https://mnre.gov.in/img/documents/uploads/3debfe9158b643d8a3e06a7a007f2ef9.pdf

[14] Details available at http://164.100.47.193/lsscommittee/Energy/17_Energy_17.pdf

4. SYSTEM STUDIES, DEMAND SIDE MANAGEMENT, TOU/ GREEN TARIFFS

4.1 System Studies

Detailed system studies including steady-state, transient and dynamic stability studies need to carried out be on a continuing basis to appropriately assess power system security and stability with high share of VRE in the generation mix. The system studies need to be carried out at all the levels — DISCOM level, State level and National level. Forecasting of demand and sub-hourly demand profile at all the levels is a pre-requisite for the system studies. DISCOMs will have to assume greater responsibility for demand and its profile, system studies, flexibility and ancillary services. SERCs may consider mandating the same in regulations.

4.2 Demand Side Management

Demand Side Management (DSM) has been an effective way of optimizing capacity utilization and minimizing the need for additional investments. The load profiles are becoming increasingly variable, with sharper morning and evening peaks. This trend will increase in the coming years. On the supply side, the growth of variable renewables will enhance intermittency in generation. Load shifting and peak shaving are some of the more cost-effective DSM measures. DSM reduces the operational costs of systems and improves reliability. The implementation of DSM in India faces challenges, which include a lack of adequate understanding and an appropriate regulatory environment. DSM can be implemented through direct measures like rostering of supply to industrial consumers or by supplying electricity for irrigation to farmers only in the late night and early morning. The better option is through the use of price signals, time of use tariff with a large difference between peak and off-peak pricing. Successful DSM would be a win-win situation for utilities, governments, regulators, and consumers.

Energy efficiency is the low hanging fruit for moderating growth in demand. At the same time, it increases consumer satisfaction with lower life cycle costs. Programmes for the promotion of energy efficiency have been remarkably successful in India. Not only is it on track to achieve its Paris commitments, but it should be able to achieve its enhanced 2030 goals. It is important to note that energy conservation practices and promotion of the use of energy-efficient appliances also moderate the rise in the peaks of the demand curve. Programmes such as star labelling of appliances, transition to the use of LED lamps, the National Street Lighting Programme, and promotion of energy-efficient agricultural pump sets are transformative. These assist in peak load management by improving energy efficiency and reducing overall demand (NBR, 2021).

The difference between peak and off-peak electricity demand would, however, continue to increase with rising per capita incomes and the absence of power cuts. Demand surges would occur with greater frequency with increasing climate change episodes. The change in demand patterns require better transmission planning, innovative solutions for grid stability, creation of reserves, ancillary services, and markets. This in turn would need appropriate coordinated policies from the central and state governments, and new regulatory mechanisms from the Central and State Electricity Regulatory Commissions. Forecasting, scheduling and imbalance handling would assume increasing importance in the coming years.

4.3 Time-of-use Tariffs

Dynamic matching of supply and demand through the introduction of time-of-use (TOU) pricing of retail electricity supply can incentivize consumers to adapt consumption patterns through appropriate price signals. More complex agreements for voluntary demand reduction or curtailment, peak demand limiters, or automated control systems can further contribute to peak load management. Several international examples implemented in California, Denmark and the UK show how tariffs can be better aligned with solar generation and peak demand by implementing TOU tariff. This model can also be implemented in Indian states, which would help reduce the cost to DISCOMs of meeting peak demand. Regular updates and revision of TOU timeslots would incentivize rooftop solar additions and demand response to reshape the load curves (IEA, 2021).

Currently, TOU tariffs are implemented by most states in India and are applicable to large consumers. The surcharge for consumption in peak hours varies from 10% to 20% compared to rebates/concessions that vary from 15% to 25% in off-peak hours. This has not led to a significant shift in consumers' response.[15] The price differential has to be much larger. Requiring all rooftop solar customers to be on time-of-day/ time-of-use tariffs can help reduce the cost of DISCOMs while also balancing the cost shift between rooftop solar customers and non-rooftop customers. Germany has installed 1.8 million rooftop PV by 2020. It is one of the finest examples of distributed energy supporting country's low-voltage network with voltage stability and reactive power (IEA, 2021). Flattening peak demand with the right price signal would reduce overall capital costs needed to maintain reliable quality supply.

Further, with price discovery of peaking power through competitive bidding, it may well turn out that storage projects become commercially viable and even attractive. If they do, then they are needed for using normal electricity from the grid for storage during off peak hours and for later use to meet peaking power needs. Later, as RE capacities grow, they can be used to store RE power during the day and supply green electricity at night. Early deployment of flexible options and storage technologies would also aid in increasing supply during the peak hours from storage to fully cater to peak demand instead of creating new thermal capacity for this purpose. There is, therefore, a strong case for early deployment of storage, which would become cheaper and affordable with economies of scale.

4.4 Green Tariffs

The concept of green tariffs has evolved as a popular option for companies to procure renewables. These are specialized retail tariffs that are offered by DISCOMs to sell renewable energy to their consumers. The time is right for the introduction of green tariffs in India.

A good beginning has been made. The Ministry of Power (MoP) has announced Electricity (Promoting Renewable Energy Through Green Energy Open Access) Rules, 2022. These rules are forward looking. These rules are notified for promoting generation, purchase and consumption of green energy including the energy from waste-to-energy plants. These rules allow consumers with a sanctioned load of 100 kW or above to purchase electricity directly from the renewable power producers through open access (DISCOMs). These rules would enable the consumers to use fossil fuel free renewable energy to become green and carbon neutral. The provisions in these rules have the potential to bring a paradigm shift in India's private renewable energy procurement while benefiting Commercial and Industrial (C&I) sector and MSME consumers. Commercial and industrial consumers are allowed to purchase green power and allows captive consumers to take power with no minimum limitation. They give individual consumers the choice to use only carbon free electricity through open access.

The next step would be for DISCOMS to offer to consumers the choice of using only carbon free green electricity from a prospective date on a net basis to begin with. Then from a later date consumers may be given the choice to buy carbon free electricity on a real time basis. The DISCOMS would have to buy renewables with storage to be able to discharge this obligation on a real time basis. The State Electricity Regulatory Commissions would need to authorize and approve these separately. Giving individual consumer the choice to buy green electricity even if it is more expensive will empower them to contribute individually to the electricity transition to zero and help save mankind from the impending disaster of global warming.

[15] CEA(2019). Details available at https://cea.nic.in/wp-content/uploads/2021/03/tariff_2019.pdf

5. GRID-SCALE STORAGE

There are grid integration challenges with increase in the share of renewables. The primary challenge is of ensuring quality supply on a real time basis – minute by minute, second by second – with a rising share of variable solar and wind generation, which is intermittent and depends on weather conditions. The power system would need to have increasing flexibility. The achievement of the target of 500 GW of non-fossil fuel capacity involves a fundamental transformation of the all India integrated electricity grid system. Electricity demand would have to be met fully when the sun does not shine, and the wind does not blow. The capacity to ramp up supply from other sources instantaneously to meet demand, to maintain grid stability and provide reliable power supply to all consumers would become more challenging.

To begin with, greater flexibility from thermal plants is needed. The CERC has modified regulations for thermal plants to have the flexibility of moving down to 55% of rated capacity and ramping. In April 2022, the MoP announced a revised scheme to replace 58,000 million unit (MU) of thermal power with renewables, which is equivalent to RE capacity of 30,000 MW.[16] The thermal power will be gradually replaced with renewables in a phased manner up to 2025–26 (i.e., 20% in 2023–24, 35% in 2024–25 and 45% in 2025–26). A snapshot of year-wise trajectory of replacement of thermal power with renewable power is detailed in Annexure-I.

As the share of renewables rises, generation for some duration would become higher than demand, then storage of excess RE would be necessary to prevent losing electricity, which has zero marginal cost. Further, if the use of thermal power between sunset and sunrise has to be reduced then storage of electricity would be the way forward as solar power would have the larger share in RE. For meeting peak demand, storage may become the better option. The CERC has recognized that storage would play a key role in improving the operating capabilities of the grid, lower power purchase cost, address the variability and intermittency of renewables and also cater to peak demand. The large-scale integration of RE with an increasing share of solar power, can only be achieved by increasing deployment of grid-scale energy storage. This would absorb variable renewable energy from the grid when generation is in excess of demand and supply electricity to the grid when demand exceeds generation. CEA estimates the optimal capacity mix by 2029–2030 to include 27,000 MW/108,000 MWh of grid-scale storage (CEA, 2020).

In March 2022, the MoP issued guidelines for procurement and utilization of battery energy storage systems (BESS) along with ancillary services. The comprehensive guidelines are for procurement of energy from BESS by the 'Procurers', through competitive bidding, from grid-connected projects to be set up on "Build-Own-Operate" or "Build-Own-Operate-Transfer" basis, for intra-state and inter-state projects. The Ministry has also introduced the scheme for bundling of thermal and hydropower stations with standalone renewables and renewables coupled with storage.[17] There would be a requirement of nurturing new market structures and evolving appropriate regulations. As the share of renewables rises especially with solar power being the main driver for achieving the 2030 target, storage becomes essential. For India, this need would come much earlier than in those countries where wind power is the main driver of the decarbonization of electricity. Wind power is generated during the day as well as during the night as wind blows round the clock. On the other hand, solar power is generated only during the day when the sun shines.

[16] Ministry of Power(2022). Details available at https://powermin.gov.in/sites/default/files/webform/notices/Trajectory_for_replacement_of_Thermal_Energy_with_about_58000MU_30%2C000MW_of_RE_by_2025_26.pdf

[17] Details available at https://powermin.gov.in/sites/default/files/Scheme_for_Flexibility_in_Generation_and_Scheduling_of_Thermal_Hydro_Power_Stations_through_bundling_with_Renewable_Energy_and_Storage_Power.pdf

In 2022, SECI issued the tender for setting up 500 MW/1000 MWh Standalone Battery Energy Storage Systems (BESS) in India.[18] Out of the total capacity being procured under the tender, 60% of the capacity will be taken by SECI on behalf of the buying entities, and the balance 40% of capacity will be with the developers for third-party or market sale. Out of the 60% capacity off taken by SECI, 30% will be earmarked to be used by the National Load Dispatch Centre (NLDC), Power System Operation Corporation (POSOCO) for Grid Ancillary Services. India has an opportunity to leapfrog in adoption of ancillary services by adopting regulatory mechanisms such as pay for performance, that creates incentives for better performing technologies to be deployed for improving grid reliability.

Assuming that the cost of wind and solar will be between ₹2.3–2.6/kWh and ₹1.9–₹2.3/kWh, respectively, while the cost of storage will have fallen by about 70% by 2030, TERI's analysis of the cost to balance the variability of renewables finds that variable renewable energy generation up to 40% would be cost-effective including the sunk costs of the existing systems (Spencer T., *et al*., 2021). Considering other renewables, hydro and nuclear, the share of zero carbon generation could be even higher, at 45%, while the share of coal falls to almost 50%. TERI's analysis further indicates that as storage costs decline and become ₹7500 (~80–100USD/kWh) and lower, renewable energy and storage can meet essentially all the incremental demand growth. As VRE increases, particularly if it is solar dominated, the seasonality introduced starts to make substantial BESS attractive because it is required on a frequency that allows the per unit power and energy costs to be attractive.

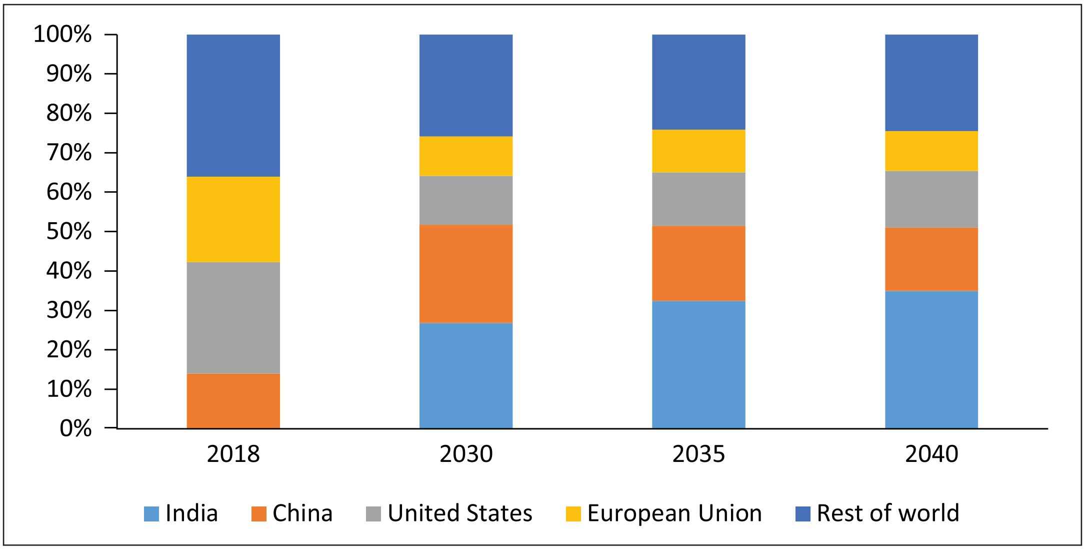

Figure 10: IEA projections of increase in BESS in India from 2018 to 2040 (IEA,2020)

The decline in storage costs is likely to be faster with volumes and competition. Figure 10 depicts IEA projections of increasing share of BESS technologies by 2040 in India occupying one-third of global share.

There are mature technology options for large-scale grid storage, which India should go in for now. This would enable scaling up with the downward movement of the cost curve that should follow with volumes and scale.

[18] PIB (2022). SECI issues tender for 500 MW/1000 MWh Standalone Battery Energy Storage Systems Details available at https://pib.gov.in/PressReleasePage.aspx?PRID=1817294

5.1 Pumped Storage Plants

Pumped Storage hydropower plants have been put up across the world, mostly in the last century for meeting peaking power requirements. The technology is relatively straightforward and accounts for 94% of world's energy storage capacity.[19] These plants are 80% energy efficient through a full cycle, and the facilities can typically provide 10 hours of electricity (TERI, 2021). Pumped storage plants (PSP) may be developed to provide a major part of the storage needed by 2030. The exercise of identifying potential sites and completing pre-feasibility studies should be taken up and completed at the earliest.

The recent draft National Electricity Policy (NEP) 2021 also emphasizes the need for large-scale adoption of Pumped Hydro Storage (PHS) for supporting the electricity grid. The Central Electricity Authority (CEA) of India has estimated a PHS potential of 96 GW. But only 3.3 GW is currently operational in India. Some of the notable pumped hydro projects in India are Kadamparai in Tamil Nadu with a capacity of 400 MW, Srisailam in Andhra Pradesh with a capacity of 900 MW, and Purulia in West Bengal with a capacity of 900 MW. Tehri in Uttrakhand with a capacity of 1000 MW, and Kundah in Tamil Nadu with a capacity of 500 MW are presently under construction.[20]

In May 2022, development of an integrated renewable energy storage project with a total capacity of 5230 megawatt (MW) has been started in Pinnapuram, Andhra Pradesh. Promising cost effective and round-the-clock power, the project comprises daily pumped storage of 1,800 MW, 3,000 MW of solar, and 550 MW of wind power. The project is being implemented by Greenko Group and funded by Arcelor Mittal Group with an investment of ₹22,000 crore (USD 3 billion) (Reddem, A., 2022).

Pumped storage plants have higher capital costs and longer gestation periods. They would need land acquisition and also have to handle R&R issues. Government would need to assume greater responsibility for their development. Long-term finance from the new development financial institution would make project implementation easier as given their long life, running into decades, they could be the cheapest option in a proper life cycle cost comparison over 50 years or more. Further, the private sector may find the uncertainties regarding actual execution costs and time, water availability and future tariffs large. The risk perception as a result may appear as a disincentive for private investment. In such cases, government could get a state agency to do the project and absorb the risk. This agency could consider awarding the project for execution on a hybrid annuity or a pure annuity contract for construction, operation and maintenance, and guaranteeing a specified level of availability.

5.2 Concentrated Solar-thermal Power (CSP)

CSP projects use mirrors to concentrate the sun's rays and store it in molten salt. This stored energy is used to run a conventional thermal plant turbine to generate electricity. Because of its ability to store solar energy thermally and convert it to power, CSP can deliver power on demand, making it an attractive renewable energy storage technology. CSP projects have seen limited modest development worldwide so far with 6.4 GW installed at the end of 2019. India has an immense solar power potential of over 2,700 GW through CSP.[21]

A study by IRENA estimates the weighted average Levelized Cost of Electricity (LCOE) of Concentrated Solar Power plants fell by 68% between 2010 and 2020, from USD 0.346/kWh (₹27.08/kWh) to USD 0.108/kWh (₹8.62/kWh). Data in the IRENA Auction and PPA Database shows a weighted-average price of electricity of around USD 0.076/kWh (₹6.27kWh) for CSP projects to be commissioned in 2021 (IRENA,2020). Figure 11 provides an overview of decline in global weighted-average total installed costs, capacity factors and LCOE from 2010–2020. In 2018 and 2019, the cost range of projects with 8 hours or more of thermal storage was between USD 4126/kW and USD 5945/kW.

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[19] Details available at https://www.hydropower.org

[20] Details available at https://cea.nic.in/hepr-report/?lang=en

[21] Details available at : Ishan Purohit and Pallav Purohit, "Technical and Economic Potential of Concentrating Solar Power Generation in India," World Bank, 2021, https://openknowledge.worldbank.org/bitstream/handle/10986/29300/j.rser.2017.04.059.pdf?sequence=1&isAllowed=y.

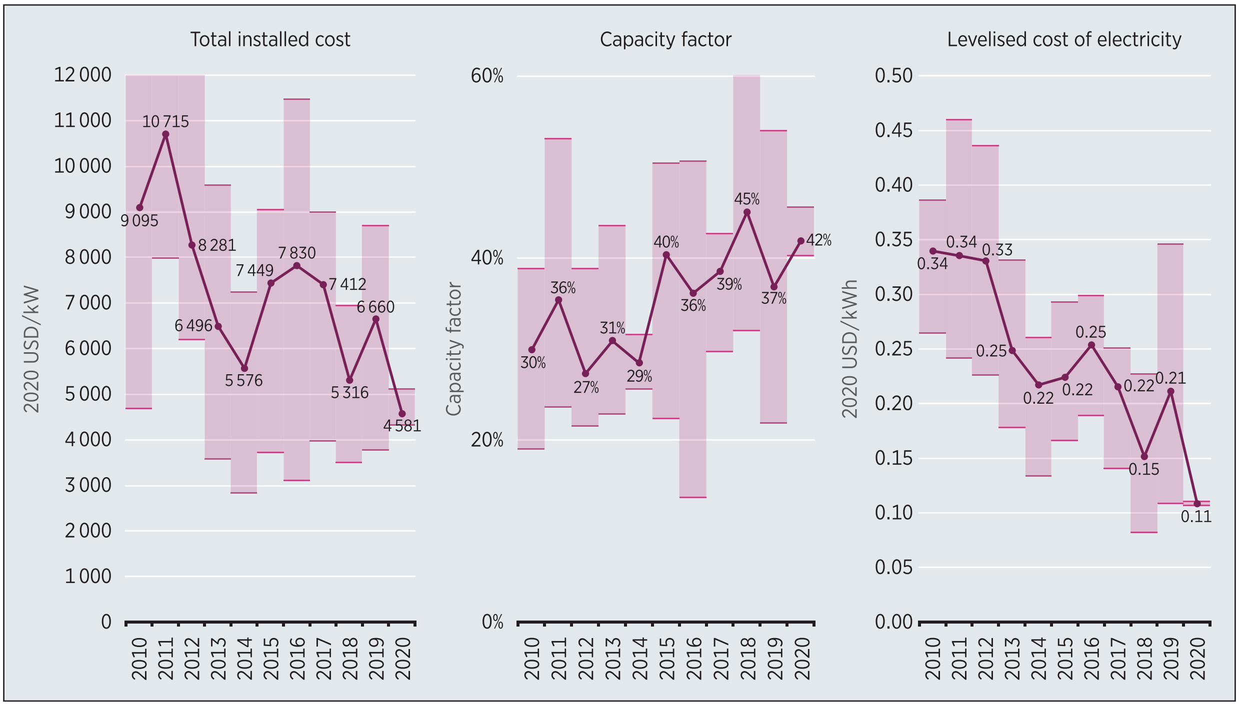

Figure 11: Global weighted-average total installed costs, capacity factors and LCOE for CSP, 2010–2020

Source: IRENA,2020

The key challenge for implementing CSP is the need for site-specific studies to prepare a reliable direct normal irradiance database so that an optimum site-specific project design can be done. In India, the development of indigenous manufacturing would cater to the demand of critical components of CSP, which include mirrors, absorber tubes, etc. Economies of scale and indigenous manufacturing are factors which could lead to cost reduction in CSP. These two factors will play an important role when Gigawatt (GW)-scale capacities start getting installed. The capital cost would reduce to ₹19.5 crore/MW (USD 2.48 million/MW) with indigenous manufacturing of sub-components and further reduce to ₹17.83 crore/MW (USD 2.27 million/MW) with indigenous manufacturing and economies of scale[22] (Bannur S, 2018).

CSP technology being able to despatch energy at any time of the day is very promising (Figure 12). The Department of Energy (DoE), US is currently funding research to explore the potential pathways of heat transfer mediums and reach the goal of reducing the cost to 5 cents per kWh through innovative solutions (Young, C., 2022). Solar towers using molten salt as a high temperature heat transfer fluid and storage medium (or other high temperature medium) appear to be the most promising CSP technology. This is based on their low energy storage costs, the high-capacity factor achievable, greater efficiency of the steam cycle, and their firm output capability. An additional advantage is that in areas with excellent solar resources, low cost solar PV can naturally be paired with CSP to allow round-the-clock generation. The confluence of extremely low-cost solar PV, onshore and even offshore wind combined with the installation of CSP could decarbonize power systems rapidly. Globally, CSP plants are concentrated in Spain (2.3 GW), the United States (1.6 GW), Morocco (0.5 GW), China (0.5 GW), and South Africa (0.5 GW). The Middle East and North Africa MENA region is at the forefront. Recently, the lowest PPA for a CSP project was granted in Dubai (United Arab Emirates) at $0.073/kWh for the DEWA 950 MW CSP-PV hybrid project.

[22] Details available at https://www.currentscience.ac.in/Volumes/115/02/0222.pdf

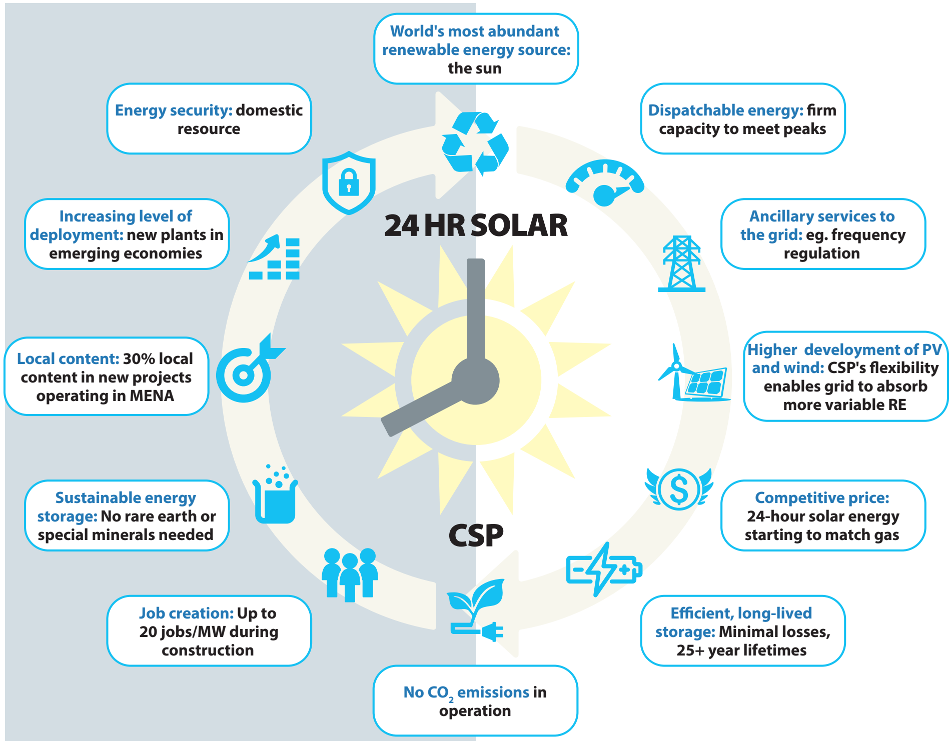

Figure 12: Key benefits of CSP technology

Source: World Bank 2020

Developing pilot projects at sites and bidding for solar thermal plants with storage should begin now. This would lead to price discovery. Successive projects of competitive bidding would give a sense of the potential movement down the cost curve. With cost reduction from volumes, competition among developers and domestic manufacturing, CSP may become a very attractive cost-effective way of achieving large-scale grid storage that India would need as it moves to achieve its 2030 goals and then on to net zero.

5.3 Battery Energy Storage Technologies

Battery energy storage technologies are gaining popularity globally for grid level applications due to rapidly reducing costs of installations along with technological advancements. It has features like quick response time, distributed energy/power- balancing capabilities, and phased installation, which make them eminently suitable for handling the reliability and intermittency of RE generation (TERI, 2021). India has initiated efforts for the deployment of grid-scale battery storage on scale through the recent SECI tenders. BESS may emerge as one of the preferred options for flexibility and ensuring grid stability. According to estimates by the International Energy Agency (IEA), the global share of India in battery deployment would be 35% by 2040 as depicted in Figure 10.

The most commonly used battery chemistries for grid-level applications in the current scenario are based on lead, sodium, nickel, transition metals (vanadium, chromium, and iron), and lithium electrochemistry. There are many technologies which are at demonstration level. Figure 13 provides an overview of various grid-scale technologies. Some of these technologies like molten rocks, flywheel, super capacitors, green hydrogen are in the nascent stages of development or are still not able to find deployment at the scales, which make them cost effective.

IRENA estimates that by 2030 the total installed cost of flow batteries, still very much in development, could drop by two-thirds; high-temperature batteries by 56–60%; flywheels by 35%; and compressed air energy storage by 17% (IRENA, 2019). Such cost declines along with expected performance improvements would make these new battery storage systems cost-competitive for more applications, particularly ones involving longer discharge periods.

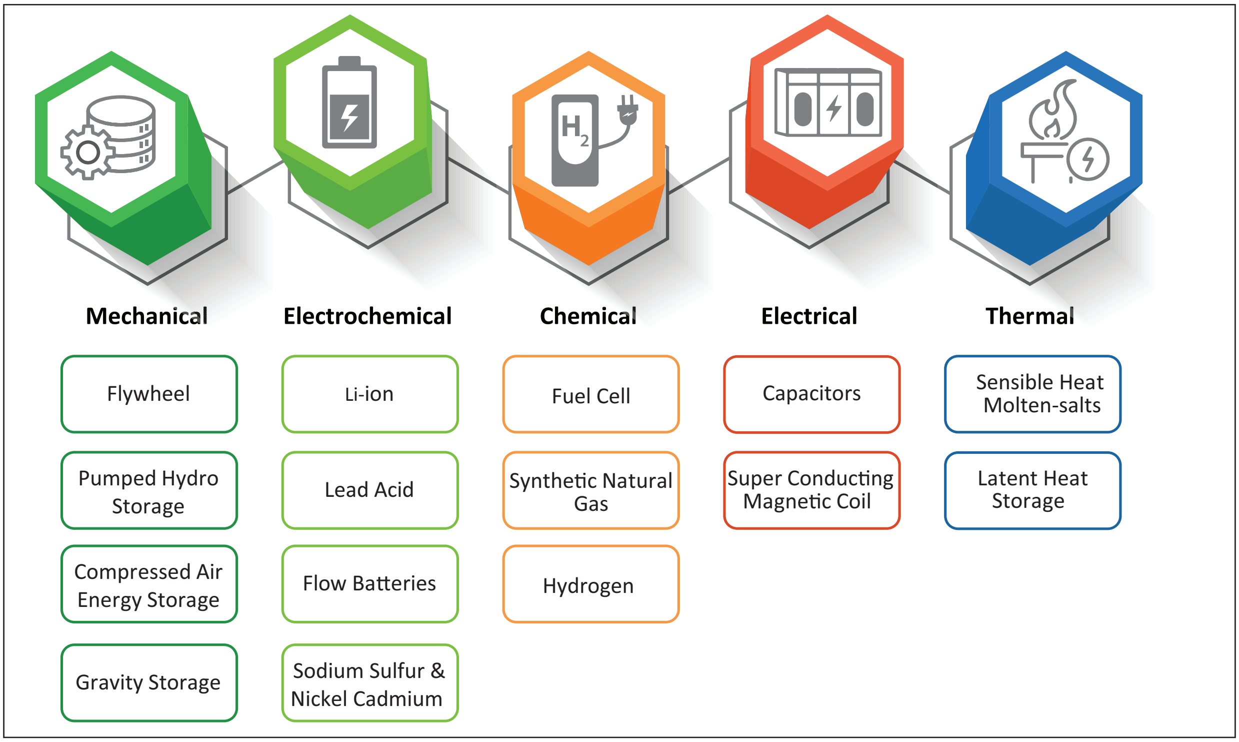

Figure 13: Classification of grid-scale storage technologies

Source: TERI 2021

The CEA has estimated that capital cost of batteries would decline from ₹7 crore/MW (USD 0.89 million/MW) in 2021–2022 to ₹4.3 crore/MW (USD 0.54 million/MW) in 2029–2030 for a 4-hour discharge duration, equivalent to ₹18,750 ($250/kWh) in 2021–2022 and ₹11,550 ($154/kWh) in 2029–2030.

5.4 Hydrogen Energy Storage Technologies

The potential of hydrogen-based energy storage, especially for medium- and long-duration storage, is being pursued because of the technical advantages it brings in comparison to battery storage. Green hydrogen, rather than fossil fuel-based hydrogen production, is the way forward for complete decarbonization. The cost of green hydrogen is declining due to the falling price of RE. The focus is now on reducing the cost of electrolysers, which is the major component in the green hydrogen value chain. Policy and regulatory support to foster production of green hydrogen is being put in place under the National Hydrogen Mission. Further, the use of hydrogen in pilot hydrogen energy projects for (a) remote locations as a substitute for diesel generation and (b) for seasonal peak needs may be taken up.

Large-scale hydrogen-based storage presents a strong case to balance long-term intermittency in electricity generation from wind and solar power, especially in relation to inter-seasonal shifts (Stafell I., *et al*., 2019). According to TERI's recent analysis, the cost of alkaline electrolysers is projected to drop 56% from around ₹6.3 crore/MW (USD 0.86 million/MW) today to around ₹2.8 crore/MW (USD 0.38 million/MW) by 2030. Hydrogen energy storage technologies would play a key role when India transitions to a full-scale decarbonization pathway beyond 2030. Taking up the implementation of pilot projects competitively using different storage technologies would have the advantage of creating domestic capacities for project execution and price discovery under Indian conditions along with a better sense of the likely movement down the cost curve. After 3–4 years, decisions on scaling up would become easier as a result.

6. DOMESTIC MANUFACTURING-ENERGY SECURITY

A key component of the vision of Aatma Nirbhar Bharat and Make in India should be manufacturing with greater domestic value addition of all renewable energy products. So far, the Indian programme in solar power has been highly import dependent. However, in wind power, India has established a globally competitive manufacturing industry. The total domestic manufacturing capacities of solar power equipment within the country are quite modest. Against an annual demand of 20 GW and more in the coming years, domestic manufacturing capacity is 3 GW for solar cells and ~9–10 GW for the modules. There is an import dependence to the tune of 80% or more.[23]

In 2021, the MNRE began implementing Production Linked Scheme (PLI) in the National Programme on High Efficiency Solar PV Modules. The Scheme aims to promote domestic manufacturing of high efficiency solar PV modules with an outlay of ₹4500 crore.[24] The PLI Scheme is now providing support for high efficiency solar PV modules and advanced chemistry cells. A TERI study has estimated domestic demand for solar equipment would be able to generate a value of ₹294,000 crore (USD 42 billion) by 2030 through import substitution (Shankar and Avni, 2020).

Domestic manufacturing could be promoted in Special Economic Zones and Special Manufacturing Hubs with high quality infrastructure of power, water, wastewater treatment, and solid waste management. Domestic manufacturing could be rapidly scaled up by inviting successive government procurement bids for solar panels with full value addition in India. The tender should offer land in the manufacturing hub with cheaper direct electricity supply and quality infrastructure. The project bid should be for offtake of, say 1 GW annually for 5 years from the date of the successful L1 bidder commencing production. If L2, L3 match the L1 price, they could get orders for the same, or 75%, of the volume of L1. Bids should be accepted even if the L1 price is a bit higher than that of imported panels. With successive bids prices would decline. Duty-free imports of machinery and spares should be allowed to enable cost competitiveness. This dispensation should enable India to have a globally competitive solar industry in five years. This approach can be replicated for storage technologies from the outset.

The PLI scheme is now providing support for solar modules and advanced chemistry battery cells. It should be extended to cover the full value chain of solar panels, reversible turbines for pump storage, and mirrors for solar thermal plants and green hydrogen. The emergence of a globally competitive domestic industry would ensure greater energy security, price stability, and potentially lower costs.

Indian industry has been forward looking. Domestic manufacturing of advanced chemistry cells (ACC) and high efficiency solar modules is gaining momentum. The major next step would be to cover the full value chain of solar panels. Battery storage is covered under the PLI, and Indian firms are exploring different battery technologies. They are also positioning themselves for becoming partners in the National Hydrogen Mission for making green hydrogen at a globally competitive cost by 2030.

[23] Details available at https://mnre.gov.in/img/documents/uploads/file_f-1619672166750.pdf

[24] Details available at https://pib.gov.in/PressReleasePage.aspx?PRID=1742795

7. WAY FORWARD

Notwithstanding its enormous development challenges and scarcity of resources, India has become a leader in pursuing the energy transition towards renewables and away from fossil fuels. The increase in solar and wind power capacities have been extraordinary. This growth of renewables has come from government initiatives and private sector investments. The public policies have provided risk mitigation and promoted the emergence of a competitive industry structure.

Despite the impressive momentum of renewables, India due to its sheer size, is the second-largest consumer of coal globally. Approximately 70% of the country's electricity was generated by coal in 2021. The highly ambitious announcements at COP26 of decarbonizing energy to 50% and creating 500 GW of non-fossil fuel capacity would bring about a qualitative transformation and create a new paradigm of energy development and pave the way for full decarbonization of India's electricity system.

Achieving 2030 goals though challenging is feasible. A rapid acceleration of the pace of new solar and wind power capacity creation has to take place primarily with private investment. Improving the financial health of DISCOMs at the earliest is essential. Markets, domestic as well as international, must not see the risk of delayed payments to RE generators as being real and growing. The central government needs to give this the highest priority and ensure timely payments to maintain market confidence and flow of the higher levels of capital needed for investments for the attainment of the 2030 targets.

The following are the key to the achievement of India's 2030 targets announced at COP26:

Firstly, renewable energy expansion has been taking place primarily through large grid-scale projects. The unlocking of the potential of decentralized renewable energy generation needs focus and appropriate policies. This paper presents a case for implementation of feed-in-tariff in the kW range for solar generation in India. This would bring benefits to DISCOMs, increase in farmer incomes, create jobs and improve the quality of power supply in rural areas.

Secondly, bidding for utility scale wind and solar power projects would need to be scaled up substantially. In addition, offshore wind power development should be initiated.

Thirdly, solar and wind power generation is variable, intermittent and depends on weather conditions. The integration of solar and wind requires an adequate amount of flexibility in power system. Flexibility would be a key necessity. This would require an ongoing process of power system studies including transient and dynamic stability studies and transmission planning. From these, the requirement of ancillary services, transmission, and storage will emerge.

Fourthly, India should initiate storage projects using mature technologies for pumped storage plants (PSP), concentrated solar thermal plants (CSP), and batteries. The state would need to take leadership for the development of pumped storage plants after identification of sites in order of priority. With price discovery, and a more realistic assessment of potential of cost reductions, decisions on scaling up in the later part of this decade would become easier.

Fifthly, India should try to become a cost effective and competitive manufacturing hub of RE. The PLI scheme should be extended to cover the full spectrum of renewable energy equipment production, solar panels, mirrors and sensors for solar thermal, batteries for grid use, and hydrogen. In addition, public procurement from a prospective date should be used to achieve full value addition in RE manufacturing.

Sixthly, in addition to the Ministry of Power's recent guidelines for green energy open access rules, the DISCOMs need to take the next step and give Commercial and Industrial (C&I) consumers the choice to buy carbon free electricity on a real time basis with separate tariffs. This choice may then be extended to all consumers. This would give consumers the ability to accelerate the transition to carbon free electricity by paying more initially. Many would choose to do so.

Early action in implementation of the full range of measures needed for achieving 2030 targets is essential. India could be at the global frontier in decarbonization of electricity. At the same time, it could become a competitive manufacturing hub. India could realize its vision of Aatma Nirbhar Bharat with greater energy security.

8. ANNEXURES

Annexure-I: Projections for 2030

Table 6 shows the share of installed capacity envisaged in 2030 in India by CEA and TERI.

Table 6: Projections of installed capacity of India by 2030

S.No.	Source	Unit	Installed Capacity		
			CEA	TERI - BCS	TERI-HRES
1	Coal	GW	267	263	263
2	Gas	GW	25		
3	Nuclear	GW	19	17	17
4	Hydro	GW	61	74	74
5	Solar	GW	280	229	189
6	Wind	GW	140	169	129
7	Other RE	GW	25	33	33
Total capacity		**GW**	**817**	**785**	**705**
Non-fossil share		**%**	**64.26%**	**66.50%**	**62.61%**
Fossil share		**%**	**35.74%**	**33.50%**	**37.39%**
Battery Energy Storage		**GW/GWh**	**27/108**		**60/120**

Source: CEA, TERI's Analysis, 2020

BCS: Baseline capacity scenario
HRES: High renewable energy scenario

As observed from the table, the share of renewables was estimated to range between 50% and 57% in the capacity mix by 2030. As per projections of the Central Electricity Authority (CEA), Glasgow announcements of achieving 500 GW of non-fossil fuel energy could be achieved by combining 435 GW from wind, solar and other RE sources; 61 GW from large hydro and 19 GW from nuclear energy capacity. The projections from various studies for 2030 capacity additions are broadly in line with India's 2030 goals announced at COP26.

In April 2022, the Ministry of Power also issued revised scheme for Flexibility in Generation and Scheduling of Thermal/ Hydro power stations through bundling with renewable energy and storage power. According to revised guidelines, there is a a scope to replace 58,000 million unit (MU) of thermal power with renewables, which is equivalent to RE capacity of 30,000 MW.[25] The thermal power will be gradually replaced with renewables in a phased manner upto 2025–26 in order to increase share of renewables and reach a national goal of 500 GW of fossil fuel free capacity by 2030.

[25] Ministry of Power(2022). Details available at https://powermin.gov.in/sites/default/files/webform/notices/Trajectory_for_replacement_of_Thermal_Energy_with_about_58000MU_30%2C000MW_of_RE_by_2025_26.pdf

A summary of year-wise trajectory of replacement of thermal power with renewable power is given in Table 7 below.

Table 7: Year-wise trajectory of replacement of thermal power with renewable power

Sector	Thermal Energy in MU to be replaced	Equivalent Solar MW needed	2023–24			2024–25			2025–26		
			(%)	(MU)	(MW)	(%)	(MU)	(MW)	(%)	(MU)	(MW)
Central	33,260	17,258	20	6,652	3,452	35	11,641	6,040	45	14,967	7,766
State	12,386	6,427	20	2,477	1,285	35	4,335	2,249	45	5,574	2,892
Private	12,224	6,343	20	2,445	1,269	35	4,278	2,220	45	5,501	2,854
Total	**57,869**	**30,028**		**9,129**	**4,737**		**15,976**	**8,290**		**20,541**	**10,658**

MW equivavlent Solar Capacity needed for replacing the thermal generation in MU calculated assuming CUF of 20%

Source: Ministry of Power, 2022

Annexure-II: Levelized Cost of Storage Technologies

In April 2020, Lawrence Berkeley National Laboratory (LBNL) estimated the cost of utility-scale lithium-ion battery systems and solar plus battery costs and resultant tariffs for the Indian market. LBNL estimates the levelized cost of storage (LCOS) for a stand-alone BESS would be ₹5.06/kWh and ₹4.70/kWh for a solar PV combined with BESS in 2025, which would drop to ₹4.12/kWh and ₹3.81/kWh by 2030. The study estimated the price for a PV-plus-storage PPA would be ₹3.32/kWh by 2025, falling to ₹2.83/kWh by 2030 (Deorah, *et al*., 2020).

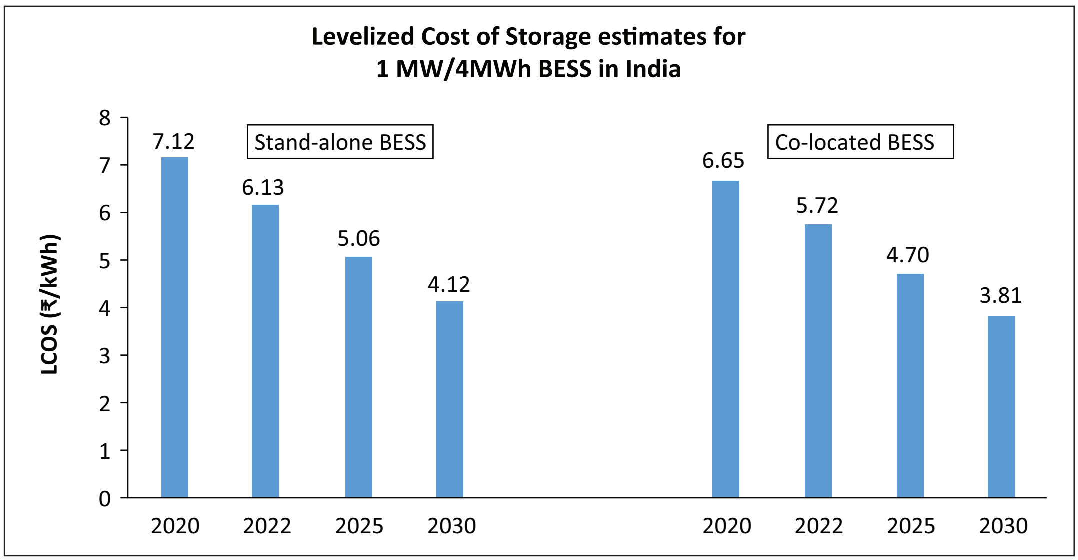

Figure 14: Estimated LCOS for stand-alone and co-located BESS in India (Lawrence Berkeley National Laboratory, 2020)

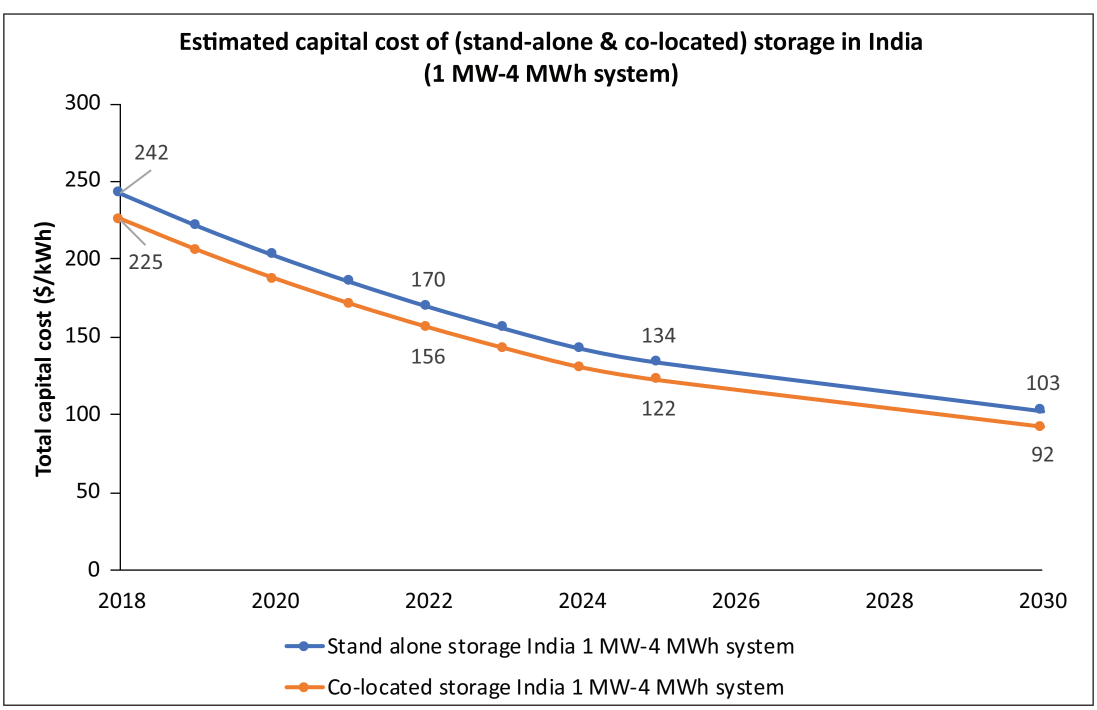

Figure 15: Estimated cost of BESS in India, with 5% annual reduction in non-pack prices (Lawrence Berkeley National Laboratory, 2020)

According to TERI's analysis and projections, solar plus battery storage cost would be at par with the costs of non-pit head coal power plants by 2030. The costs of generation from various technologies levelized over its lifetime have been estimated as indicated in Figure 16.

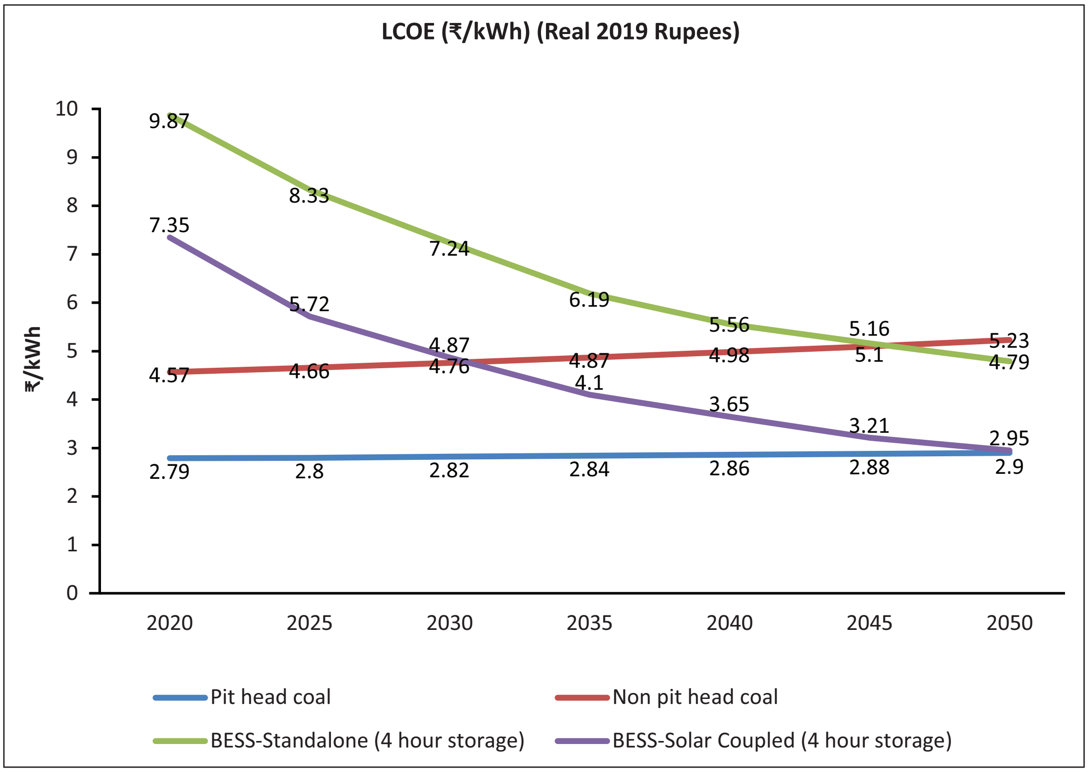

Figure 16: Levelized cost projections of BESS and coal-based power station

Source: TERI's analysis, 2021

Battery energy storage systems (BESS) based on low-cost Li-ion batteries may enable India to use stored solar energy to meet peak demand in mornings and evenings. As per TERI's analysis in a high renewable generation scenario for India, wind and solar curtailment would be reduced from 4% without storage to less than 0.2% with BESS. The LBNL analysis predicted that by 2030, 4–6 hours of energy storage would be cost-effective for diurnal balancing. Since their development and implementation cycles are much shorter than thermal power plants, renewables and storage could provide a pathway for India's energy transitions.

Annexure-III: Cost Projections of Different Storage Technologies

Analysis from different studies have found that with continued investment cost reduction, lithium ion could outcompete vanadium redox flow at high frequencies and displace pumped storage plants at high discharge durations to become the most cost-efficient technology for most modelled applications by 2030. At the same time, hydrogen storage becomes more cost efficient than compressed air for long discharge applications.

A snapshot of cost projections of different storage technologies (in ₹ crore/ MW) is showcased in Table 8 and Figure 17 below. It is clear that cost of different storage technologies observes a declining trend by 2030 and by 2050.

Table 8: Projections of capital cost of different storage technologies

Projections of capital cost of different storage technologies (₹ crore/MW)					
₹ Cr/ MW	**2020**	**2030**	**2035**	**2040**	**2050**
Lithium-Ion BS Capital Cost	2.7	1.4	1.3	1.2	1.2
Sodium Sulphur BS	3.4	2.2	2.0	1.9	1.6
Vanadium Redox Flow BS	2.1	1.4	1.3	1.3	1.1
Hydrogen	4.2	2.9	2.5	2.3	2.2
Pumped Hydro	2.8	2.8	2.8	2.8	2.8
Compressed Air	1.8	1.8	1.8	1.8	1.8
Flywheel	14.0	9.1	7.4	6.9	6.3
Super Capacitor	38.5	26.3	21.0	18.9	14.7

Source: TERI's compilation from various studies

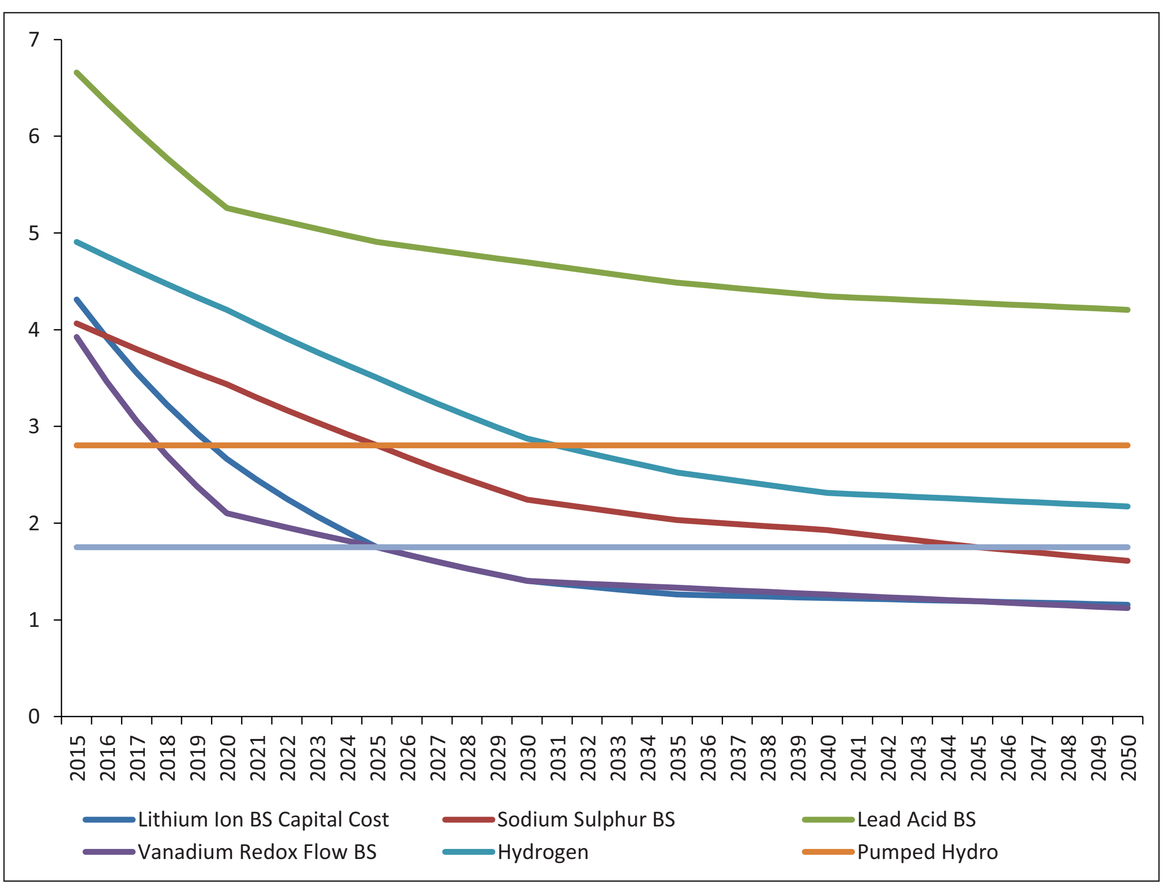

Figure 17: Projections of capital cost of different storage technologies up to 2050 (TERI's compilation from various studies)

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The Energy and Resources Institute (TERI) is an independent non-profit organization, with capabilities in research, policy, consultancy and implementation. TERI has multi-disciplinary expertise in the areas of energy, environment, climate change, resources, and sustainability.

With the vision of creating innovative solutions for a sustainable future, TERI's mission is to usher in transitions to a cleaner and more sustainable future through the conservation and efficient use of the Earth's resources and develop innovative ways of minimizing waste and reusing resources.

TERI's work across sectors is focused on:

- Promoting efficient use of resources across sectors
- Increasing access and uptake of sustainable practices
- Reducing the adverse impact on environment and climate

TERI works with a diverse range of stakeholders across governments, both at the National and State levels, international agencies, and civil society organizations to help deliver research-based transformative solutions. Headquartered in New Delhi, TERI has regional centres and campuses in Bengaluru, Gurugram, Guwahati, Mumbai, Nainital, and Panaji.

Currently, TERI's work is structured around seven sectors namely:

- Agriculture
- Climate
- Energy
- •Environment
- Habitat
- Health and Nutrition
- Resources

TERI brings out Discussion Papers on key contemporary issues in these sectors with multi-disciplinary and multi-sectoral implications for use by policy makers, legislators, researchers and practitioners. Discussion Papers are recommended for publication by a sub-committee of Distinguished Fellows at TERI. This Discussion Paper has been brought out by the Resource Efficiency & Governance Division as a part of TERI's work on mineral resources.

For more information, please visit: **http://www.teriin.org/**

The Energy and Resources Institute (TERI)
Darbari Seth Block, IHC Complex, Lodhi Road,
New Delhi- 110003

Tel: 71102100 or 24682100
Fax: 24682144 or 24682145
Web: www.teriin.org
E-mail: pmc@teri.res.in