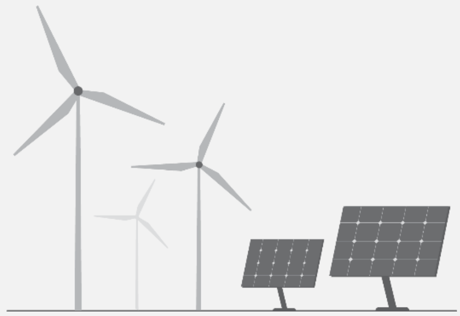
Science & Technology Policy Brief
Renewable Energy



Adoption of renewable energy technologies is crucial to efforts towards climate change mitigation. Solar and wind energy have emerged as two major renewable energy choices. This note explains engineering, costs, and policy challenges with adoption of solar and wind energy in India's context.

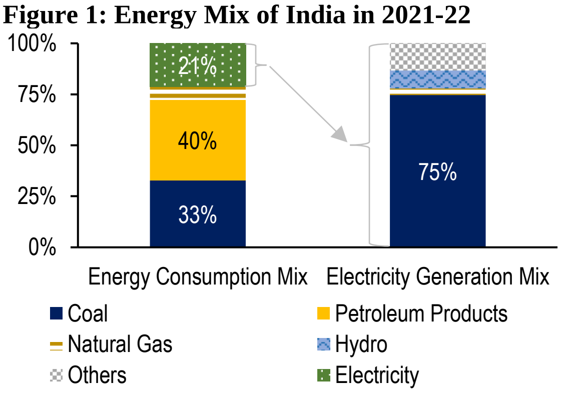
Summary

- Greenhouse gas emissions from renewable energy sources such as solar and wind are at least 20 times lower than coal.
- Solar and wind energy are intermittent in nature. This limits their reliability as energy source and increases grid stability challenges.
- Battery or pump storage is needed to integrate solar and wind energy.
- Including storage costs, solar and wind energy are not cost competitive yet. This may change as solar panel and battery prices decline.
- Capacity addition targets have been missed. Recently, time of day metering has been introduced to balance demand.

Background

In 2021-22, 95% of India's energy supply was sourced from fossil fuels– coal, crude oil, and natural gas (Figure 1).[1] Fossil fuels are the largest contributor of greenhouse gas emissions (~75% globally), leading to global warming.[2,3] Hence, transition to cleaner energy sources is the centrepiece of climate change mitigation.[4] This transition is envisaged in two key ways: (i) shifting to non-fossil sources for electricity generation, and (ii) shifting to electricity for final consumption.[5] In 2021-22, about 21% of the energy consumed was in the form of electricity; 75% of electricity was generated from coal.[1]

Figure 1: Energy Mix of India in 2021-22



Source: India Energy Statistics 2023, MoSPI; PRS.

Among non-fossil sources, solar and wind have emerged as key choices. They are replenishable in nature and have lower emissions. However, their intermittent nature leads to increased complexity in grid balancing and additional costs towards backup capacity.[6] This has implications for reliability, availability, as well as affordability of electricity.

Electricity Generation Technologies

Electricity is generated primarily in three ways: (i) by moving turbine coupled to a generator coil, which rotates inside a magnetic field to generate electricity, (ii) by directing light on semiconductor material (e.g. solar energy), and (iii) converting chemical energy to electricity (e.g. batteries).[7,8] Turbine may be moved using: (i) pressurised steam generated by heating water using coal, natural gas, or nuclear energy, (ii) water stream in cases of hydel and tidal power, or (iii) air flow in case of wind power.

Table 1: Key electricity sources- advantages and disadvantages[9]

Source	Advantages	Disadvantages
Fossil Fuel	Available on demand	Emissions, Finite resources
Nuclear	Available on demand, Clean	Safety concerns, Fuel availability, Waste disposal
Solar/wind	Replenishable, Clean	Not always available on demand, disposal of solar panels
Hydro	Replenishable, Clean, Available on demand	Ecological Impact, Displacement of people

Source: Dr. Armaroli, N., et al. (2010); PRS.

Emissions from Electricity

Lifecycle emissions from solar and wind are estimated to be at least 20 times lower than coal (Table 2 on next page).[10,11,12] While solar and wind sources do not emit greenhouse gases in the course of generation, the related manufacturing processes and logistics involve such emissions.[13] Lifecycle emissions take all such emissions into account.

Saket Surya
saket@prsindia.org

Harshit Padia
harshit@prsindia.org

July 31, 2023

Table 2: Lifecycle greenhouse gas emissions from electricity (gCO₂ equivalent per kWh)[14]

Source	Emission range
Coal	753-1095
Coal with CCS*	149-470
Natural Gas	403-513
Natural Gas with CCS*	92-221
Hydro^	6-147
Solar	7-83
Wind	8-23
Nuclear	5-6
Battery Storage	18-82

Note: *CCS: Carbon Capture and Storage Solutions. ^Hydro power has high site-specificity and variability in biogenic emissions from sediments in reservoirs.
Sources: Carbon Neutrality in UNECE Region; United Nations Economic Commission for Europe, March 2022; Lifecycle Greenhouse Gas Emissions from Electricity Generation Update; National Renewable Energy Laboratory of USA, September 2021; PRS.

Issues in Increasing Renewables

The Central Electricity Authority projects that much of the renewable energy capacity will come from solar and wind.[6] By 2031-32, solar and wind are projected to have 42% and 14% share in the total installed capacity (Table 3).[6,15] 35% of the total generation is expected to be met from these two sources.[6] The scope of building large hydro projects is limited due to land requirement, which leads to both displacement and ecological damage.[6]

Challenges due to Intermittence

While solar and wind are cleaner and unlimited sources of energy, the energy output at any point of time depends on the prevailing weather conditions.[16] These conditions are beyond human control. This causes variability in both intensity of energy output and duration of generation.[17,18,19] These variations could occur from day-to-day or on even second-to-second basis. For instance, cloudy sky at certain instances during the day could change the output of solar energy. Similarly, there are seasonal variations, for instance, average wind speed is higher during winter.[20] There may often be mismatch between demand and supply. For instance, there may be higher demand for electricity during the evening hours in the summer, but at that time, solar energy cannot be generated. This presents certain technical challenges in utilising these energy sources, which also has economic costs.

Balancing Grid

Currently, the electricity supply is managed with two key considerations. First, electricity cannot be stored at a large scale economically, hence, as demand varies, generation must be instantaneously adjusted. Second, electricity must be supplied at a rated voltage and frequency, as fluctuations may result in damages to equipment, and sub-optimal energy efficiency.[21,22,23]

Table 3: All-India installed capacity (in GW)

Source	June 2023		March 2032 Projected*	
	Capacity	In %	Capacity	In %
Solar	70	17%	365	42%
Coal	213	50%	260	30%
Wind	44	10%	122	14%
Large Hydro (>25 MW)	47	11%	62	7%
Gas	25	6%	25	3%
Nuclear	7	2%	20	2%
Biomass	11	3%	16	2%
Small Hydro (<=25 MW)	5	1%	5	1%
Diesel	1	0%	-	-
Total	**422**	**-**	**874**	**-**
Pumped Hydro Storage	-	-	27	-
Battery Storage	-	-	47	-

Sources: Installed Capacity Report for June 2023, Central Electricity Authority; National Electricity Plan Generation Vol. I, May 2023, Central Electricity Authority; PRS.

In case of sources such as coal, nuclear, gas, and hydro, one can control the power generated. Increase or decrease in demand for power is met by increasing or decreasing the rotating speed of the turbine. In case of thermal power, increasing rotating speed could involve burning more fuel to generate more pressurised steam. In case of hydro, it would involve increasing water flow. In case of solar and wind, generation depends on external factors such as light intensity and wind speed.

Along with control on input power, the rate of increasing or decreasing generation is also crucial.[16,19,25] It is more expensive and technically less feasible to change the rate in case of coal and nuclear power than for gas and hydro.[24,25] It is easier in case of solar and wind as one has to connect or disconnect few windmills or solar panels from the system.

Need for Storage

In case of solar and wind, matching demand at given specifications requires having: (i) adequate forecasting systems, and (ii) backup systems which can be ramped up and down when needed.[25] One such option could be storage systems which would store any surplus generation, and supply electricity when needed.[25] Another option is to have complementary capacity which is available on demand. For instance, a gas or hydro power plant can be set up as backup. However, such systems would involve additional capital costs.

Capacity Planning

For the same amount of power generation, a higher installed capacity is needed in case of solar and wind as compared to other sources. For instance, coal capacity can be utilised up to 90% of the time, whereas the highest possible capacity utilisation in case of solar is estimated to be 20%-22% and that of wind power in the range of 30%-40%.[26] Suppose instead of one MW of additional coal power, renewable capacity needs to be set up. We would need about four times capacity in case of solar (4-4.5 MW) or two-three times capacity in case of wind (2.2-3 MW). Further, the generation will be variable, hence, storage capacity would also be required. Storage requirement will vary widely based on generation, demand, and load patterns.[27]

Energy Storage Technologies[28,29,30,31]

Pumped Hydro: Water is pumped and stored upstream with surplus energy, which can later be used to run turbines.

Battery Energy Storage Systems: These use various battery technologies such as lithium-ion and lithium-polymer.

Compressed Air: Electrical energy is used to store compressed air, which can later be used to run turbines.

Thermal storage: Surplus energy is used to heat or cool fluids or heat molten salts. The stored energy is then used to generate electricity using heat exchangers and turbines.

Hydrogen: Renewable energy is used to produce hydrogen from water. Hydrogen could be used to produce hydrogen fuel cell, which could act as power source for vehicles.

Cost of Generation and Storage

Cost is an important consideration in adoption of energy sources as affordability of electricity is crucial for economic growth and competitiveness, as well as equitable access. As per estimates by the International Energy Agency (2022), the cost of electricity generation from both solar and wind are already lower than coal over the project lifecycle and is expected to decline further in coming years (Table 4).[26,32] However, due to intermittence, backup systems need to go hand-in-hand with capacity planning, and comparison must take costs of such systems into account.

Table 4: Levelised Cost* for India (Rs per kWh)

Source	2021	2030	2050
Coal	4.8	4.4-6.8	4-16
Nuclear	5.6-6	5.2	5.2
Solar	2.8	1.6	1.2
Wind Onshore	3.6	2.8-3.2	2.8
Wind Offshore	9.6	5.2-6	3.6-4
Large Hydro	2.1-8.4	-	-
Small Hydro	3.2-5.4	-	-
Pumped Hydro^	4.5-5.5	4.5-5.5	-
Battery Storage^	6.7-7.1	3.8-4.1	-

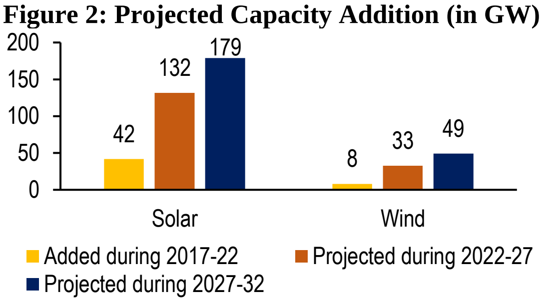
Note: *Levelised Cost of Electricity/Storage (LCOE/LCOS) considers all costs over lifetime including capital costs, fuel costs, and maintenance costs. The above estimates include taxes and subsidies, and do not include external costs on health and environment. LCOE converted from USD/MWh to Rs/kWh at the rate of Rs 80 for one USD. ^LCOS for eight-hour storage.
Sources: Global Energy and Climate Model, International Energy Agency, 2022; Renewable Power Generation Costs in 2021, International Renewable Energy Agency; Estimating the Cost of Grid-Scale Lithium-Ion Battery Storage in India, Lawrence Berkeley National Laboratory, 2020; PRS.

Battery and pump storage are expected to be two primary options for storage in India.[6] Battery storage prices are expected to decline in over next few years, driven by increase in demand, enhanced economy of scale, and technological improvements.[28,33] Pump storage is relatively mature technology, hence, the price may not vary as much.[6,28] In case of solar power in India, IEA (2021) observed that as of 2020, new solar power with battery storage systems were more expensive than new coal power.[34] Although, this is expected to change by 2030 (30% lower per unit).[34] By 2030, solar energy with battery storage is also expected to be competitive with existing coal capacity.[34] This is expected to be driven by a consistent decline in prices of batteries as well as solar panels.[11,28,26,34]

Challenges in Adding Capacity

As per the National Electricity Plan by the Central Electricity Authority, India is projected to significantly step-up capacity addition in both solar and wind (Figure 2).[6] By 2022, India had set a target of achieving installed capacity of 100 GW of solar and 60 GW of wind power.[36] As of December 2022, the installed capacity of solar stood at 63 GW and that of wind at 42 GW.[35] Key reasons for underachievement on targets include: (i) issues with land acquisition, (ii) delay in clearances, (iii) contractual disputes, (iv) disruption in global supply chain due to COVID-19, and (v) policy uncertainty due to changes in tariff regimes and renegotiation of power purchase contracts.[6,36,37]

Figure 2: Projected Capacity Addition (in GW)



Source: National Electricity Plan Generation Vol. I, May 2023, Central Electricity Authority; PRS.

Rooftop solar: India had set a target to add 40 GW of rooftop solar by 2022.[38] However, against this target, only 8 GW capacity has been installed as of February 2023.[38,39] The advantages of rooftop solar include reduction in: (i) requirement for dedicated land, (ii) load on grid by generating power at the point of consumption, and (iii) costs towards transmission and distribution.[40] However, distribution utilities (discoms) have shown reluctance in facilitating rooftop solar installation for customers.[38] This is due to: (i) potential loss of revenue from high-paying consumers, and (ii) uncertainties in demand forecasting, leading to system stability issues.[38,41]

Rooftop solar requires upfront capital investment from consumers. Typically, industrial, and commercial consumers would have the means to undertake such installation.[40] These customers are also high-paying consumers for discoms and cross-subsidise other consumer categories.[42] If these consumers shift to rooftop solar, discoms stand to lose revenue.

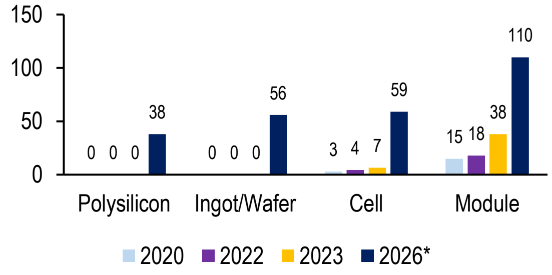
Solarisation of agricultural pumps: The PM-KUSUM scheme aims to achieve a solar capacity of 31 GW through solarisation of agricultural pumps and small solar power plants on barren agricultural land.[43] It aims to add 10 GW of small solar power plants and install a total of 35 lakh solar pumps.[43,44] Originally, this capacity was to be added by 2022.[44,45] The target has subsequently been revised to 2025-26.[46] As of June 2023, a capacity of 113 MW of small solar plants has been installed.[43] Also, a total of 2.45 lakh solar pumps have been installed.[43] The Ministry of New and Renewable Energy (2023) observed that onset of COVID-19 pandemic affected capacity addition during 2020-21 and 2021-22.[43] It also observed that access to affordable finance and lack of subsidy from state governments are among key reasons for poor uptake of the scheme.[43,47]

Availability of Solar Panels

In the recent years, India has imported more than 75% of its installed solar panels.[11,48] To arrest import, the central government has taken several measures.[48,49] It has increased import tariffs on solar panels as well as raw material for such panels.[48] These policies have led to an increase in price in the short-term and have affected the rate of capacity addition.[38] At the same time, the central government has introduced the production-linked incentive to promote domestic manufacturing.[50]

Driven by these incentives, domestic manufacturing capacity for solar panels is expected to rapidly increase over the next five years and be sufficient to meet the domestic demand thereafter.[48] However, India may need to continue to import polysilicon and wafer. Polysilicon is high-purity crystalline silicon product, which is heated to liquid mass to make wafers (thin slices).[11,51] These wafers are used to fabricate photovoltaic cells.

Figure 3: Domestic Solar PV manufacturing capacity (in GW)



Note: *Projected.
Source: India's Photovoltaic Manufacturing Capacity Set to Surge, JMK Research and Institute for Energy Economics and Financial Analysis, April 2023; PRS.

Waste from Solar Panels

Solar panels contain elements such as silicon, aluminium, silver, copper, lead, and cadmium.[11] If proper dismantling and disposal of panels is not ensured, it poses environmental and health risks.[11,52,53] Existing panels were not designed to be recycled.[11] Also, the extraction of the constituent elements from modules is technically difficult and expensive.[11] This might lead to a large amount of waste reaching landfills. By 2050, solar panel waste is estimated to be 80 million metric tonnes.[53] Similar concerns exist with waste from batteries, which will become more pronounced with their use for energy storage and electric vehicles.[54,55]

Demand-side Challenges

Demand Response

To optimise the requirement for capacity as well as storage in case of renewable energy, demand may need to be shifted to periods of higher-availability of power.[16] Policy measures for enabling this shift include tariff-based interventions such as differential tariffs based on the time of day and the time of use. For instance, tariffs could be higher during low-availability and high-consumption periods and vice-versa. Adoption of such measures are contingent on modernising metering infrastructure. The central government has taken certain initiatives in these directions. It has mandated installation of smart meters by March 2025.[56] It has also mandated the introduction of time-of-day tariff for all retail consumers (except for agricultural consumers) by April 2025.[57,58]

A second approach is to regulate supply to consumer categories who do not need power all the time. Currently, about 21-24% of the total electricity supply is estimated to be consumed in the agricultural sector.[59] IEA (2021) observed that the demand of this sector has shifted in certain states by creating dedicated feeders for them and then scheduling power to them in low demand hours.[34] It added that tariff-based mechanisms for agricultural sector can be one of the most cost-effective solutions to improve system flexibility.[34]

Demand Augmentation

To spur demand for renewable energy, distribution utilities (discoms) are obligated to procure a minimum percentage of their electricity supply from renewable sources, referred to as renewable purchase obligation (RPO). However, only six states had met this target in 2019-20.[36] At the national level, achievement was 10.8% against a target of 17.5%.[36] The Union Ministry of Power had observed that discoms perceive renewable energy to be expensive and having additional costs towards integration.[36] As per a July 2022 notification, RPO is set at 25% for 2022-23 and will progressively rise to 43% in 2029-30.[60]

[1] Energy Statistics India – 2023, Ministry of Statistics and Programme Implementation, https://www.mospi.gov.in/sites/default/files/publication_reports/Energy_Statistics_2023/EnergyStatisticsIndia2023.pdf.

[2] "Climate Action", Website of United Nations Organisation, as accessed on July 15, 2023, https://www.un.org/en/climatechange/science/causes-effects-climate-change.

[3] Synthesis Report of the Sixth Assessment Report, Intergovernmental Panel on Climate Change, March 2023, https://www.ipcc.ch/assessment-report/ar6/.

[4] "Cabinet approves India's Updated Nationally Determined Contribution to be communicated to the United Nations Framework Convention on Climate Change", Press Information Bureau, Union Cabinet, August 3, 2022, https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1847812.

[5] Tracking Clean Energy Progress, International Energy Agency, July 2023, https://www.iea.org/reports/tracking-clean-energy-progress-2023.

[6] National Electricity Plan, Generation Vol-I, Central Electricity Authority, May 2023, https://cea.nic.in/wp-content/uploads/irp/2023/05/NEP_2022_32_FINAL_GAZETTE-1.pdf.

[7] "Electricity explained", Energy Information Association, as accessed on July 12, 2023, https://www.eia.gov/energyexplained/electricity/how-electricity-is-generated.php.

[8] "How Does Solar Work", Office of Energy Efficiency and Renewable Energy, as accessed on July 12, 2023, https://www.energy.gov/eere/solar/solar-energy-technologies-office.

[9] Dr. Armaroli, N., et al. (2010). Energy for a sustainable world: From the Oil Age to a Sun Powered future. Wiley.

[10] Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources, United Nations Economic Commission for Europe, March 2022, https://unece.org/sites/default/files/2022-04/LCA_3_FINAL%20March%202022.pdf.

[11] Solar PV Global Supply Chains, International Energy Agency, August 2022, https://iea.blob.core.windows.net/assets/d2ee601d-6b1a-4cd2-a0e8-db02dc64332c/SpecialReportonSolarPVGlobalSupplyChains.pdf.

[12] Life Cycle Greenhouse Gas Emissions from Electricity Generation: Update, National Renewable Energy Laboratory of USA, September 2021, https://data.nrel.gov/submissions/171.

[13]Amponsah, N., *et al*, (2014). Greenhouse gas emissions from renewable energy sources: A review of lifecycle considerations, Elsevier, https://www.sciencedirect.com/science/article/abs/pii/S1364032114005395.

[14] gCO_2 per kWh represents total greenhouse gas emissions per unit of electricity generated. kWh represents one unit of electricity supply. gCO_2 equivalent is a metric that converts emissions of other greenhouse gases such as methane and nitrous oxide into the amount of CO2 that would have same warming effect over a given timeframe.

[15] Installed Capacity Report-June 2023, Central Electricity Authority, https://cea.nic.in/wp-content/uploads/installed/2023/06/IC_June_2023_Updated.pdf.

[16] Integrating Variable Renewable Energy: Challenges and Solutions, National Renewable Energy Laboratory, September 2013, nrel.gov/docs/fy13osti/60451.pdf.

[17] "Renewable Energy Intermittency Explained: Challenges, Solutions, and Opportunities", Scientific American, as accessed on June 15, 2023, https://blogs.scientificamerican.com/plugged-in/renewable-energy-intermittency-explained-challenges-solutions-and-opportunities/.

[18] Agarwal, P., & Jain, S. (2019). Challenges Faced and Measures Adopted for RE integration in Indian Power System. CIGRE, https://posoco.in/wp-content/uploads/2021/01/Challenges-Faced-and-Measures-Adopted-for-RE-Integration-CIGRE-Canada-2019-Paper-186.pdf.

[19] Renewables Integration in India, International Energy Agency, July 2021, https://iea.blob.core.windows.net/assets/7b6bf9e6-4d69-466c-8069-bdd26b3e9ed1/RenewablesIntegrationinIndia2021.pdf.

[20] Managing Seasonal and Interannual Variability of Renewables, International Energy Agency, April 2023, https://iea.blob.core.windows.net/assets/bfe623d2-f44e-49cb-ae25-90add42d750c/ManagingSeasonalandInterannualVariabilityofRenewables.pdf.

[21] Kothari, D. P. (2018). Electric machines. The McGraw-Hill Companies.

[22] Indian Electricity Grid Code, Central Electricity Regulatory Commission, https://cercind.gov.in/2010/ORDER/February2010/IEGC_Review_Proposal.pdf.

[23] D. Tommassini. (2011). Dielectric insulation and High Voltage Issues. CERN, https://cds.cern.ch/record/1342701/files/335.pdf.

[24] Ramping Up the Ramping Capability, India's Power System Transition, National Renewable Energy Laboratory of USA, September 2020, https://www.nrel.gov/docs/fy20osti/77639.pdf.

[25] Report on Optimal Generation Mix 2030 Version 2.0, Central Electricity Authority, April 2023, https://cea.nic.in/wp-content/uploads/irp/2023/05/Optimal_mix_report__2029_30_Version_2.0__For_Uploading.pdf.

[26] Global Energy and Climate Model, International Energy Agency, October 2022, https://www.iea.org/reports/global-energy-and-climate-model.

[27] Renewables 2022, International Energy Agency, December 2022, https://www.iea.org/reports/renewables-2022.

[28] Electricity Storage and Renewables: Costs and markets to 2030, International Renewable Energy Agency, October 2017, https://www.irena.org/publications/2017/oct/electricity-storage-and-renewables-costs-and-markets.

[29] Energy Storage System Roadmap for India: 2019 – 2032, NITI Aayog, August 2019, https://www.niti.gov.in/sites/default/files/2019-10/ISGF-Report-on-Energy-Storage-System-%28ESS%29-Roadmap-for-India-2019-2032.pdf.

[30] "Pumped Storage Hydropower", US Department of Energy, as accessed on June 19, 2023, https://www.energy.gov/eere/water/pumped-storage-hydropower.

[31] "Compressed Air Energy Storage", American Clean Power, as accessed on June 19, 2023, https://energystorage.org/why-energy-storage/technologies/compressed-air-energy-storage-caes/.

[32] Renewable Power Generation Costs in 2021, International Renewable Energy Agency, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jul/IRENA_Power_Generation_Costs_2021.pdf?rev=34c22a4b244d434da0accde7de7c73d8.

[33] Estimating the Cost of Grid-Scale Lithium-Ion Battery Storage in India, Lawrence Berkley National Laboratory, April 2020, https://international.lbl.gov/publications/estimating-cost-grid-scale-lithium.

[34] India Energy Outlook 2021, International Energy Agency, https://iea.blob.core.windows.net/assets/1de6d91e-e23f-4e02-b1fb-51fdd6283b22/India_Energy_Outlook_2021.pdf.

[35] All India Installed Capacity (in MW) of Power Stations as on December 31, 2022, Central Electricity Authority, https://cea.nic.in/wp-content/uploads/installed/2022/12/IC_Dec_2022.pdf.

[36] 17th Report: Action Plan for Achievement of 175 GW Renewable Energy Target, Standing Committee on Energy, 17th Lok Sabha, March 2021, https://sansad.in/getFile/lsscommittee/Energy/17_Energy_17.pdf?source=loksabhadocs.

[37] Hemi H. Gandhi, Bram Hoex, Brett Jason Hallam,

Strategic investment risks threatening India's renewable energy ambition, Energy Strategy Reviews, Volume 43, 2022, 100921, ISSN 2211-467X, https://doi.org/10.1016/j.esr.2022.100921.

[38] 34th Report: Demand for Grants 2023-24, Standing Committee on Energy, 17th Lok Sabha, March 2023, https://sansad.in/getFile/lsscommittee/Energy/17_Energy_34.pdf?source=loksabhadocs.

[39] Unstarred Question No. 1584, Ministry of New and Renewable Energy, Rajya Sabha, March 14, 2023, https://sansad.in/rs/questions/questions-and-answers.

40 Sarangi, G. K. and F. Taghizadeh-Hesary. 2021. Rooftop Solar Development in India: Measuring Policies and Mapping Business Models. ADBI Working Paper 1256. Tokyo: Asian Development Bank Institute. https://www.adb.org/sites/default/files/publication/697186/adbi-wp1256.pdf.

41 Renewables Integration in India, International Energy Agency, https://iea.blob.core.windows.net/assets/7b6bf9e6-4d69-466c-8069-bdd26b3e9ed1/RenewablesIntegrationinIndia2021.pdf.

42 Report on Performance of Power Utilities 2020-21, September 2022, https://www.pfcindia.com/DocumentRepository/ckfinder/files/Operations/Performance_Reports_of_State_Power_Utilities/Report%20on%20Performance%20of%20Power%20Utilities%202020-21%20(1).pdf.

43 Unstarred Question No. 159, Ministry of New and Renewable Energy, Lok Sabha, July 20, 2023, https://sansad.in/getFile/loksabhaquestions/annex/1712/AU159.pdf?source=pqals.

44 Annual Report 2022-23, Ministry of New and Renewable Energy, https://mnre.gov.in/img/documents/uploads/file_s-1683099362708.pdf.

45 No. 32/645/2017-SPV Division, Ministry of New and Renewable Energy, November 4, 2020, https://mnre.gov.in/img/documents/uploads/file_s-1604916676296.pdf.

46 "PM-KUSUM - Grid-connected solar power plants of 89.45 MW capacity installed; 2.09 lakh agriculture pumps have been solarized; Reduction in carbon dioxide (CO2) emissions by 0.67 million tonnes and diesel consumption by 143 million litres of diesel per annum- Union Power & NRE Minister – Shri R. K. Singh", Press Information Bureau, Ministry of New and Renewable Energy, March 16, 2023, https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1907703.

47 "24th Report: Demands for Grants 2022-23 of Ministry of New and Renewable Energy"; Standing Committee on Energy, March 2022, https://loksabhadocs.nic.in/lsscommittee/Energy/17_Energy_24.pdf.

48 "India's PV Manufacturing Capacity set to surge", JMK Research, Institute for Energy Economics and Financial Analysis, April 2023, https://jmkresearch.com/wp-content/uploads/2023/04/Indias-Photovoltaic-Manufacturing-Capacity-Set-to-Surge-April-2023.pdf.

49 Photovoltaic Manufacturing Outlook in India, Institute for Energy Economics and Financial Analysis, February 2022, https://ieefa.org/resources/photovoltaic-manufacturing-outlook-india.

50 "Government allocates 39600 MW of domestic solar PV module manufacturing capacity under PLI (Tranche-II)", Press Information Bureau, Ministry of Power, March 28, 2023, https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1911380.

51 "Solar Photovoltaic Manufacturing Basics", US Department of Energy, as accessed on July 18, 2023, https://www.energy.gov/eere/solar/solar-photovoltaic-manufacturing-basics#:~:text=The%20manufacturing%20typically%20starts%20with,interconnect%20pathway%20between%20adjacent%20cells.

52 "Solar panels face recycling challenge", May 22, 2022, C&EN, https://cen.acs.org/environment/recycling/Solar-panels-face-recycling-challenge-photovoltaic-waste/100/i18.

53 Heath, G., *et al.* (2020). Research and development priorities for silicon photovoltaic module recycling to support a circular economy, Nature, https://www.nature.com/articles/s41560-020-0645-2.

54 Harper, G., Sommerville, R., Kendrick, E. et al., Recycling lithium-ion batteries from electric vehicles. Nature 575, 75–86 (2019), https://doi.org/10.1038/s41586-019-1682-5.

55 Thompson, D. L., et al., (2020). The importance of design in lithium ion battery recycling–a critical review. Green Chemistry, 22(22), 7585-7603, https://doi.org/10.1039/D0GC02745F.

56 F.No. 23/35/2019-R&R, The Gazette of India, Ministry of Power, May 23, 2022, https://egazette.gov.in/WriteReadData/2022/236032.pdf.

57 The Electricity (Rights of Consumers) Rules, 2020, Ministry of Power, https://static.pib.gov.in/WriteReadData/userfiles/final%20-%20Copy%202.pdf.

58 The Electricity (Rights of Consumers) Amendment Rules, 2023, Ministry of Power, https://powermin.gov.in/sites/default/files/webform/notices/30_d_Electricity_Rhts_of_Consumers_Amendment_Rules_2023..pdf.

59 Report on Performance of Power Utilities – 2021-22 (updated up to May 2023), Power Finance Corporation, https://www.pfcindia.com/DocumentRepository/ckfinder/files/Operations/Performance_Reports_of_State_Power_Utilities/Report%20on%20Performance%20of%20Power%20Utilities%20-%202021-22%20%20updated%20up%20to%20May%202023.pdf.

60 F. No. 09/13/2021-RCM, Ministry of Power, July 22, 2022, https://powermin.gov.in/sites/default/files/Renewable_Purchase_Obligation_and_Energy_Storage_Obligation_Trajectory_till_2029_30.pdf.