



ENERGY TRANSITIONS
COMMISSION



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RESOURCES INSTITUTE
Creating Innovative Solutions for a Sustainable Future

Sustainable Action Dialogue New York

Leadership Coalition on
Energy and Industry Transition

24 September, 2019



SECOND INTERNATIONAL PRE-EVENT OF THE
WORLD SUSTAINABLE DEVELOPMENT SUMMIT 2020

29 - 31 January, 2020 | New Delhi, India

ABOUT ENERGY TRANSITIONS COMMISSION

The Energy Transitions Commission (ETC) brings together a diverse group of individuals from the energy and climate communities: investors, incumbent energy companies, industry disruptors, equipment suppliers, energy-intensive industries, non-profit organisations, advisors, and academics from across the developed and developing world. Their aim is to accelerate change towards low-carbon energy systems that enable robust economic development and limit the rise in global temperature to well below 2°C. The ETC is co-chaired by Lord Adair Turner and Dr Ajay Mathur. The ETC members agree on the importance of cutting carbon emissions, and share a broad vision of how the transition to a low-carbon energy system can be achieved.

VISION AND ROLE OF ETC IN INDIA TO ENABLE DECARBONISATION

ETC India aims to foster the adoption of low carbon pathways in India through intense and informed discussions between Indian partners, key policymakers and others concerned with technology options and investment opportunities for evolving policy. ETC India is led by TERI as the secretariat. In its first year, ETC India focused on decarbonising the power sector. Whilst that work is still continuing, in the second year, ETC India has initiated research on decarbonising industrial sectors, with a particular focus on the 'harder-to-abate' sectors such as iron and steel, cement and petrochemicals. In this work, we will liaise with industry representatives to understand the challenges with decarbonising Indian industry. Future decarbonisation strategies for industry will need to adopt a 'clean growth' approach, whereby economic growth, competitiveness, and job creation go hand-in-hand with a low carbon transition.

This document contains two thematic papers, which provide a summary of the work carried out in these areas to date. The first paper covers India's electricity sector and the transition to renewables, whilst the second outlines the status of India's heavy industry sectors and the possible options for emissions reduction.

Acknowledgements and Disclaimer

TERI would like to express its gratitude to the ETC India project partners, Climate Policy Initiative (CPI), and the National Renewable Energy Laboratory (NREL). We would also like to acknowledge the valuable inputs of our knowledge partner, the Power System Operation Corporation (POSOCO). The contributions and insights from our corporate partners, Siemens, NTPC, BRPL, Giriraj Renewables, and CLP, have been invaluable.

Without the support of our Foundation Partners, Bloomberg Philanthropies, Hewlett Foundation, Oak Foundation, Shakti Foundation, Growald Family Fund, and Children's Investment Fund Foundation, this project would not have been possible. We are deeply grateful.

All findings and views expressed herein, and any eventual errors or omissions, are those of TERI alone.

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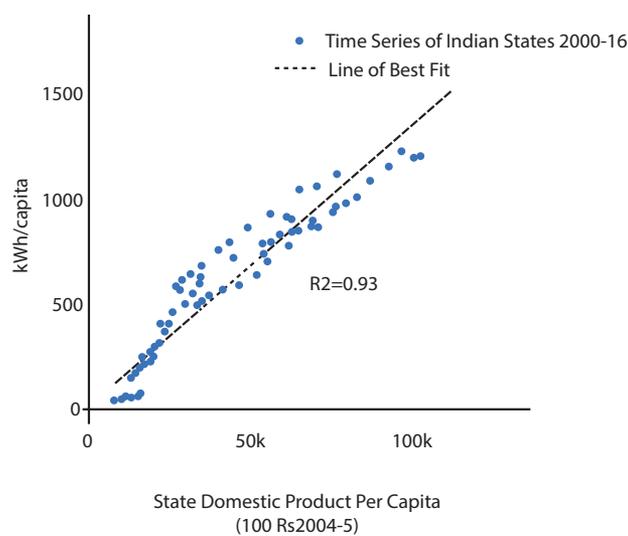
UNDERSTANDING INDIA'S ELECTRICITY SECTOR TRANSITION TO RENEWABLES

THOMAS SPENCER, FELLOW, TERI

Electricity is Crucial to India's Development

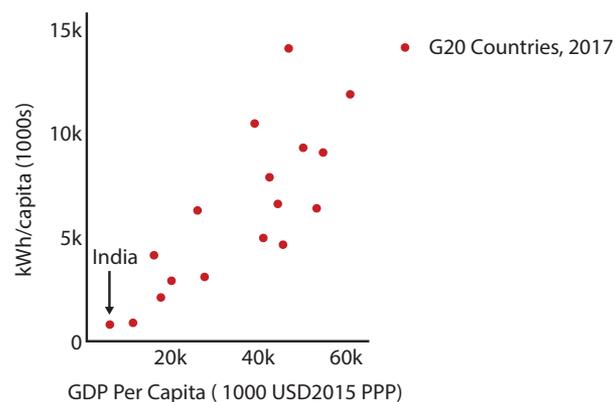
Reliable and affordable electricity supply is a prerequisite for India's development. Electricity increases household welfare and productivity, as well as the productivity and competitiveness of manufacturing. For India's large agricultural sector, access to affordable electricity has become essential for pumping groundwater, increasing farm productivity and income resilience, although with negative consequences in terms of excessive, inefficient groundwater withdrawal. The strong relationship between electricity consumption and state-level GDP per capita in India is shown in Figure 1. The poorest states in India have much lower levels of electricity consumption per capita than the richer states. Here there is clearly a dual causality. Low incomes prevent affordability of reliable electricity supply; lack of reliable electricity supply depresses economic opportunity and keeps incomes low. Figure 2 also shows that India's electricity consumption per capita is extremely low in an international perspective.

Figure 1: State-level GDP per capita versus electricity consumption per capita, India, 2000–16



Source: TERI, based on data from (CEA, n.d.; Reserve Bank of India, 2019)

Figure 2: G20 countries GDP per capita versus electricity consumption per capita



Source: TERI, based on data from (IEA, 2019; World Bank, 2019)

India's electricity consumption will continue to grow as India develops its economy.

THE INDIAN ELECTRICITY SECTOR HAS SIGNIFICANTLY INCREASED ITS PERFORMANCE IN RECENT YEARS

For decades after Independence in 1947, the Indian electricity sector was playing catch up on the very low level of development at Independence. In 1947, India's electricity consumption per capita was only 12 kWh, compared to 75 kWh in the United States as early as 1902, and 25 kWh per capita in Great Britain and Germany as early as 1910. At Independence, therefore, India's electricity sector was essentially at the level of those of the developed countries near the turn of the previous century (see Table 1). After Independence, India's growth in electricity generation, consumption and electrification was relatively rapid, compared to the rates achieved in the developing countries at the dawn of their electricity sectors. Growth in generation output per capita was almost 10% per year in the first few decades of India's independence (CEA, 2018).

Table 1: Electricity consumption per capita in major economies in a historical perspective

Country	Year	Per Capita Consumption (kWh)
United States	1902	75
Germany	1910	25
United Kingdom	1910	25
Russia	1913	13
India	1947	12

Source: TERI based on data from (Byatt, 1979; Carter et al., 2006; CEA, 2017; Coopersmith, 1992; Rahlf, n.d.)

However, for a number of decades heading into the 2000s, the performance of the Indian electricity sector still left much to be desired. For several decades since 1980, the annual energy deficit (i.e. unmet demand due to inadequate or unavailable generation resources) averaged about 10%, while the peak deficit was as high as 15-20% (CEA, 2018). In 1999 the rural electrification rate was only 49% and the increase in the rural electrification rate was showing clear signs of stagnating (Aklin, Harish, & Urpelainen, n.d.).

However, since the mid-2000s, India's electricity sector has made significant progress. The energy and peak deficits have declined to less than 1%. Rural electrification has advanced tremendously, with the country approaching 100% household electrification (Ministry of Power, 2019b). An important programme of largely coal-fired capacity addition occurred in the years 2010-2015, largely from the private sector spurred by the liberalization of electricity generation under the Electricity Act, 2003. This substantially increased available generation resources, and the energy and peak deficits fell to less than 1% in recent years.

DESPITE THIS PROGRESS, THE PERFORMANCE OF THE ELECTRICITY SECTOR IS STILL TO BE IMPROVED IN A NUMBER OF AREAS

Despite these important steps forward, there are a number of areas where the performance of the Indian power sector still requires improvement. The financial foundations of the sector are still shaky, with a pervasive yet incomplete cross-subsidy on tariffs from high-paying industry and commercial consumers to tariffs

from low-paying agricultural and residential consumers. In order to plug the gap in the tariff subsidy, state governments also provide direct budgetary support to electricity distribution companies. State government subsidies to electricity distribution companies in just six states amounted to INR 361 billion in the fiscal year 2017 (USD 5.2 billion, 0.2% of GDP) (Das, Dabadge, Chirayil, & Manabika Mandal, 2019).¹ Yet the gap in the tariff subsidy is not fully made up for by such fiscal subsidies from state governments, leaving distribution companies with large accumulated and still growing losses. As of June 2019, about 674 billion in dues were outstanding from distribution companies to generators, equating to USD 9.6 billion or 0.4% of GDP (Ministry of Power, 2019a). Outstanding dues from renewable energy generators amounted to about INR 68 billion in August 2019. All this is after a bailout of distribution company debt to the tune of INR 2.32 trillion under the Uday scheme (1.3% of GDP).²

While supply has improved and the energy deficit has come down significantly, many parts of India still face unreliable supply with rural areas still facing typically more than 20-30 interruptions per month. Aggregate technical and commercial losses in the electricity sector have also come down, but at about 18.7% they remain very high in an international comparison, and there is evidence that the actual number is higher still (Spencer & Awasthy, 2019). Electricity markets are still under development in India, with the vast majority of generation tied up in long-term, capacity-based contracts, and electricity exchanges accounting for only a tiny proportion of electricity transactions (6%). End-user prices are distorted by the cross-subsidy, with an aggregate gap between cost of supply and revenue realization still of about 0.26 Rs/kWh (Ministry of Power, 2019c). This implies, at a rough calculation, an annual revenue shortfall, which must eventually be made up from somewhere including state subsidies, of about INR 326 billion (0.19 % of GDP every year, or 1.6% of the total annual tax intake). The end-user price distortion promotes wasteful consumption in subsidized segments (notably agriculture, where it leads to ecologically harmful and wasteful consumption of groundwater), and undermines the economic competitiveness of high-tariff consumers notably manufacturing.

Due to the occasionally reckless expansion of coal-fired generation capacity in the period 2010-2015, there is now a substantial capacity of coal-fired plants that are stranded or stressed assets. About 54 GW of coal-fired capacity, and 7 GW of natural gas-fired capacity, are stranded or stressed assets. About INR 1 trillion of loans to the thermal power sector have gone bad, equating to a whopping 18% of total outstanding loans to the power sector or 0.6% of GDP. The causes of these stranded assets were the imprudent capacity expansion that occurred in the period 2010-15; demand growth slowdown after 2012; and upstream (coal linkages) and downstream (PPA tie-ups) challenges in the power sector value chain. It is not true, as of yet, that the growth of renewables has caused the stranded asset issues, although the future growth of competitive renewables may make the turnaround of these stranded projects unviable.

Thus, despite all its progress, the Indian power sector still faces a highly challenging context of incomplete markets and distorted price signals; lower technical capacities; and a pervasive, pernicious yet socially and politically unavoidable large-scale subsidy to huge swathes of the lower income population and agriculture. It is in still this challenging context that the transition to renewable electricity is occurring.

¹ Page three of the above-quoted source provides details on the data and methodology, as well as the limitations thereof. Suffice it here to quote a few relevant sentences: "This report, thus, has to refer to several sources other than regulatory documents, such as reports of the Comptroller and Auditor General (CAG), government notifications and documents and DISCOM audit reports. Efforts have been made to use audited data where available. Subsidy details are also reported in periodic reports published by the Power Finance Corporation (PFC) on the performance of state power utilities. There are several substantial discrepancies between data from the PFC and that from regulatory documents...". The study should thus be understood as the best possible effort to shed light on an un-transparent issue.

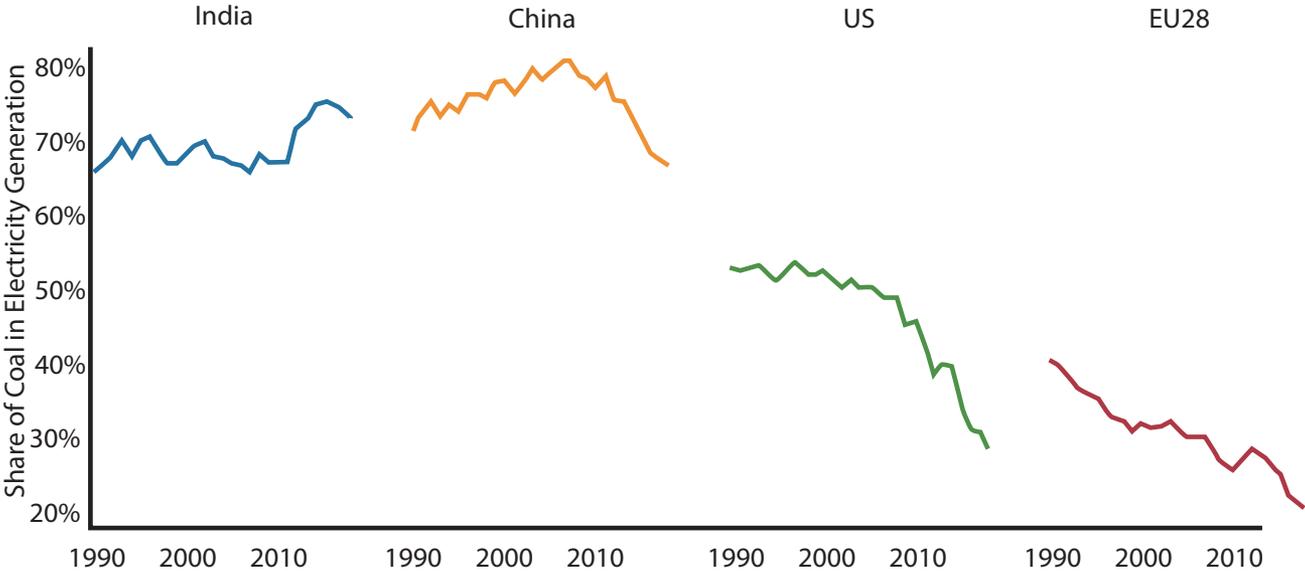
² Taken to be the total amount of bonds issued by state governments to taken on DISCOM accumulated debt. According to the Uday Portal (Ministry of Power, 2019c), a total of 2.32 trillion Rupees worth of bonds have been issued.

RENEWABLES ARE BY FAR THE CHEAPEST SOURCE OF NEW GENERATION

India has long experience with the exploitation of renewable energy, with the Ministry of New and Renewable Energy being established as early as 1992. However, the sector received a real boost in 2010 and then 2015, with the adoption respectively of the Jawaharlal Nehru National Solar Mission and the 175 GW target for renewable energy capacity by 2022. At the time of the adoption of the 175 GW target, solar PV tariffs typically ranged between INR 6 and INR 8/kWh and wind between INR 4 and INR 6/kWh (Prayas, 2019). Today, competitive auctions for solar and wind range between INR 2.5 and INR 3.0/kWh. This is significantly cheaper than the modelled cost of new coal, and cheaper even than the short-run marginal cost of a very substantial part of the existing coal fleet (Spencer, Pachouri, Renjith, & Vohra, 2018).

Driven by the government’s strong push, capacity expansion in renewables has accelerated significantly. On the back of this, the growth of renewable generation has allowed the share of coal generation to peak and start to decline. Figure 3 shows that the share of coal in India’s electricity generation has peaked in 2015, at a level lower than China and certainly lower than that of major European countries at comparable levels of development (in 1920, coal accounted for 99.56% of the energy input into electricity generation in the UK). India thus has the potential to peak and decline its share of coal in electricity at a far earlier stage of development that was achieved by either the early industrialisers or the catch-up industrialisers (China).

Figure 3: Share of coal in electricity generation, India, China, US and European Union (EU28)



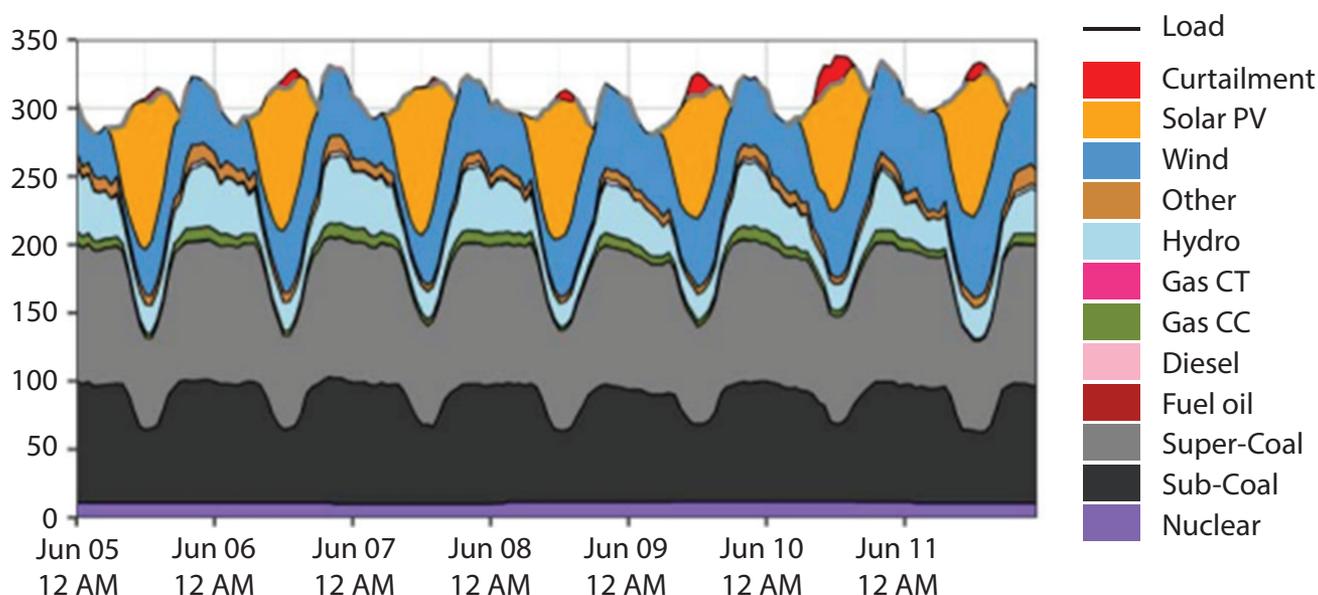
Source: TERI, based on data from (IEA, 2019)

THE RATE OF DEVELOPMENT OF RENEWABLES WILL DEPEND ON THE RATE OF INCREASE IN THE FLEXIBILITY OF THE POWER SYSTEM

With cost per kWh of renewable electricity no longer being an issue in India, the primary constraint on the growth of renewables in the future will be the rate at which the power system can be made more flexible to accommodate the variability of renewables. This variability of renewables poses a number of technical

challenges and additional costs to power systems, which must balance demand and supply in real time at every location in the grid. Figure 4 shows an output of a simulation of electricity system operation in one week in 2030, under a scenario of high renewables penetration. While high, this scenario for renewables penetration is well within the range considered in current official planning documents (see the following section). Figure 4 shows how the daily variability in renewables, particularly solar, leads to a large need for highly flexible operation of the electricity system, visible, for example, in the daily cycling of the coal fleet (see the variable daily output of the dark grey and light grey series).

Figure 4: Dispatch Simulation of the Indian Power System in 2030 With High Renewables



Source: Palchak, Chernyakhovskiy, Bowen, & Narwade, 2019

Thus, the key constraint to the rate of growth of renewables is the speed with which the Indian power system can be made more flexible to absorb variable renewables.

Dispatchable power plants must be able to vary their output quickly and flexibly to follow the scheduled and unscheduled variations in the output of variable renewables. In addition, electricity demand should be scheduled to the extent possible at times of high renewable energy availability, and consumption avoided at times when renewable energy is not available. There is a large potential for this from shifting agricultural pumping from the night, the current practice, to the daytime when solar electricity is available. In the near future, storage will become competitive with fossil fuels to provide peaking services, for example to meet the peak of electricity demand in the evening (Schmidt, Melchior, Hawkes, & Staffell, 2019). This could avoid substantial new build of expensive coal plant ‘peakers’, which would run only limited hours in the day. The expansion of transmission capacity between Indian states and regions is also necessary to allow the large-scale transfer of power across the country, from areas where renewables production is high to areas where demand is high.

All these changes in electricity system technology and operations need to be underpinned by the right planning processes, regulatory mandates and price signals, notably from more sophisticated and closer to real-time electricity markets. The Central Electricity Regulatory Commission (CERC) is moving forward on a number of electricity market reforms to introduce this kind of more sophisticated price signal into Indian electricity markets, and increase the depth and liquidity of Indian electricity markets.

Other countries such as the United Kingdom, Denmark and Germany, or subnational jurisdictions like Texas, South Australia or California, have succeeded in having quite a high level of variable renewables in their power systems. However, India presents some important differences which are likely to make it more difficult to integrate variable renewables in the Indian electricity system. Firstly, unlike mature economies, India's electricity and peak demand is growing rapidly. For example, in the United Kingdom peak demand has declined by about 2.8% per year since 2010, whereas it has grown by about 5% per year in India. Adding enough renewables to meet annual electricity demand growth is one issue; adding enough flexible electricity system capabilities (dispatchable capacity, demand response, or storage) to meet rapidly rising peak demand is a proposition that is just as challenging, if not more. Secondly, whereas high renewables electricity systems tend to be more reliant on wind, with a more constant output, India will have to rely to a large degree on solar energy, with a highly variable diurnal cycling of output (visible in Figure 4).

Thus, India's ambitions to transition to renewable energy in the electricity sector should be seen for what it is: an economically and environmentally desirable, yet institutionally and technically difficult process of systemic transition, in an already challenging environment. It will necessitate clear policy, technical and systems innovation, institutional learning, and rapid capacity building.

2030 VISIONS FOR THE POWER SYSTEM

TERI has studied in depth the evolution of the electricity system to 2030 (Pachouri, Spencer, & Renjith, 2019; Palchak et al., 2019; Spencer & Awasthy, 2019; Udetanshu, Pierpont, Khurana, & Nelson, 2019). This section presents the main conclusions of some of this analysis, as well as reflecting on official policy ambitions.

India's electricity demand is projected to grow about 6% per year between now and 2030, reaching about 2040 TWh of grid-based electricity demand.³ Including projected T&D losses and auto-consumption, the generation requirement would be in the order of 2400 TWh. This growth rate in itself presents a challenge to substantially increasing the share of renewables, requiring an extremely rapid rate of capacity addition to meet incremental demand growth. Within aggregate demand, the growth trajectory of cooling, in particular air conditioning, is expected to be particularly rapid, at about 10% per year (Spencer & Awasthy, 2019). This may present a real challenge to the integration of renewables, as much of India's residential cooling demand falls at night when solar is not available.

Scenarios studying the grid integration of renewables clearly show that the need for power system flexibility is projected to grow significantly under ambitious scenarios for the increase in renewables. While total demand is projected to roughly double by 2030, the need for daily balancing (shifting energy within a day to balance the variability in solar output, notably) is projected to grow six-fold by 2030 (Udetanshu et al., 2019). By the mid-2020s, the available supply of flexibility would be exceeded, posing an absolute constraint on the growth of renewables, unless proactive measures are taken to increase the flexibility of the power system. Nonetheless, India has a large potential to increase the flexibility of its power system, including by demand response, supply-side flexibility, and rolling out storage. A scenario with very high penetration of renewables shows no incremental system costs against a scenario with far more moderate renewables deployment, provided that a cost-effective and comprehensive portfolio of flexibility options is developed (Udetanshu et al., 2019). This portfolio needs to encompass supply-side flexibility from the dispatchable coal, gas and hydro fleet, demand respond and demand shifting, as well as the deployment of storage.

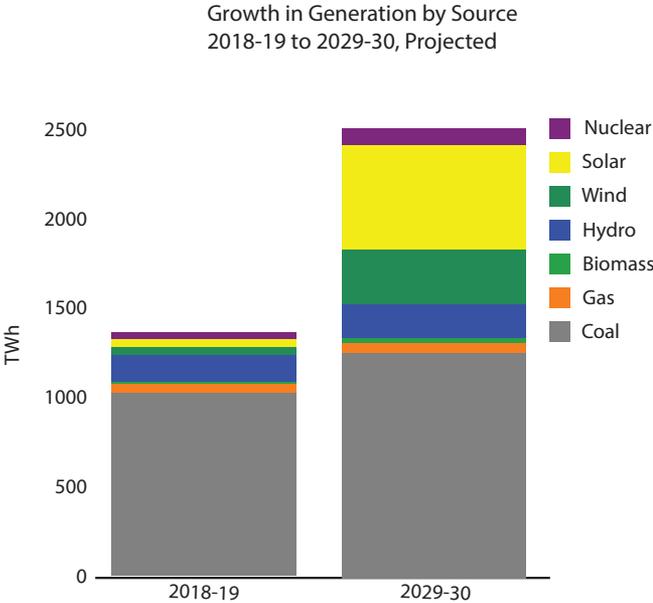
On the supply side, multiple scenarios, including from official sources, have now emerged with a variable renewables penetration of greater than 30% by 2030, the majority of which comes from solar (CEA, 2019;

³ Grid-based electricity demand excludes captive and off-grid generation. The figure above is for consumption, i.e. exclusive of technical and commercial losses.

Pachouri et al., 2019). The very high penetration of solar (>20%) would be unprecedented as of today, with no country having achieved a penetration of solar electricity greater than 10% (the penetration of solar electricity in California was 11.4% in 2018).⁴ If one includes hydro and nuclear, the share of total zero carbon generation is projected to reach greater than 45%. This is way above India's Nationally Determined Contribution (NDC), which targets zero-carbon generation capacity, not generation share, of 40% (under such scenarios the zero carbon generation capacity would be in the order of 60-65%). The share of coal generation would drop to 50%, although in absolute terms it would still have grown by some 2% per year on the 2018 level. Some very ambitious renewables scenarios see an absolute peak in coal generation attained just before 2030, declining thereafter (Spencer et al., 2018). Thus, while India may be unable to commit to absolute peaking of total emissions, pathways towards a sectoral peak in power generation are emerging.

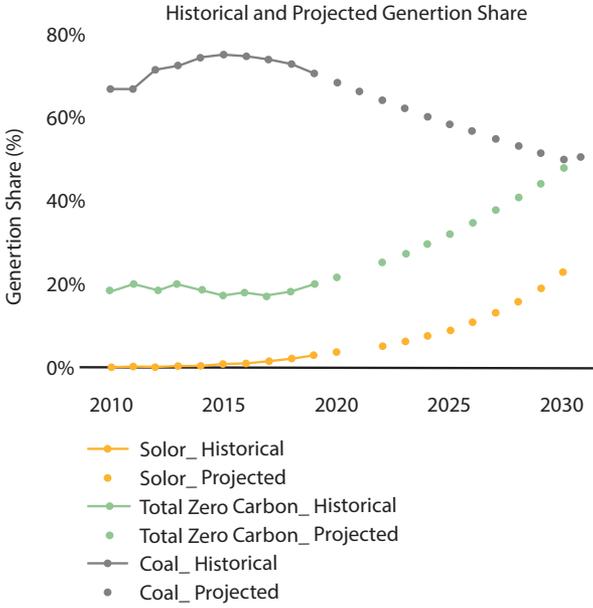
Figure 5 shows the projected generation by source in 2030, according to a recent study by the Government of India (CEA, 2019). The moderate growth in coal from current levels and the huge growth in solar and wind generation can clearly be seen. Figure 6 shows the historical and projected generation shares of coal, total zero carbon sources, and within zero carbon sources, solar. The importance of the dramatic ramp up in the share of solar can be seen. The source for this projection is a recent study from the Government of India (CEA, 2019), which accord quite closely with the analysis done by TERI (Pachouri et al., 2019).

Figure 5: Historical (FY18-19) and projected generation by source



Source: TERI, based on data from (CEA, 2019)

Figure 6: Historical and projected generation shares



Source: TERI, based on data from (CEA, 2019; IEA, 2019)

To summarize this section: ambitious visions are emerging, including from the Government of India, for a power sector that would be substantially transformed by 2030, with a zero-carbon share reaching almost 50% and a solar share reaching of more than 20% - an absolutely unprecedented level as of today.⁵ However,

⁴ The largest global penetrations of solar among major national economies as of 2018 was 8.24% in Italy, 6.79% in Greece, and 6.09% in Germany. A handful of small national power systems have achieved penetrations somewhat above this level.

⁵ The largest global penetrations of solar among major economies was 8.24% in Italy, 6.79% in Greece, and 6.09% in Germany. A handful of small power systems have achieved penetrations somewhat above this level.

analysis of the grid integration challenge of variable renewables in India clearly show that this transformation will be unachievable unless substantial progress is made in developing a comprehensive portfolio of flexibility options. While not a panacea, cost-effective storage will be crucial before 2030 for meeting evening peak demand, in order to smoothen the daily cycling of solar, and here global deployment efforts in stationary storage deployment matter tremendously to drive down the learning curve. For India, the cost of solar plus storage needs to reach parity with that of coal by the mid-2020s in order to give confidence that the trajectories seen in Figure 5 and Figure 6 are possible.

CONCLUSION: TRANSITION IN A CHALLENGING CONTEXT

The purpose of this paper is to give an overview of the emerging transition of the Indian power sector. Importantly, it is crucial to understand this with the Indian context firmly in mind. India is still a lower middle-income country, and improving the lives of its people means that its economy must grow rapidly. Evidence within India and from cross-country comparison shows that increasing the level of electricity consumption is crucial to this growth. The key question is how to cater to this growing demand, without exacerbating, and if possible, substantially mitigating, the challenges of resource scarcity, import dependence and environmental degradation.

The Indian electricity sector, thanks to the policy push given by the Government of India and the economic competitiveness of renewables, is firmly embarked on a trajectory of transition. However, this transition is occurring in a still-challenging context, where the performance of the electricity sector, while substantially improved, still leaves much to be desired. Improving the technical and financial performance of the electricity sector is important to deal with the challenge of integrating variable renewables securely into the Indian grid. The problems faced in the sector are deeply entrenched in India's political economy, and addressing them will not be easy.

In the future, the pace of the growth of renewables will be determined not by the cost of solar or wind electricity, but rather by the rate at which the operation and installed technology of the electricity system can be made more flexible. There is no quick fix here: cost-effectiveness requires that a portfolio of flexibility options are developed (Udetanshu et al., 2019). While battery storage can be a crucial component of this portfolio, under no reasonable scenario can it be a panacea by 2030. India will still need to improve the flexibility of its coal fleet, activate large scale demand shifting, develop an even more integrated grid infrastructure and operation to support large-scale power transfers across the country, and develop more sophisticated electricity markets. If this can be achieved in the years to come, a substantially lower carbon, cost-effective electricity system would start to emerge by 2030.

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