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WORKING TO TURN AMBITION INTO REALITY

The politics and economics of India's turn to renewable power

Rahul Tongia and Samantha Gross

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ABOUT THE AUTHORS

Rahul Tongia is a Fellow with Brookings India, and part of the Cross-Brookings Initiative on Energy and Climate. His work focuses on technology and policy, especially for sustainable development. He leads the energy and sustainability group at Brookings India, and also is active in broader issues of technology. Tongia's work spans the entire gamut of electricity, with focuses on supply options including renewable energy (covering finance, grid integration, etc.); smart grids, which use innovative information and communications technology to improve management of the electric utility grid; issues of access and quality; and broader issues of access, reforms, and regulations, including electricity pricing. He is also an adjunct professor at Carnegie Mellon University, where he was previously on the faculty for a dozen years. He was the founding technical advisor for the Government of India's Smart Grid Task Force, and remains founding advisor for the India Smart Grid Forum, a public-private partnership for smart grids in India established by the Ministry of Power. He has a bachelor's degree in electrical engineering from Brown University, and a Ph.D. in engineering and public policy from Carnegie Mellon University.

Samantha Gross is a Fellow at the Brookings Institution, and part of the Cross-Brookings Initiative on Energy and Climate. Her work focuses on the intersection of energy, environment, and policy. Gross has more than 20 years of experience in energy and environmental affairs. She was a visiting fellow at the King Abdullah Petroleum Studies and Research Center, where she authored work on clean energy cooperation and on post-Paris climate policy. She was also director of the Office of International Climate and Clean Energy at the U.S. Department of Energy. In that role, she directed U.S. activities under the Clean Energy Ministerial, including the secretariat and initiatives focusing on clean energy implementation and access and energy efficiency. Prior to her time at the Department of Energy, Gross was director of integrated research at IHS CERA. She holds a Bachelor of Science in chemical engineering from the University of Illinois, a Master of Science in environmental engineering from Stanford, and a Master of Business Administration from the University of California at Berkeley.

EXECUTIVE SUMMARY

Even before signing the Paris climate agreement, the Indian government announced extremely ambitious renewable energy (RE) targets that would quadruple the country's RE capacity between late 2014 and 2022, to 175 gigawatts (GW).[1] From India's relatively small RE base, this target implies annual growth of 25 percent—a targeted buildout rate even faster than China's, which is widely seen as the world's leader in deploying RE. However, a set of political and economic contradictions are built into this ambitious plan. These contradictions reveal how policymaking and implementation work in India and why visions for change often don't become reality.

At the center of India's contradictions are two core facts.

The first fact is that investment has created a vibrant and competitive RE market in India. The private sector is central in building most new RE capacity—it has developed aggressive financing mechanisms and is mobilizing massive amounts of capital. The RE industry is a heavily Indian affair. Foreign capital has not rushed in, thanks to costly foreign currency hedging and wariness about securing contracts and steady payments. But the RE business has risen in magnitude and power.

The other core fact is that RE faces a host of challenges, some particularly acute in or unique to India. RE cannot yet compete against most existing coal-fired generation, which remains the dominant source of power in India. Grid-scale solar and wind projects have found bids as low as 2.4 rupees per kilowatt-hour (about 3.9 cents per kilowatt-hour, or kWh),[2] a 70 percent decline in just a few years. Falling RE costs have inspired discussions of "grid parity"—an imagined moment when RE will push coal off the Indian grid. That moment is still far in the future when one includes the full costs of integrating RE into the grid. We find that the best performing RE systems, with aggressive assumptions about the cost of integration, are competitive with the most expensive new coal projects, but not with existing coal plants.

Another key challenge is that India's grid and utilities are weak. The electricity distribution companies (DisComs), almost all owned and controlled by state governments, play central roles. Most DisComs are struggling financially in ways that can lead them to delay payments, renegotiate power purchase agreements (PPAs), or avoid signing new PPAs.

The difficulties of integrating RE into India's power grid will worsen as RE's share of generation increases, causing disproportionate strain on states rich in RE resources. Other sources of generation—notably coal—will need to back down to accommodate rising yet variable RE generation. RE integration would be easier across larger balancing areas within the grid, but that approach would require substantial investments in long-distance RE-centric transmission, which have been limited so far. Energy storage could help, and we project the need for massive new storage capabilities at acceptable cost starting in the early to mid-2020s. However, a roadmap for obtaining affordable storage is also elusive.

Despite these sobering facts, the Indian government has repeatedly emphasized that its RE goals are the core of its energy policy. This insistence remains despite growing evidence that India does not need to meet its RE targets to achieve its goals under the Paris climate agreement. This contradiction persists because of the politics of RE in India. The central government sees RE as a vehicle for building new industries and rewiring investment incentives in the power grid, and as an extension of what Prime Minister Narendra Modi achieved when he was chief minister of Gujarat, a pro-business state in India that became a beacon for private sector-led shifts to renewable and cleaner power, not to mention an improved electricity grid.

Yet consumers are largely indifferent to renewables and concerned much more about electricity cost and reliability. The political power of coal also remains strong, along with the power of the railroads that earn much

[1] The 2015 Indian budget presented in February 2015 formalized the 175 GW RE target, but Power Minister Piyush Goyal spoke of higher targets at least as early as November 2014.
[2] "Year End Review 2017," Ministry of New and Renewable Energy, Government of India, http://pib.nic.in/newsite/PrintRelease.aspx?relid=174832.

of their revenue from moving coal. RE's impact on coal has been relatively limited thus far. Coal remains the dominant supply source, and is likely to grow at approximately 4 percent per year in terms of generation through 2030, a high growth rate in absolute terms, but lower than the past.[3]

Within this context, the central government has led by announcing bold goals for RE while failing to create the political, policy, and regulatory conditions that allow those goals to become reality. States often express hostility to rapid RE growth. Areas with high RE growth are likely to face high costs, especially when factoring in the impact on the rest of the grid. The states lag the central government in RE ambitions, and do not have Renewable Purchase Obligations (RPO) that add up to the national targets.

How did these contradictions emerge and persist? First, India's energy planning is rooted in years of scarcity, with more supply seen as the answer to all problems. Second, a silo-based approach across generation sources, rather than a portfolio-based approach, informed policy design and execution. This was exacerbated by a target-oriented approach (following Soviet-styled 5-Year-Plans, instead of a market-oriented system that allowed realistic signaling). Such a focus on adding generation worked, more or less, in the past, but recent growth of generation capacity and lower electricity demand growth changes the entire calculus. The question today is not one of sufficient energy, but of energy available at the right time and place with the right characteristics, such as ramping and predictability. RE is particularly disruptive in a power system designed for large, centralized supply.

Looking to the future, growing RE's share of generation will require institutional and regulatory actions to reduce the cost of grid integration. New market incentives are needed to create the right types of supply based on location, seasonal or daily availability, and ramping capabilities. Particularly important is a focus on the DisComs, which are a weak link in the existing system and quite vulnerable to disruption. The highest paying commercial and industrial customers are among the biggest investors in rooftop solar resources. An even bigger push toward RE by these important customers could accelerate the downward spiral of DisCom finances.

The world is watching India's transition to cleaner energy. Many are ready to support the growth of RE, particularly at the expense of coal. However, India's RE ambitions should be viewed not in terms of specific targets and numbers, but broader trends. Holistic policies will accelerate the transition.

[3] "World Energy Outlook 2015," (Paris: International Energy Agency, 2015), http://dx.doi.org/10.1787/weo-2015-en. A detailed bottom-up analysis on coal demand through 2030 by Sahil Ali (Brookings India, forthcoming) shows total coal growth inclusive of industrial use of approximately 3.8 percent.

Working to turn ambition into reality

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Introduction: Context for renewable energy in India

India's electricity sector—improving but still miles to go

India's economy has been a leader among developing nations, with gross domestic product (GDP) growing at 6.9 percent between financial year (FY) 2012 and FY 2018.[4] Energy and electricity demand have grown along with the economy and India now has the third-largest electricity grid in the world, with a gross installed capacity of 344 gigawatts (GW) in March 2018 (the end of FY 2018).[5] Nonetheless, with India's population of about 1.4 billion people, the grid supplies just under 900 kilowatt hours (kWh) of generation per capita (FY 2018), which is one-third of the world average and 14 times less than average U.S. consumption. In addition to low average consumption, approximately 32 million homes still lack an electricity connection as of April 2018.[6] The Indian government has ambitious plans to connect all homes to electricity by 2019.

The chronic shortfalls of electricity supply that plagued India in the past have abated, with an official peak shortfall for electricity of approximately 1 percent in terms of kilowatts (kW) and virtually no shortfall for energy (kWh).[7] These are average numbers across India, and pockets and times of shortfall remain.[8] India has experienced a sharp increase in installed generation capacity in the last few years, mostly from coal-fired power stations. Much of the recent growth in capacity (Figure 1) has come from the private sector (Figure 3), due to

[4] "Annual estimates of GDP at constant prices, 2011-12 series," (New Delhi: Ministry of Statistics and Programme Implementation, 2018), http://mospi.nic.in/sites/default/files/press_releases_statements/STATEMENT_12_const_2017-18_6may18.xls.

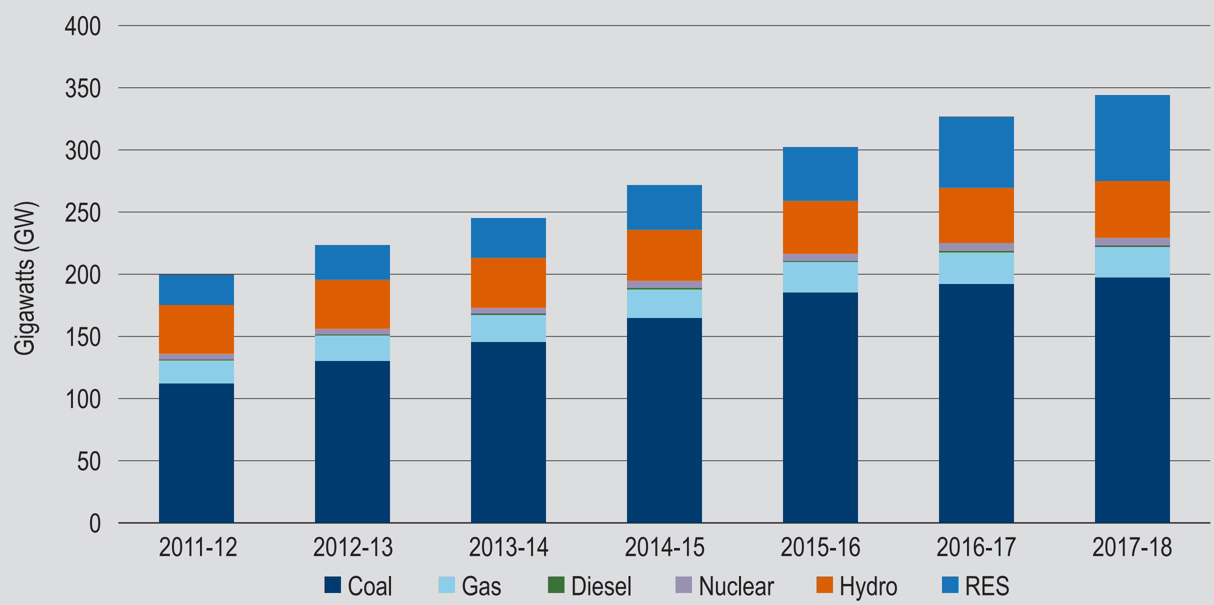
[5] "Power Sector March 2018", (New Delhi: Central Electricity Authority, 2018), http://www.cea.nic.in/reports/monthly/executivesummary/2018/exe_summary-03.pdf.

[6] Rajesh Kumar Singh and Saket Sundria, "India Nears Power Success, But Millions Still in the Dark," *Bloomberg*, April 26, 2018, https://www.bloomberg.com/news/articles/2018-04-26/india-nears-power-success-but-millions-are-still-in-the-dark.

[7] "Load Generation Balance Report 2017-18," (New Delhi: Central Electricity Authority, 2017), http://www.cea.nic.in/reports/annual/lgbr/lgbr-2017.pdf.

[8] The Central Electricity Authority's "Load Generation Balance Report 2017-18" indicates virtually no shortfall on paper. See Ibid. However, there are significant methodological flaws in how shortfalls are calculated. See Rahul Tongia, "Re-thinking Access and Electrification in India: From Wire to Service," (New Delhi: Brookings India, 2014), https://www.brookings.edu/wp-content/uploads/2014/09/electrification-from-wire-to-service.pdf.

Figure 1. India's installed gross power generation capacity.[10]



Note: Alternative data sources give a slightly different number for RE capacity, in part because some sources estimate distributed RE as well. These exclude captive and back-up power (true for the entire paper unless stated otherwise). RES refers to renewable energy sources, including biomass, mini-hydro, and others.

renewable energy (RE) additions and because the states could not generate capital for capacity expansion.

Coal dominates installed capacity, and its dominance is even starker in terms of generation (Figure 2). The share of hydropower, prized for its flexibility, has decreased due to social concerns over land. India has approximately 25 GW of gas-fired capacity, but the plant load factor (PLF) for these facilities is very low due to high gas prices. Government policies prioritize gas as a feedstock, especially for fertilizer production, and the economic value of gas is higher in non-power uses. Most gas capacity is base-load oriented combined cycle technology, which is not ideal for fast-ramping or fast-starting generation. Overall, lack of such nimble generation to balance RE is a substantial challenge.

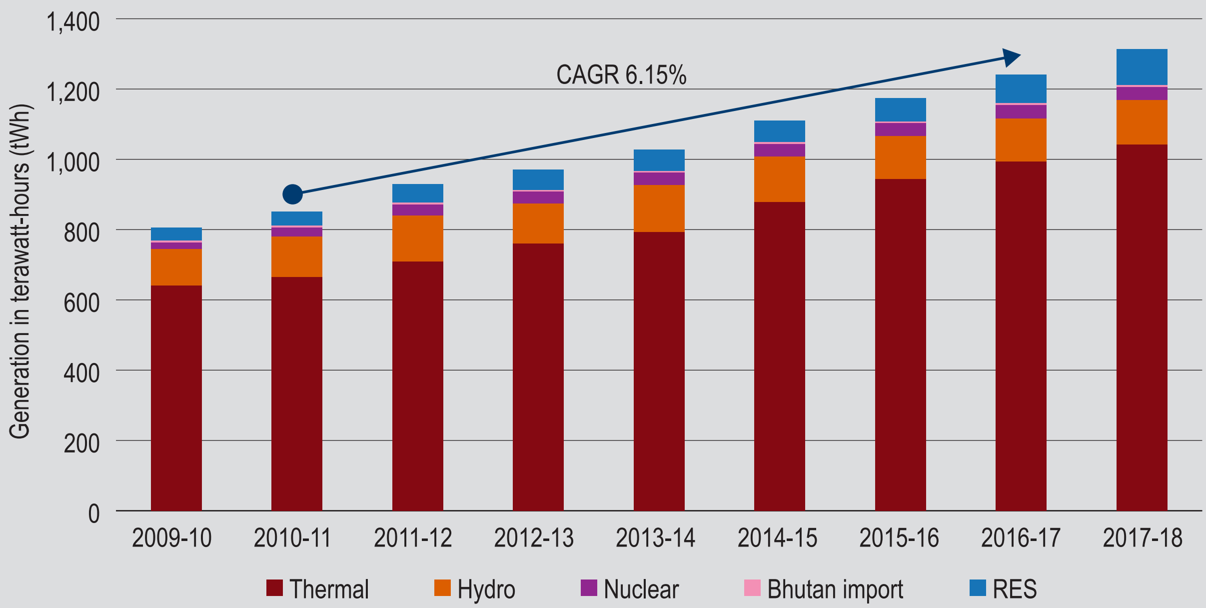
RE capacity has been growing rapidly, with wind and solar accounting for 65 percent of overall power sector capacity growth in 2017. Nonetheless, RE is not growing fast enough to meet incremental power growth; coal remains the residual source of capacity addition and generation. RE was only 6.6 percent of gross generation in FY 2017, rising to 7.8 percent in FY 2018.[10] India's share of RE generation in 2017 was comparable to the United States and even China (wind and solar only), but in Costa Rica and a number of countries in Europe, wind and solar have an electricity generation share measured in tens of percent.

The governance and structure of India's electricity sector

Electricity is a "concurrent" issue in the Indian Constitution, meaning that it is under both state and central jurisdiction. The Central Electricity Regulatory Commission governs interstate power flows and the respec-

[10] "Monthly Executive Summaries," http://cea.nic.in/monthlyarchive.html. For more detailed data, see the monthly executive summaries for March of the corresponding year.
[11] Calculated from CEA generation data, as per CEA Monthly Reports, Executive Summaries, March/April, 2017 and 2018.

Figure 2. Gross electricity generation in India.[12]



Note: Thermal includes all fossil fuel, but is predominantly coal. TWh refers to terawatt-hours, which are equivalent to a billion kWh or billion units (BU).

tive State Electricity Regulatory Commissions govern intrastate flows.

India's electricity sector has a mix of public and private ownership. Generation opened to the private sector in 1991, but reforms accelerated after 1998, when states began to unbundle their State Electricity Boards into separate generation, transmission, and distribution companies (DisComs). For the most part, these entities remain public sector enterprises. Private generation capacity has been the largest source of growth in recent years (Figure 3).

DisComs purchase power from a mix of publicly-owned and private generators. The DisComs are in precarious financial positions, losing on average just over 0.8 rupees per kWh sold (over 1 cent/kWh), despite enormous subsidies paid by the state governments and periodic bailouts.[12] Retail tariffs, set by the ostensibly independent State Electricity Regulatory Commissions,[13] are insufficient to meet their costs. The DisComs also lose an average of about 23 percent of their power to technical and "commercial losses" (theft).

DisComs purchase most power through power purchase agreements (PPAs), which are generally long-lived (frequently 25 years), with simple formulae for generator cost recovery that separate fixed (capacity) and variable (energy) charges for thermal power. RE power has a single part tariff since fuel charges are zero. Only 3.3 percent of India's power is sold through power exchanges.

Renewable energy in India—ambitious goals

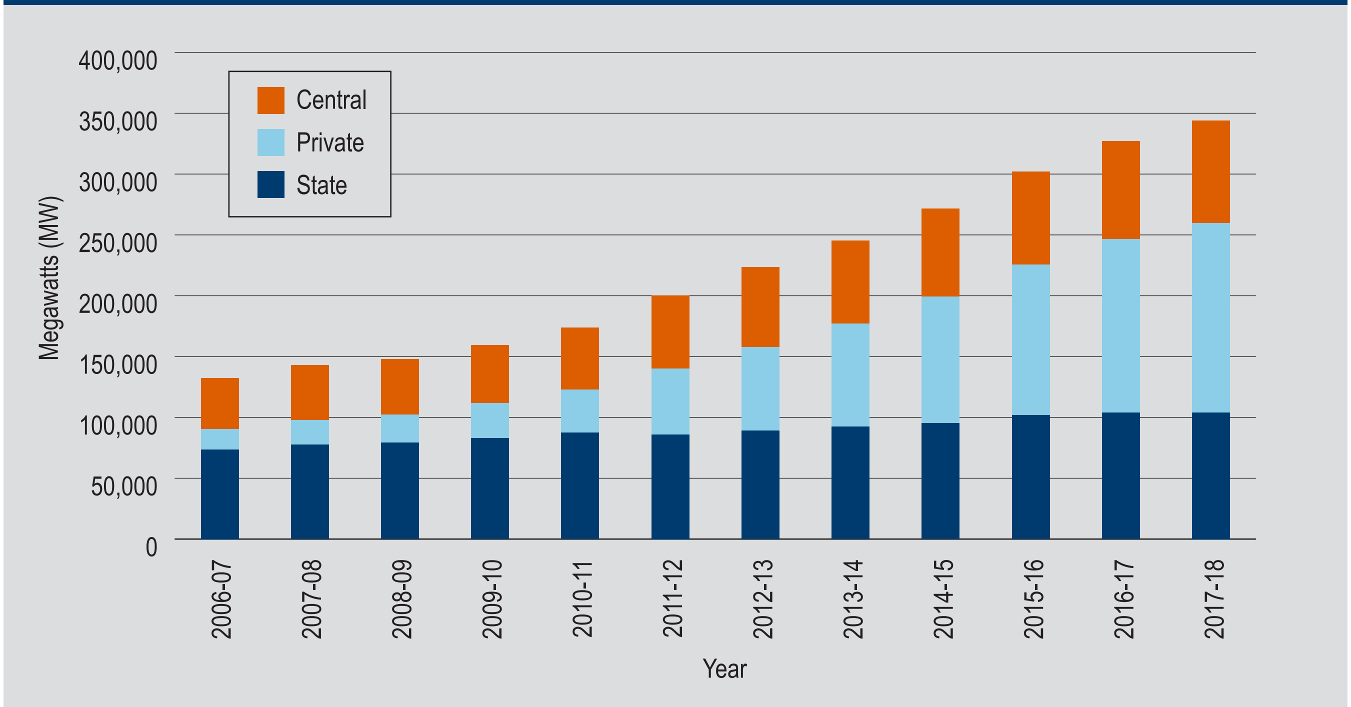
In early 2015, Prime Minister Narendra Modi formally established India's ambitious RE target, aiming to quadruple installed RE capacity to 175 GW by 2022. The target calls for 100 GW of solar (including 60 GW of

[11] "Monthly Executive Summaries," (New Delhi: Central Electricity Authority, 2012-18), http://cea.nic.in/monthlyarchive.html. For more detailed data, see the monthly executive summaries for March and April of the corresponding year.

[12] The official figure for 2015-16 is an average loss of Rs. 0.7/kWh as reported in the nodal agency Power Finance Corporation's (PFC's) report on Performance of State Power Utilities 2015-16. That uses input energy as a basis, instead of total losses divided by energy *sold* as calculated above.

[13] State governments exert control over State Regulators in a number of ways, from selecting Commission Members to, in extreme cases, even avoiding appointment of Members to avoid quorum, thus postponing tariff hearings (and inevitable tariff rises). State Commissions are also cash and manpower deficient and routinely rely on consultants and deputized utility staff.

Figure 3. Generation capacity ownership.[15]



grid-scale and 40 GW of rooftop solar), 60 GW of wind, and an additional 15 GW of other renewables, including micro-hydro and biomass.[15] These RE targets correspond to an annual capacity growth of over 25 percent, compared to recent annual growth rates for all grid-based electricity of about 6 percent.[16] This growth rate is multiple times higher than goals in China, the EU, or the state of California.[17]

Solar generation capacity would need to grow over 50 percent annually from 2015 through 2022 to meet the target. Wind power began with a much higher installed base, so its required growth rate is significantly lower than for solar. In 2014, the installed wind capacity of 21 GW was an order of magnitude larger than solar installed capacity of 2.6 GW.

2030 is a far more interesting year for analysis, not merely because of the Paris agreement. Policy changes and investments take time. Coal power plants take about five years to build. A solar power system can be built in six months, but accounting for the entire process of acquiring land, bidding, and contracting, it becomes at least a two-year process. Thus, a significant fraction of the capacity expected by 2022 is already planned or in the pipeline.

Although there are no official targets for RE after 2022, public statements by senior government officials suggest a 350 GW RE target for 2030. This target would represent an RE annual growth rate of only 9 percent from 2022 to 2030, counter to expectations of decreasing technology costs over time. The government's statutory Central Electricity Authority (CEA) models scenarios with 110 to 120 GW of RE by 2022.

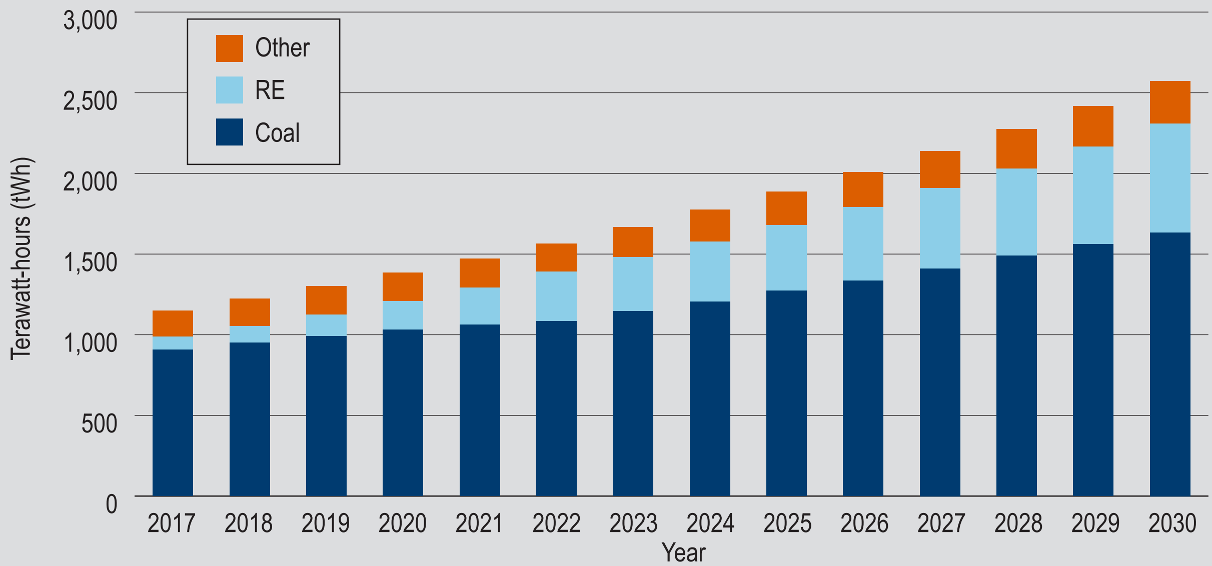
[14] 2006-07 to 2012-13 data is from http://planningcommission.nic.in/reports/genrep/rep_arpower0306.pdf, 2013-14- to 2017-18 data is from CEA Monthly Reports for March of the respective year.
"Monthly Executive Summaries," (New Delhi: Central Electricity Authority, 2012-18), http://cea.nic.in/monthlyarchive.html. For more detailed data, see the monthly executive summaries for March and April of the corresponding year.

[15] India does not categorize hydropower as renewable energy under the purview of the Ministry of New and Renewable Energy (MNRE), but rather as conventional energy under the Ministry of Power.

[16] Captive power, used extensively by industries seeking reliable power supply, has grown faster than grid-based electricity in recent years, and is not part of most statistics on electricity demand.

[17] The estimate for California is based on the 50 percent RE target by 2030, the EU estimate is based on the 20-20-20 plan that asked for 20 percent RE by 2020, and China's targets are as per the 2030 target for 30 percent RE, *inclusive of hydropower*.

Figure 4. Projected Indian power generation.



Note: This is based on Brookings India's modeling for RE meeting 2022 targets of 175 GW and 350 GW by 2030, and residual supply coming from coal. 2017 data reflect actual generation data. Overall demand is projected to grow at a 6.4 percent compound annual growth rate, which includes meeting a number of development targets of the government, such as Housing for All. The Appendix has more details.

Converting capacity into generation shows that if the RE targets are met, the share of RE in the generation mix would rise from less than 7 percent in FY 2017 to nearly 20 percent in 2022 and more than 26 percent in 2030. (More detailed calculations are in the Appendix.) Nonetheless, this is not enough renewable energy to eliminate growth in demand for coal-fired power. Assuming electricity demand growth of 6.4 percent per year, India's coal demand will not reach a peak before 2030.[18] Even lower electricity demand would not stop the growth of coal, but the growth rates would come down dramatically.

This paper focuses on the cost and competitiveness of RE in India. However, RE also offers benefits, reducing both local air pollution (at mines and power plants) and greenhouse gas emissions from coal-fired power. However, quantifying these benefits is beyond of the scope of this paper, in part because India does not price-in such externalities. Recent attempts to limit power plant emissions have been based on standards, rather than placing a cost on pollutants or allowing tradeable markets for emissions. The heterogeneity and uncertainty in emissions impacts is another challenge in quantifying RE's benefits. Although the precise value of RE's benefits is open to debate, the negative health impacts of coal-fired power are undisputable, especially in areas with many power plants. Indeed, coal-fired power plants cause approximately 100,000 additional deaths annually in India.[19]

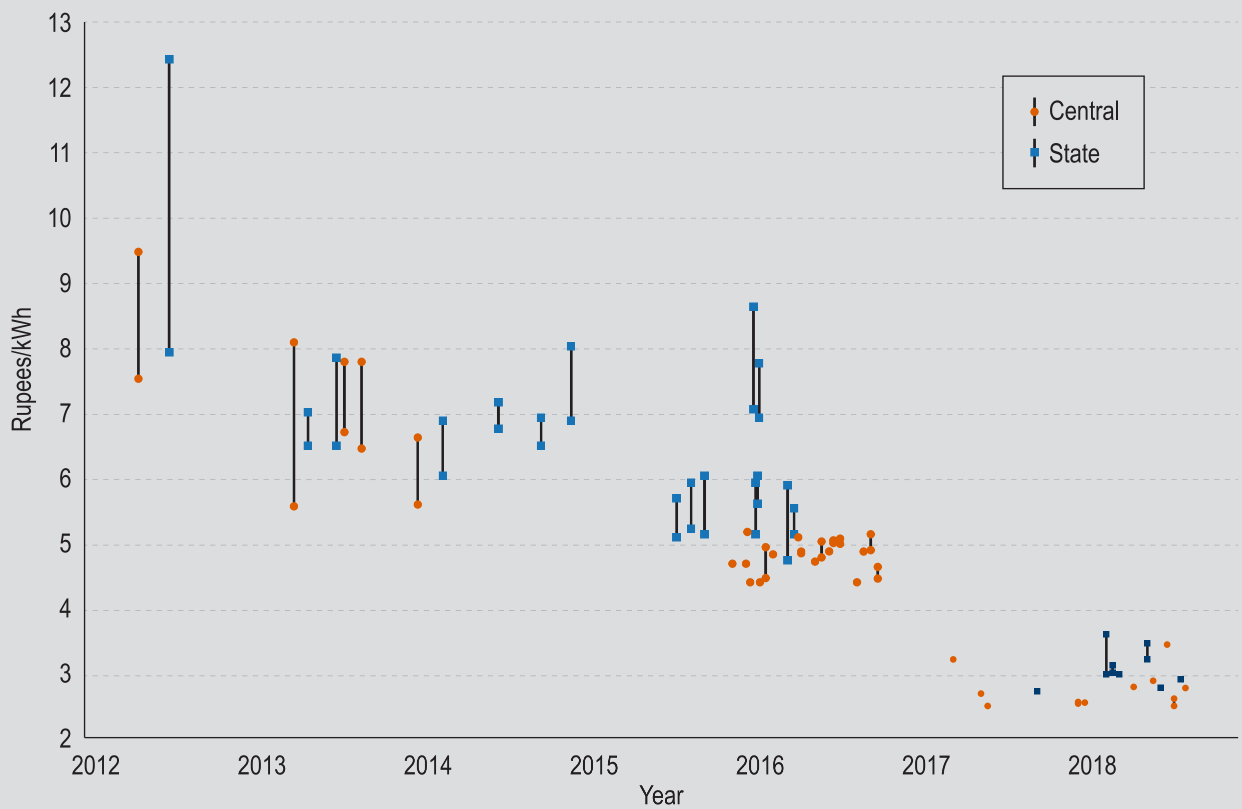
The competiveness and future of renewable energy

Bids for grid-scale solar generation have fallen dramatically in the last few years (Figure 5), resulting in newspaper headlines stating that solar power is cheaper than coal. Although solar bids have come in as low as 2.4 rupees/kWh of capacity (about 3.5 cents/kWh), compared to bids for new coal power plants of 4 or 5 rupees/kWh (about 5.8 or 7.2 cents/kWh), this is not

[18] This demand estimate is slightly on the higher side, but factors in the "Make in India" initiative as well as housing development objectives. This is based on modelling by Sahil Ali (Brookings India, forthcoming).

[19] "Coal Kills: Health Impacts of Air Pollution from India's Coal Power Expansion," (Mumbai: Conservation Action Trust, 2014), http://www.indiaairquality.info/wp-content/uploads/docs/Air%20Pollution%20from%20India%20Coal%20TPPs%20-%20LowRes.pdf.

Figure 5. Solar bids in India.[21]



Note: Vertical lines show the spread between the lowest and highest bids, where Central spans Jawaharlal Nehru National Solar Mission bids (earlier), the National Thermal Power Corporation and its arms, and the Solar Energy Corporation of India.

an apples-to-apples comparison. Most importantly, coal power is dispatchable while solar power is intermittently available. Additionally, grid-scale RE enjoys a number of support mechanisms, including a waiver of cross-subsidy charges (relevant for certain buyers) and of wheeling charges applicable to other generators, and even free transmission. Solar parks, which have the lowest bid prices, are huge facilities that come with discounted land or bundled land acquisition. (Land acquisition is a significant hurdle across India.) Importantly, coal and RE do not compete directly in bidding; each type of fuel has its own set of state or utility auctions, often with a fixed location in mind.

The majority of recent RE bids, and all of the "record low price" bids, have been in response to auctions by central government entities, such as the Solar Energy Corporation of India (a Special Purpose Vehicle for bidding RE), or the National Thermal Power Corporation's solar arm. These entities have healthier balance sheets than the DisComs and the ability to pool risk. A number of analysts and stakeholders have called the lowest bids not just aggressive, but bordering on irrational.[21] Others believe the bids reflect financing maturity, where financers are willing to accept lower rates of return than in the past.[22] Efforts continue to secure lower cost financing.

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[20] Data from Bridge to India compilation, used with permission.

[21] See "India RE CEO Survey 2018," (Gurgaon: Bridge to India, 2018), http://bridgetoindia.com/revamp/wp-content/uploads/2018/05/BRIDGE-TO-INDIA-India-RE-CEO-Survey-2018.pdf. The report indicates that 70 percent of CEOs thought that bidding was irrationally aggressive.

[22] Gagan Sidhu, "A Relook at Indian Renewable Offtake Risk," *LinkedIn*, July 9 2018. https://www.linkedin.com/pulse/relook-indian-renewable-offtake-risk-gagan-sidhu/.

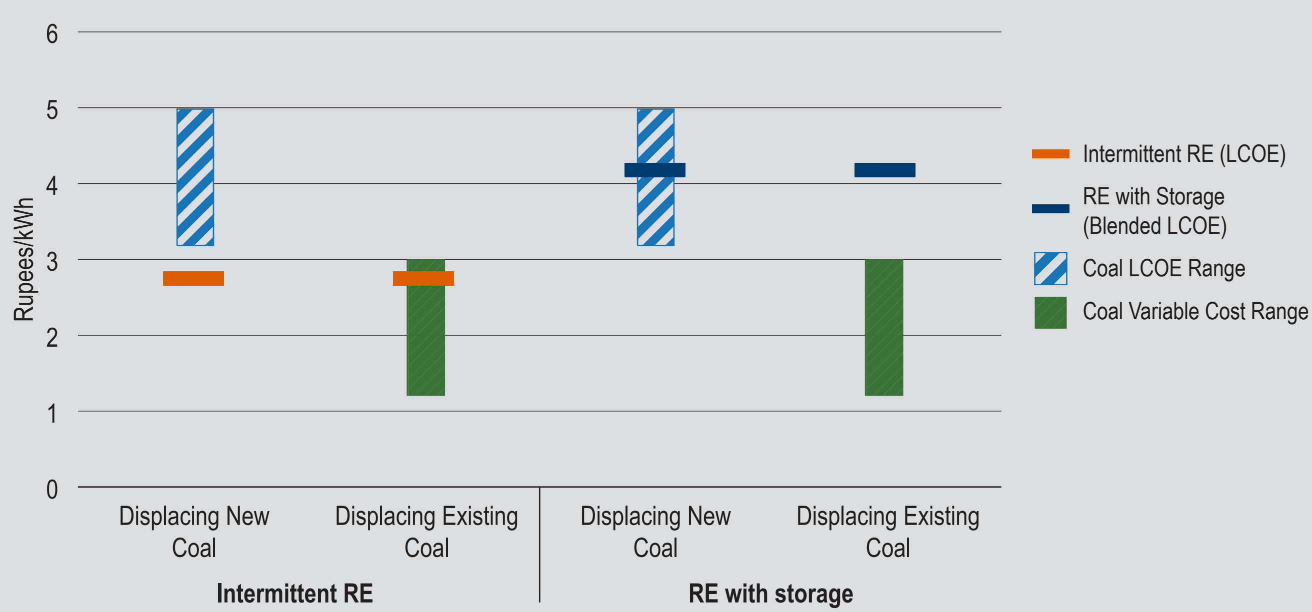
Economics are a critical component of evaluating the role and growth potential of RE, but RE's economics depend on the rest of the grid. Leaving aside for now details of grid integration and supply optimization, a simplified framework for considering the value of RE considers two extremes of competitiveness. At one end is the value of the RE when it is available, given that it is not dispatchable nor coincides with peak demand. At the other end, RE can be combined with storage to become available on demand and substitute for base-load power generation, such as coal.

Intermittent RE has a realistic forward bid price of about 2.8 rupees /kWh today (about 4 cents/kWh). This estimate includes slightly increasing prices for Chinese solar panels and India's new tax regime (the Goods and Services Tax), but does not include any Indian import duties on Chinese panels, which has just been announced at 25 percent.[23]

Costs for coal plants vary according to technology, efficiency, and distance from the coal mine. Transport dominates coal cost for plants located far from the mines. The fuel cost for pithead coal plants can be as low as 1.2 rupees/kWh (about 1.7 cents/kWh), inclusive of coal taxes, royalties, and other obligations. Together these levies are almost 40 percent of the pithead coal price.

Figure 6 shows cost comparisons for RE and coal in the two cases. The first set of comparisons for intermittent RE assumes that there is sufficient demand to absorb RE when it is available. When considering whether to build a new coal plant or RE, the appropriate comparison is the levelized cost of electricity (LCOE) for both plants. RE is a clear winner here, particularly at the high end of coal costs. Conversely, when considering whether new RE can displace existing coal, an appropriate comparison is the variable cost of coal to the LCOE of RE. The economics in this case generally favor coal.

Figure 6. Representative coal vs. renewable energy comparison; renewable energy with storage is prospective.



Note: Data based on Brookings India calculations. The spread in costs for coal are based on differences in variable (fuel) costs due to transportation. For RE with storage, this draws from Brookings India calculations that assume 40 percent of the RE power goes through a battery that costs $100/kWh (see Figure 7 for more details).

[23] Until early 2017, Chinese manufacturers were offering lower solar cell prices in India than in China. It is unclear how much this was a strategic decision versus any difference in quality of cells. Quality is a concern, given the very high temperatures in India, which can degrade panel conversion efficiency and performance over time. India's Directorate General of Safeguards proposed the 70 percent duty, but this could raise solar prices by 25 percent. See "Safeguard duty of 70% will put 3 GW solar projects at risk," *CRISIL*, January 17, 2017, https://www.crisil.com/en/home/newsroom/press-releases/2018/01/safeguard-duty-of-70percent-will-put-3-gw-solar-projects-at-risk.html. Recent announcements are for a 25 percent safeguard duty on solar panels.

At high levels of RE penetration, the system requires storage solutions so that RE can provide power when it is needed. Figure 6 demonstrates that RE with storage could still be competitive with the most expensive new coal plants, but that it is not competitive with existing coal plants. For the above calculations, we assume future fully-loaded battery costs (system level, including packaging, inverter, etc.) of $100/kWh, a marked reduction from today's cost. Pumped hydropower costs are a bit lower, but implementation timeframes are uncertain and the efficiency is also lower than for next-generation lithium-ion battery systems.

At what level of renewable energy does storage become necessary, and how much storage is needed?

Integrating 175 GW of RE will be challenging for the Indian grid. Most regulators have notified RE as "must-run" when it is available, meaning that other sources of electricity may need to be backed down to accommodate RE.[24] But not all other sources of power can be backed out of the system—nuclear plants and some coal plants must remain in operation. Additionally, RE potential, especially wind power, is concentrated in a handful of states. RE output on some days will likely surpass total electricity demand in these states, even by 2022.[25] Adding to the challenge, the frameworks for sharing power across state borders are not robust.

As RE's share grows, no amount of transmission to ship power to distant consumers will overcome an oversupply, necessitating storage to complement RE generation. How much storage will be required and when are tricky questions that require assumptions about how the rest of the grid grows. In less than a decade, RE capacity could exceed total mid-day demand. Assuming 6 percent annual growth in India's noon demand of about 160 GW today implies 2030 noon demand of 320 GW. Although this is less than the 350 GW RE goal (and not all RE would generate simultaneously, especially wind), not all other supply options will be able to curtail their output. Assuming that coal plants can reduce output to 55 percent of capacity, storage might be required at approximately 220 GW of RE capacity, assuming strong transmission and scheduling frameworks to carry power across state borders. These back-of-the-envelope numbers are based on average RE and typical noon demands. There are also days of lower electricity demand and days when wind and solar both produce near their maximum. Thus, the real-world level of RE that requires storage is likely to be measurably lower than a theoretical average calculation would suggest. The alternative would be more RE curtailment.

Estimating the cost for RE plus storage requires a number of assumptions. The two key variables for battery costs are their capital costs and how much storage is built per kWh of RE. Figure 7 shows the implications of these two key variables on the combined (weighted average) costs. At $100/kWh for the battery, and roughly 2.2 kWh of battery (corresponding to 40 percent of solar power stored in the battery), the combined costs are 4.2 rupees/kWh (about 6.4 cents/kWh).

The amount of storage needed for a 1 kW solar panel (producing 5 kWh/day) depends on the purpose of storage, ranging from grid stability to time-shifting. The amount also depends on RE's growth rate, the rest of the grid, demand growth, and the technical capability of coal plants to reduce their output.

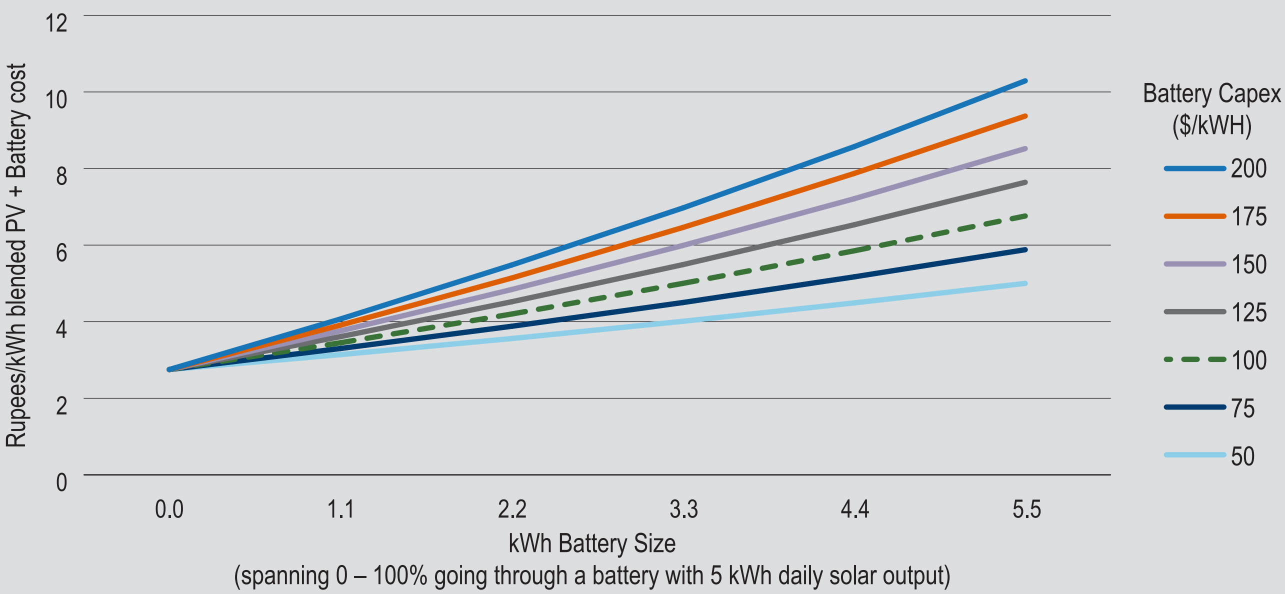
The above calculation is relevant mainly for grid-based solar power because it is the only RE technology amenable to storage at the generation source. End-users or third parties manage rooftop solar. Wind power, especially coastal wind, is heavily seasonal and thus hard to time-shift via storage.

Pumped hydropower is a proven storage technology, but its deployment is limited in India because of competing uses for power, such as irrigation. There is also little incentive to build storage, given that the time of

[24] In late 2017, a few states with surplus overall generation began to revoke must-run status for RE. These are state-level decisions taken counter to central government plans and guidelines, and are disputed as of now.

[25] See "Greening the Grid: Pathways to Integrate 175 Gigawatts of Renewable Energy into India's Electric Grid," (New Delhi and Washington, DC: Indian Ministry of Power and USAID, 2017), https://www.nrel.gov/analysis/india-renewable-integration-study.html. The study projected surplus RE by 2022 for multiple states, with occasional RE curtailment required.

Figure 7. Battery costs with a solar panel.



Note: Data based on Brookings India calculations. This chart shows RE plus battery costs with a 1 kW solar panel. This assumes base solar is 2.8 rupees/kWh without a battery (about 4 cents/kWh), a 15-year battery lifespan, and a 10 percent discount rate, for a high-efficiency battery system. A popular global benchmark price is $100/kWh. The x-axis shows the size of battery required for a 5 kWh daily solar input to span the share of electricity stored in the battery from zero to 100 percent. E.g., a 40 percent share, or 2 kWh of solar generation, translates to about a 2.2 kWh battery size (higher because of battery depth of discharge limitations).

day is not included in the value of electricity. The policy directive for high RE penetration is leading a nascent push toward pumped storage, rather than a direct price signal.

The exact details of storage are complex and require extensive modeling, but continued Indian RE growth depends on reasonably-priced storage technologies within 10 years, and perhaps sooner if air conditioning loads grow rapidly in homes, leading to a disproportionate rise in evening peak demand instead of day-time demand. Policies that encourage electricity consumption when it is available, such as time-of-day pricing, would postpone India's need for RE storage. Retail time-of-day pricing could take years to roll out, necessitating metering upgrades, but bulk consumers that already have amenable digital meters represent nearly half of India's electricity consumption.

The bottom line is that RE looks increasingly competitive only under today's LCOE-oriented framework, without feedback mechanisms for the system-level costs of RE.

Challenges for renewable energy in the Indian context

A lack of systems-level planning

Overcoming the variability of RE requires careful co-ordination among generation and load-serving entities. Although some RE stakeholders believe that the variability of RE can be managed through a "symphony" of generation sources,[26] India's grid is not quite ready for such precision.

India does not have sufficient transmission capacity across regions to accommodate an ever-growing share of RE. India's five regional grids were integrated into a synchronized national grid at the end of 2013, but the

[26] Mark Dyson and Amory Lovins, "The Grid Needs a Symphony, Not a Shouting Match," June 12 2017, Rocky Mountain Institute, https://www.rmi.org/news/grid-needs-symphony-not-shouting-match/.

interconnections between regions are modest. The balancing area and ultimate dispatch remain at the state level, and interstate transmission is sometimes tied to specific generation.

The grid can deliver power across state borders, but delivery must be scheduled a day ahead and deviations from the scheduled amount beyond plus or minus 150 megawatts (MW) or 12 percent of scheduled (whichever is smaller), are penalized.[27] This is a particular issue for RE, as predicting generation is challenging. The government attempted to mandate 30 percent accuracy of RE prediction, but developers were not ready and fought this move.[28] Even if RE generation could be predicted with 30 percent accuracy, this error would swamp the 150 MW schedule deviation aggregate limit for high-RE states.

Ultimately, mechanisms for power flow across state lines must be more flexible and dynamic to accommodate greater RE development. There are plans to build extensive long-distance transmission for RE, called Green Corridors. The economic justification for these investments, however, is uncertain, because the load factors on the lines may be low, linked to the low capacity utilization factor of RE.

The structure of Indian power markets also makes RE integration a challenge. Most power is purchased through PPAs that treat all kWh the same, regardless of when they are generated. This system provides a limited signal for when additional generation is needed. A transition to some form of time-of-day pricing at the wholesale level could facilitate RE development by encouraging development of peaking power, fast-ramping power, storage, and ancillary services such as frequency support and ramping. The current single-price framework does not signal the need for different *types* of electricity provision and services.

The dominance of PPAs means little power is traded at the wholesale level using demand-linked pricing. If there were a wholesale power market, the rise of RE (which would be dispatched first by design or fiat) would lower the average wholesale cost. We see this in extremes through occasional negative prices in Germany and parts of the United States. India's electricity system design does not directly allow this RE-related reduction in wholesale prices.

Finally, at the state level, a *non*-independent operator often handles load dispatch, with limited resources and computational/integrated planning skills and, in many states, without real-time visibility into the system. The central scheduling and balancing entity, POSOCO, was an outlier, relatively independent from its owner, the Central Transmission Utility (CTU), PowerGrid Ltd., a public sector enterprise. POSOCO's independence was further strengthened when it recently became a standalone entity, but the real challenges remain at the state level.

For far too long, India's grid has relied on the "cheapest" and most effective, but worst form of balancing: load-shedding. Brownouts will continue until utilities are forced to procure sufficient power to meet consumer demand.[29] As of now, there are few penalties for load-shedding. Until this loophole is addressed, a cynical view of "how much RE can the Indian grid handle?" would be answered by "as much as supplied," with the proviso that outages might increase.

System-level costs

The economic calculations above are at the generator-level and do not consider RE's system-level costs on other generators, such as the wear and tear due to fluctuating and fast-ramping outputs or the loss of efficiency when running at lower output levels. The per-unit cost of coal power plants will increase when they operate at lower PLFs, as they must spread their fixed costs over less generation. Adding storage reduces but does not eliminate system-level costs, since any addi-

[27] "Report of the Expert Group Volume II: Review of the Principles of Deviation Settlement Mechanism (DSM), Including Linkage with Frequency, In light of Emerging Markets," (New Delhi: Central Electricity Regulatory Commission, December 2017), http://cercind.gov.in/2018/Reports/ASB.pdf.

[28] For an extensive analysis of the frameworks for grid integration and scheduling, see Ashwin Gambhir, Jatin Sarode, and Shantanu Dixit, "Grid Integration of Renewables in India: An Analysis of Forecasting, Scheduling and Deviation Settlement Regulations," (Pune: Prayas, September 2016), http://www.prayaspune.org/peg/publications/item/327-grid-integration-of-renewables-in-india.html.

[29] The central government has repeatedly tried to end-load shedding, but numerous rules (including the Electricity Act of 2003, National Tariff Policy, etc.) have either been ignored or not operationalized at a state level.

tional RE-centric transmission will have low utilization factors, thus causing a disproportionately higher cost for RE compared to thermal generation.

In a December 2017 report, India's CEA estimated the hidden cost of RE on the rest of the system at approximately 1.5 rupees/kWh (about 2.1 cents/kWh) of RE for selected high-RE states.[30] Large grid integration studies, such as the Greening the Grid (GTG) study by the U.S. National Renewable Energy Laboratory and the Indian Ministry of Power, suggest that increasing the balancing area from states to regions could lower such costs.[31] The challenges of integrating RE increase as its scale grows, even before storage is needed.

Financing constraints

Availability and cost of capital are recognized impediments to RE development in India. Forty GW of additional *grid-scale* solar in four years might require $30-33 billion in capital for generation alone. The cost for wind might be similar if not higher. The Central Bank lending rate in India was 6.5 percent in June 2018, while the U.S. inter-bank rate was 2.2 percent.[32] This difference in interest rates makes RE in India more expensive, although the difference between the rates decreased markedly in 2017. Current foreign exchange hedge costs eliminate most, if not all, of the arbitrage possible between cheap foreign debt and Indian debt. A number of stakeholders have suggested the need for the Indian government to enable or facilitate a cheaper hedge.[33]

Domestic capital in India is relatively limited, especially debt. The Reserve Bank of India (RBI) states that the power sector, predominantly fossil fuel plants, represents one of the largest sources of stressed or non-performing assets. The Credit Suisse December 2016 Corporate Health Tracker reported that 63 percent of power sector debt had interest coverage less than one, meaning cash flows do not cover interest payments for a total of approximately 3.4 trillion rupees of such debt (about $49 billion).[34]

Securitization—bundling and selling the ongoing revenues of a number of projects—is frequently used to finance RE projects in other parts of the world. However, the project's returns can only be securitized after operations begin, bringing a steady stream of cash flows. One mechanism for attracting cheaper capital is improving the regulations for capital restructuring and resale without undue tax burdens, especially for foreign investors, which can help grow the inflow of secondary capital. Foreign capital also brings a lower interest rate, freeing up primary capital for growth.[35]

Initial capital for RE project construction demands a higher rate of return than after the project starts operating, as the period of building the project, getting a PPA, and garnering steady cash flows is riskier. The government has cancelled a number of bids in green energy, especially in allied systems like batteries, while others await conversion to a contract. The central government has announced tens of gigawatts of RE tenders in the coming years to meet the RE target. These include detailed plans and siting. However, there have been far fewer auctions leading to purchase contracts—in 2017 there were announcements and tenders for 10 GW of solar, but auctions for only 6.5 GW.[36]

[30] "Report of the technical committee on study of optimal location of various types of balancing energy sources/energy storage devices to facilitate grid integration of renewable energy sources and associated issues," (New Delhi: Central Electricity Authority, December 2017), www.cea.nic.in/reports/others/planning/resd/resd_comm_reports/report.pdf.

[31] "Greening the Grid," https://www.nrel.gov/analysis/india-renewable-integration-study.html.

[32] For the U.S. rate, see "3-Month or 90-day Rates and Yields: Interbank Rates for the United States," Federal Reserve Bank of St. Louis, https://fred.stlouisfed.org/graph/?id=IR3TIB01USM156N.

[33] The Clean Energy Finance Forum (CEFF), a voluntary, multi-stakeholder body invited by Piyush Goyal, minister for power and RE, provided a series of recommendations for financing RE in India. See "Home," India Clean Energy Finance Forum, http://ceff.strikingly.com/#documents-and-reports.

[34] Ashish Gupta, Kush Shah, and Prashant Kumar, "India Corporate Health Tracker," (Mumbai: Credit Suisse, December 2016), https://research-doc.credit-suisse.com/docView?language=ENG&format=PDF&sourceid=csplusresearchcp&document_id=1068301671&serialid=fui64XwTbBUaYjIFQPhqssu27zm9FVnp03B0ws9HndY%3D. Norms of classification of debt as "stressed," "restructured," and "non-performing" are being tightened periodically.

[35] "Home," India Clean Energy Finance Forum, http://ceff.strikingly.com/#documents-and-reports.

[36] Substantial uncertainty in bidding was due to lack of clarity on duties, including import duties, as well as the backlash from record-low bid prices of 2.4 rupees/kWh (about 3.6 cents/kWh) at Bhadla, Rajasthan, prompting some states to try and renegotiate contracts. See Saumy Prateek, "Almost 10 GW of Solar Tendered and 6 GW Auctioned in India in 2017," *Mercom*, February 26, 2018, https://mercomindia.com/tender-auction-2017/.

Counter-party risk remains the largest threat to investment in power generation. Cash-strapped DisComs have periodically delayed payments to generators (or simply refused to offtake, and thus pay for power), and the private sector is least able to address this issue. While central generators like the National Thermal Power Corporation (NTPC) have taken over state generation assets in lieu of payments after defaults, such options are difficult for private developers. RE is often worst off in terms of payments, in part because they are often smaller players with lower political influence. The private sector develops most RE projects, but depends on government frameworks and a near-monopsony public sector buyer in the DisComs.

RE PPAs have had several issues that increase the risk to lenders. RE power faces dispatch and curtailment risks. Although still far lower than in China, curtailment has been concentrated in a handful of states and the risks are growing. In some cases, states are attempting to re-negotiate RE PPAs on more favorable terms. Given falling solar costs (Figure 5), even two- to three-year-old contracts look very expensive today, but developers point out that those were actual costs at the time of installation. The central government has frowned on such state efforts, but the sanctity of contracts is a lingering problem.

Nonetheless, both global and domestic investors value the Indian RE market and consider PPAs bankable. States and the central government value RE investment, and it is much easier to fund than new coal projects, which are unwelcome in many financing circles. Thus far, RE has experienced a dramatic fall in prices, discovered through bidding and buttressed through standardization of bids (at least at a central level).

India wants RE, but do Indians? The political economy of renewable energy

The political economy of RE development matters because the market, left to itself, would likely continue to focus on coal-fired power. Nonetheless, India has been a pioneer in its pursuit of RE. India was the first major country to have a dedicated Ministry for RE and Prime Minister Modi led a highly effective RE buildout in Gujarat when he was the state's chief minister. The central government focuses on RE to show leadership in energy policy. Moreover, it sees RE policies as a way to attract global capital, which is not forthcoming for coal. RE developers are a natural ally in this vision.

Globally, interest in India's RE sector focuses on the positive carbon implications of a greener India. Many global voices and donors want to see an end to coal. On the other hand, some in India are concerned about this Western "support," especially when viewed through the lens of "carbon imperialism," a phrase used in a lecture by the government's chief economic advisor.[37]

Indian consumers are somewhat indifferent to RE; they prioritize quality, affordable electricity supply. Outages and shortfalls are decreasing, but as of March 31, 2018, there were still about 32 million homes (down from almost 100 million just a few years ago) without an electricity connection. The government has plans to offer all of them electricity by 2019. Local air pollution is a concern, particularly in certain urban areas such as New Delhi, but most studies do not implicate coal-fired power generation as a primary cause; vehicles, road and construction dust, crop burning, and other combustion in the city (waste, heating, and cooking) dominate.[38] Climate change is far from most people's concerns.

India's federal system and the challenge of renewable energy

India's federal system challenges the ability of the central government to translate its RE ambition into reality because the central government cannot set RE targets for states. At a recent review meeting for achieving the targets, the best language the center could muster was that states were "requested" to align their Renewable

[37] Arvind Subramanian, "Darbari Seth Memorial Lecture 2017," (speech, Energy and Resources Institute, New Delhi), https://www.youtube.com/watch?v=ROosJwcHXys.

[38] Urban Emissions compiles data from multiple studies and their own analysis, suggesting only 5 percent of Delhi's pollution might be from power plants. See "What's Polluting Delhi's Air?" *Urban Emissions*, March 2016, http://www.urbanemissions.info/blog-pieces/whats-polluting-delhis-air/.

Purchase Obligations (RPOs) to national targets.[39] How states react to these targets varies. Where RE is far ahead, like in Karnataka, the targets are being met. Other states openly resist the targets, particularly if the political party in power there isn't allied with the center. The overwhelming majority of RE is anticipated in a handful of RE-rich states with high targets that bear a disproportionate burden in terms of grid integration. Lacking compensation mechanisms and facing an overall surplus of electricity supply, many of these states, especially in the south and the west, have slowed the signing new PPAs for RE. Nearly all states with RE targets above 10,000 MW have a strong wind component, emphasizing RE's location-specific nature.

In 2016, the central government translated RE capacity targets into generation shares through national-level RPOs, which are somewhat contradictory between wind and solar power; despite the overall RE target including more solar capacity, the RPOs include a higher obligation to purchase wind. This may reflect the reality that wind is ahead of solar today in capacity. The capacity addition targets for solar are also front-loaded, instead of growing gradually over time. India does not manufacture solar cells today and building such capacity will take time. Therefore, these targets do not sync with Prime Minister Modi's "Make in India" initiative, which extends to RE manufacturing.[40]

These state RPOs are not sufficient to meet the national targets and are not enforced.[41] Moving forward with RE might require RPOs with teeth, but states are resisting. The burden and costs of RE are now borne almost entirely by the RE-rich states. Recognition of this issue is growing, such as in CEA's December 2017 report on RE integration,[42] and there are discussions on how to spread this burden across India. But it will take time for mechanisms to be put in place, let alone accepted. There are limits to "socialization," today's preferred mechanism for handling hidden costs and disproportionate burdens. Spreading costs out over all generation makes them appear smaller on a per unit basis, but does not change the total.

The political economy of coal versus renewable energy

Coal is the mainstay of India's electricity generation and will remain so for the foreseeable future. Coal India Limited (CIL), the largest coal miner in the world, produces about 80 percent of India's coal. The Indian central government owns the majority of CIL and returns almost 80 percent of its profits to the government's coffers.

Although coal's externalities are under-controlled and unpriced, coal does not receive subsidies.[43] Rather, coal pays into society via CIL profits and through levies and transportation costs, which dominate the cost of coal delivered to power plants in India. These royalties and fees total about 850 rupees/ton (about $12.38/ton). Transport cost varies by distance, with a weighted average of more than 800 rupees/ton (about $11.65/ton). For FY 2017, coal makes up about 40 percent of Indian Railways' freight volume and an even larger share of profits.[44] Coal transport disproportionately subsidizes a 43 percent under-recovery of passenger rail costs. Any fall in coal's usage due to growing RE generation will thus have important implications for the railways—the largest civilian employer in India.

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[39] The agenda for the January 2017 review meeting by MNRE states: "Request to States: i. Ensure RPO Compliance by increasing the share of renewable energy; ii. States have an option to comply RPO either through purchase of Renewable power or through purchase of REC. Due to non-RPO compliance, REC inventory is increasing; and iii. States shall align RPO level as suggested in the revised Tariff Policy and long term RPO trajectory as declared by the Ministry of Power on 22 July 2016." See "Agenda Note for National Review Meeting of State Principal Secretaries and State Nodal Agencies of Renewable Energy on 23rd and 24th January 2017,"(New Delhi: MNRE, 2017), https://solarrooftop.gov.in/notification/Notification-09012017.pdf.

[40] Rahul Tongia, "India's Updated (2016) Renewable Energy 'Guidelines': Bold targets, but can we meet them?" (New Delhi: Brookings India, August 24, 2016), http://www.brookings.in/in-focus/indias-updated-2016-renewable-energy-guidelines-bold-targets-but-can-we-meet-them/.

[41] See especially Chapter 2 on compliance, "Report of the Comptroller and Auditor General of India on Renewable Energy Sector in India," (New Delhi: MNRE, 2015), http://www.cag.gov.in/sites/default/files/audit_report_files/Union_Civil_Performance_Renewable_Energy_Report_34_2015.pdf.

[42] "Report of the technical committee," www.cea.nic.in/reports/others/planning/resd/resd_comm_reports/report.pdf.

[43] Most calculations of subsidies for coal are based on "reduced taxation" or imputed values, instead of actual cash subsidies. See, for instance, "India's Energy Transition: Mapping subsidies to fossil fuels and clean energy in India," (Winnipeg: International Institute for Sustainable Development, 2017), https://www.iisd.org/sites/default/files/publications/india-energy-transition.pdf.

[44] Puneet Kamboj and Rahul Tongia, "Indian Railways and Coal: An Unsustainable Interdependency," (New Delhi: Brookings India, July 2018), https://www.brookings.edu/wp-content/uploads/2018/07/Railways-and-coal.pdf.

The prospect of RE displacing coal consumption would be particularly challenging in coal-producing regions, some of which enjoy enormous political influence. India's politics offers disproportionate power to selected regional political parties, often from coal-bearing regions. Coal was a central issue in the general election of 2014, focused not on jobs but on corruption, including the so-called "coal scam" concerning how coal mines were allocated instead of auctioned to the private sector for captive mining.

New coal power plants are typically larger and thus situated outside cities, and are increasingly built near mines to reduce coal transportation cost. The coal-bearing regions of India are often less developed and there is less public resistance to pollution from the plants. However, the presence of coal mining and significant coal-fired generation in these areas furthers their economic reliance on coal and their vulnerability to any future decline in coal use.

Other parts of today's coal value chain are more receptive to RE. NTPC, by far India's largest coal power generator, aims to become a dominant player in RE. NTPC plans to grow from nearly zero to 32 GW of solar capacity by 2032, a capacity more than half its total installed capacity today. NTPC would also be the largest beneficiary if new proposals for a Renewable Generation Obligation come into force, forcing coal generators to bundle RE with their sales, a model to overcome the lethargy of RPOs. It may lead to RE by fiat, but in a manner that has less flexibility than RPOs, and is also a distortion that is based on a framework that lacks feedback mechanisms.

Renewable energy winners and losers in the Indian power system

Rooftop solar development presents particular challenges in achieving India's RE ambitions. The target calls for 40 GW of rooftop solar by 2022, but as of FY 2018, only about 1.5 GW was installed.

Rooftop or distributed solar is attractive for many reasons. Consumers handle the financing, rather than utilities. From a grid integration perspective, rooftop solar is superior to a large solar park since it does not require large transmission investments and is much less prone to sudden cloud cover that can affect hundreds of MW of capacity simultaneously.

On the other hand, rooftop solar creates headaches for utilities. The low-voltage distribution grid was not designed for two-way power flows, creating technical challenges. Exacerbating the technical challenges, each state has different net-metering norms for rooftop solar, and there is no mandate or incentive for "smart inverters" to manage greater rooftop solar penetration.

Rooftop solar also raises the risk of the "utility death spiral," whereby the best customers exit or reduce their use of the grid, raising the costs of the grid for others, in turn prompting more exits. Indian retail tariff distortions make this challenge worse. Commercial and industrial users overpay by at least 50 percent to subsidize most residential and all agricultural consumption.

As awareness of RE and its financial benefits (for developers and end-users who deploy their own generation) grows and costs fall, demand for RE will grow, a useful reversal of today's supply-driven push. In addition to market forces, proper frameworks (including net-metering, third party sales, etc.) will help spur demand. Awareness campaigns and quality signaling also have a role to play, since consumers are not only concerned about economics, but also the reliability of the system, especially over time.[45]

However, as RE grows, utilities will continue to push back due to RE's direct and indirect costs.[46] This resistance is both overt and covert, just as utilities resisted bulk consumers exiting the grid under "open access" retail norms allowed under the Electricity Act of 2003.

The system hit the first wall when early adopting states pulled back on signing new RE PPAs. RE development

[45] Rahul Verma et al., "A national certification scheme to enhance trust and quality in the Indian residential solar PV market," *The Electricity Journal* 29, no. 6 (July 2016): 11-14.

[46] RE has a capital-intensive, front-loaded cost structure. Comparing a coal project to an RE project with an identical LCOE, the coal project will start cheaper on a cash-flow basis, with future costs rising due to fuel costs. This makes utilities extra wary of RE, not to mention there is ostensibly no option to refuse RE (thanks to its "must run" status).

will hit a second wall when RE-rich states are forced to curtail RE or demand compensation for their high RE percentage (in part to cover the fixed costs of non-RE generation capacity). For example, the state of Karnataka has peak demand of about 10.5 GW and roughly 12 GW of RE capacity. The state expects 8 GW of total solar by 2019, based on already sanctioned projects, including the world's largest (2,000 MW) solar park in Pavagada. On the other hand, approximately 4 GW of additional coal power capacity can come online within the year from new state-owned assets. But the state cannot absorb all this supply in the near term. The government of Karnataka understands that this high level of RE brings costs, but does not have mechanisms to cover them. Owing to a lack of integrated planning mechanisms, the answer across India thus far has been to pass these costs onto consumers.

Integration and system costs will be the ultimate bottleneck for RE. To date, in most states these costs have been relatively small, especially on a generation basis, but that will not remain the case for long. Hidden costs today are approximately 150 billion rupees per year (about $2.2 billion per year), if we use CEA's estimate of 1.5 rupees/kWh of RE (about 2.2 cents/kWh). Given that the difference in cost between RE and coal is declining, a better estimate may be approximately 100 billion rupees (about $1.5 billion).[47] Over time, the share of RE is projected to increase faster than RE generation and integration costs decrease, meaning that these hidden costs could rise over time, to be offset to some degree by a stronger grid. DisComs may not be able to pass through all of these costs. Regulators might allow such a pass through, but paying consumers might exit the grid instead, accelerating the utility death spiral. In FY 2016, power procurement was about 76 percent of DisCom costs,[48] and RE may make this figure higher.

Many potential stakeholders could favor RE in the future. India has an ambitious plan to sell only electric passenger vehicles by 2030. Increasing demand for power, and RE in particular, could be a fringe benefit of this plan, but timing vehicle charging with RE availability could be a challenge. Nonetheless, a simple tax break or other incentive for rooftop solar connected to electric vehicle charging could create an entirely new constituency in favor of RE. Commercial and industrial users, who today enjoy incentives to use RE, could increase the pressure for captive or renewable energy service company (RESCO) RE, citing differentials in global competitiveness due to high energy costs. Thanks to policies favoring RE, such as free transmission and waiver of cross-subsidy surcharges, captive RE (meaning grid-scale but not behind-the-meter) is the cheapest energy available to many users, much more so than captive thermal power.

Conclusion: Renewable energy in India—moving from evolution to revolution

India's weak grid and the rapid anticipated growth rate of RE raise important challenges to RE development. Is there a point beyond which India would not want more RE? At an abstract level, either RE meets an energy need cost-effectively, or it meets other criteria such as energy security or local pollution abatement. Alternatively, RE becomes cost-effective with an implicit price on carbon or other pollutants. However, these other benefits are not directly valued today. The translation from RE targets to higher-level objectives, such as carbon emissions reduction, is missing. A holistic analysis would give impetus to other efforts, such as energy efficiency. But the conversation remains focused on meeting the targets.

The targets are in contrast to a more market-oriented mechanism to encourage RE development due to its benefits or value. Targets have been helpful in motivating industry and finance, and many believe states would otherwise be laggards. Yet RE could crowd out other investments that may be superior or even complementary, such as peaking or fast ramping power. To-

[47] CEA's national estimate of 2022 costs of RE integration are 1.1 rupees/kWh (about 1.6 cents/kWh), assigning zero cost for backing down coal, a calculation that assumes 2.5 rupees/kWh for RE (about 3.6 cents/kWh), and 3.5 rupees/kWh for coal based generation (about 5.1 cents/kWh). This integration cost appears low since the variable cost of coal is often lower than RE's cost, especially at locations near coal mines.

[48] "The Performance of State Power Utilities 2013-14 to 2015-16," (New Delhi: Power Finance Corporation), http://www.pfcindia.com/DocumentRepository/ckfinder/files/Operations/Performance_Reports_of_State_Power_Utilities/1_Report%20on%20the%20Performance%20of%20State%20Power%20Utilities%202013-14%20to%202015-16.pdf.

day's targets are also front-loaded, despite expectations that costs will fall in the future and technologies such as batteries will mature over time.

India's 2022 RE targets have been a game changer not because of the actual capacity added thus far, but because they have brought a change in conversation and focus—RE is no longer a fringe supplier. To date, RE has primarily been a disruption at the supply level, affecting other generators more than DisComs or consumers. If rooftop solar investment picks up, DisComs will feel the heat. As the task at hand changes from attracting capital to integrating RE, stakeholder pressures will change, leading to new coalitions.

Instead of top-down planning and decisionmaking in silos, policymakers need to focus on frameworks and policies that enable RE deployment. These include frameworks for attracting global capital and decreasing the cost of capital; improving RE prediction and grid integration; granular signaling of the state of the grid (by time and location); and broader visibility into system operations, curtailment, and payment histories. All of these changes would facilitate RE deployment, but the ultimate barrier remains counterparty risk from insolvent DisComs.[49]

A major flaw of many government plans and studies is that they do not factor in uncertainty and variance in RE supply. The simplest studies convert between capacity (kW) and energy (kWh) with a simple multiplier. Even sophisticated studies like the GTG study—the flagbearer of detailed studies—make a number of assumptions on RE output, often because better data (like actual RE output at a granular level) are not available in India.

The 2022 RE targets are ambitious, but even if India does not meet them, it is still likely to meet its 2030 Nationally Determined Contribution (NDC) under the Paris agreement. The NDC calls for a 33-35 percent reduction in intensity of greenhouse gas emissions with respect to GDP. The 2030 NDC does not depend on high RE penetration and India is on track to meet it. Secondary declarations, such as 40 percent carbon-free generation capacity, should be viewed as means to an end.[50] Actual energy usage (and resultant greenhouse gas emissions) are the metrics that matter.

The Appendix details that, even with 350 GW of RE by 2030, coal-fired generation is likely to continue to grow at perhaps 4.6 percent per year. Coal efficiency will improve as new supercritical plants are built and older plants are shut down, meaning that even this growth in coal generation should pose no challenge for meeting the NDC. However, the NDC should be viewed as a minimum goal. The world would benefit from India exceeding its commitments, meaning that high RE penetration does matter, along with decarbonization of its growing transportation system.

India needs *clarity*, *consistency*, and *coordination* to grow its RE ambitions. The multitude of challenges described in this paper are inevitable in any large-scale transition, and many are not unique to India. However, India's timeframes are exceptionally aggressive and it is starting with a much weaker grid, so greater effort will be needed to plan for a high RE future.

India needs global stakeholders to play an active role in its journey toward RE—in financing, in RE technologies and adjacent technologies such as batteries and smart grids, and in experience and expertise that can further the electricity system transition. These contributions can make RE part of broader development and electricity sector stability, instead of a point of contention.

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[49] See, especially, Working Group 4 on Policy Issues in "Report of the Clean Energy Finance Forum," (New Delhi: Clean Energy Finance Forum, 2016), https://uploads.strikinglycdn.com/files/ead5c63a-ef85-4c6f-8058-57c3f65413de/2016-12-16-CEFF-Report-Presentation.pdf.

[50] For an explanation of how non-fossil capacity and RE scaling plans do not add up unless overall capacity in 2030 is inordinately high, see Radhika Khosla and Navroz K. Dubash, "What does India's INDC imply for the future of Indian electricity?" *Centre for Policy Research*, October 15, 2015, https://cprclimateinitiative.wordpress.com/2015/10/15/what-does-indias-indc-imply-for-the-future-of-indian-electricity/.

APPENDIX: Projections for renewable energy growth and share relative to targets.[52]

	Type	Formula/notes		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
A	Input to the model	Progressive growth through the periods	RE capacity [GW]	*54.0*	68.3	86.4	109.3	138.3	*175.0*	190.8	208.1	226.9	247.5	269.9	294.3	321.0	*350.0*
B	Assumed except 2017	Progressive improvement to match assumptions in red	RE plant load factor (PLF)	*17.3%*	17.5%	18.0%	18.5%	19.0%	*20.0%*	20.0%	20.5%	20.5%	21.0%	21.0%	21.0%	21.5%	*22.0%*
C	Modeled as per compound annual growth rates (CAGR)	Demand CAGR assumed as 6.4% annually	Total utility generation [BU]	1149.0	1222.5	1300.8	1384.0	1472.6	1566.9	1667.1	1773.8	1887.4	2008.1	2136.7	2273.4	2418.9	2573.7
D	Calculated	A * 8760 * B	RE generation [BU]	81.8	104.7	136.3	177.2	230.2	306.6	334.3	373.7	407.6	455.3	496.5	541.4	604.5	674.5
E	Calculated	D - C	Other (non-RE) generation [BU]	1067.2	1117.8	1164.5	1206.8	1242.4	1260.3	1332.8	1400.1	1479.8	1552.9	1640.2	1732.0	1814.4	1899.2
F	Assumed	Declining hydro share	Share non-coal, non-RE	15%	15%	15%	14.50%	14.50%	14%	14%	14%	14%	14%	14%	14%	14%	14%
G	Residual	E - F	Coal generation [BU]	907.1	950.1	989.8	1031.8	1062.2	1083.8	1146.2	1204.1	1272.6	1335.5	1410.6	1489.5	1560.4	1633.3
H*	Calculated	D / C	Share RE	7.1%	8.6%	10.5%	12.8%	15.6%	19.6%	20.1%	21.1%	21.6%	22.7%	23.2%	23.8%	25.0%	26.2%
I	Calculated	Annual difference	RE growth [BU]	N/A	22.9	31.6	40.9	53.0	76.4	27.7	39.4	33.8	47.7	41.2	44.9	63.1	70.0
J	Calculated	Annual difference	Non-RE growth [BU]	N/A	50.6	46.7	42.3	35.5	17.9	72.5	67.3	79.7	73.1	87.3	91.8	82.4	84.8
K	Calculated	Annual difference	Coal growth [BU]	N/A	43.0	39.7	42.0	30.4	21.6	62.4	57.9	68.5	62.8	75.1	79.0	70.9	72.9
L	Calculated	Annual difference	Total growth [BU]	N/A	73.5	78.2	83.2	88.6	94.2	100.3	106.7	113.5	120.8	128.5	136.7	145.5	154.8
M	Calculated	Annual difference	RE growth year over year (y/y)	N/A	28.0%	30.1%	30.0%	29.9%	33.2%	9.1%	11.8%	9.1%	11.7%	9.1%	9.1%	11.6%	11.6%
N	Calculated	Annual growth rate	Other growth y/y	N/A	4.7%	4.2%	3.6%	2.9%	1.4%	5.8%	5.1%	5.7%	4.9%	5.6%	5.6%	4.8%	4.7%
O	Calculated	Annual growth rate	Coal growth y/y	N/A	4.8%	4.2%	4.2%	3.0%	2.0%	5.8%	5.1%	5.7%	4.9%	5.6%	5.6%	4.8%	4.7%
P	Assumed	Linear growth to reach assume terminal value	Coal capacity [GW]	185.0	189.2	193.5	197.7	201.9	206.2	210.4	214.6	218.8	223.1	227.3	231.5	235.8	*240.0*
Q	Calculated	1000 * Coal Generation [BU] / (Coal capacity [GW] * 8760)	Corresponding coal PLF	56.0%	57.3%	58.4%	59.6%	60.1%	60.0%	62.2%	64.0%	66.4%	68.3%	70.8%	73.4%	75.6%	77.7%
				Energy [BU] CAGR (until 2030)	**6.4%**			**1st period RE capacity CAGR (until 2022)**	**26.5%**							**2nd period RE capacity CAGR (2022-2030)**	**9.1%**

Note: This assumes targets are met for FY 2022 and FY 2030 as 175 GW RE and 350 GW RE, respectively, and overall demand grows at 6.4 percent in billion units [BU, or billion kWh], and calculation assumptions or starting points are shown in red italics. Coal capacity is not a bottleneck as generation is the residual calculation for coal (Row G). 240 GW matches one estimate of coal capacity in 2030 based on existing capacity, capacity already under construction, and modest retirement of older plants. We note there are some discontinuities in growth rates, which are an artifact of the 2022 aggressive timeline for RE. Green text indicates the share of RE over time.

* The generation share for RE (Row H) is higher than actual for 2017 as much of the capacity comes online towards the end of the year, and so doesn't contribute generation commensurate to the nameplate capacity throughout the year.

[52] Data based on Brookings India calculations.

BROOKINGS
1775 Massachusetts Ave., NW
Washington, D.C. 20036
brookings.edu