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Accelerating India's Transition to Renewables: Results from the ETC India Project

India's renewables trajectory can allow unprecedented changes in the energy mix

1. India can achieve **30% of variable RE generation by 2030 (wind and solar)**, and **45% zero carbon generation**, including hydro and nuclear.
2. **This would make India's power sector as clean as Japan's today**, and would be unprecedented leapfrogging to decarbonisation of the electricity sector.

Declining costs of renewables means consumers will not be impacted

3. Wind and solar are the cheapest source of new electricity – cheaper than coal – and still have a way to fall. By contrast coal tariffs are projected to increase because of rising transport and capital costs. Costs of storage technologies are projected to decline dramatically, which, along with untapped potential for demand response, could be transformational for integrating RE into the grid.

By 2030, we project that the cost of wind and solar will be **between 2.3-2.6 Rs/kWh and 1.9 – 2.3 Rs/kWh** respectively, while the cost of storage will have fallen by **about 70%**.

4. Even considering the additional costs required to balance the variability of renewables, the study projects that a grid with 30% RE generation **is cost-effective as compared to a moderate RE system, and does not raise costs for Indian consumers.**
5. The investments required in a high renewables scenario (**₹1.65-1.75 trillion annually**) are slightly above the rate achieved over the last decade.



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Flexibility of the power system will be the prime determinant of the rate of renewables growth

6. To balance the variability of renewables, the need for power system flexibility will exceed the current flexibility capacity of the grid by the mid-2020s, even in scenarios with more moderate RE deployment. **Increasing the flexibility of the electricity system is an urgent, complex and substantial challenge: if not addressed, the transition to renewables will stall.**
7. An **integrated approach to flexibility is required**: on the demand side, by shifting demand patterns to match RE production; on the supply side, by adapting the operation of the dispatchable fleet; and flexibility through the deployment of storage technologies.
8. An integrated portfolio approach to flexibility **lowers implementation risks and system costs**, with costs of a high renewables scenario comparable to a scenario with much lower penetration of renewables.

Demand growth means that policies and planning for the mid-term (2030) must be undertaken now

9. Electricity demand in India is projected to grow, and by the early 2020s, demand growth will have absorbed the current overcapacity. **New investment decisions will then have to be made**; but getting them right requires informed planning now.
10. In 2030, residential and services are projected to represent 50% of electricity demand, with air conditioning alone representing around 10%. Demand from these sectors is more variable than baseload industrial demand, **which poses challenges for renewable energy (RE) grid integration.**

Accelerated renewable ambitions can be achieved with the right conditions

11. Phase 1 of India's RE policy focused on creating the conditions to bring costs of RE down, and achieved this spectacularly
12. Phase 2 should be a holistic, overarching renewables policy (a "**Flexibility Mission**"), with targets, data collection and analysis, market reforms, regulatory initiatives and institutional innovations, providing orientation to the sector beyond the current 2022 milestone

India could then aim for at least 420 GW RE capacity by 2030



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Key results: summary version

Electrifying Development

In the 1920s, when electricity was being extended to all households of the United States, one Tennessee farmer commented on this transformation, saying: “The greatest thing on earth is to have the love of God in your heart, the next greatest thing is to have electricity in your home”.¹ Throughout history, the provision of affordable and reliable electricity has been one of the keys to transforming lives for the better. India has taken remarkable strides in this regard in recent decades, with electricity shortages declining and connectivity approaching 100 percent of households. However, there is still a long way to go. India’s per capita electricity consumption is some 900 kWh, as against a world average of almost 3000 kWh. Electricity generation is also the largest contributor to India’s energy-related CO₂ emissions, and a major contributor to local air pollution and other environmental problems.

Can India grow its electricity consumption and transform the lives of its citizens, without a concomitant worsening of its environmental footprint? In recent years, a positive answer to this question has been emerging, as the costs of renewable energy have fallen precipitously. However, renewables have problems: they only produce when the sun is shining or the wind is blowing. Does this intermittency condemn renewables to always be a small-time player in the Indian electricity mix? **This question has not been sufficiently studied in the Indian context, with both proponents and detractors of renewable energy tending to treat it only superficially.** The Energy Transitions Commission India (ETC India) project aims to provide a thorough and scientific answer to these questions. This summary paper presents the main findings of the three detailed technical reports on how India can grow the share of renewables in its electricity system by 2030.

India’s Electricity Demand Will Transform by 2030: This May Create Challenges for Renewables

From the 2015 level of 862 TWh, India’s grid-based electricity demand will grow to around 2040 TWh by 2030, at a growth rate of about 6 percent per year. Meeting this demand growth is a significant challenge. On an annual basis, the incremental demand growth is equivalent to the output of about 12 GW of coal capacity, or 35 GW of renewables capacity. By the early 2020s, demand growth will absorb the current overcapacity, and new investment decisions will have to be taken. **These decisions will have long-term consequences for India’s fuel mix and CO₂ emissions, and getting them right will require early forethought, planning and analysis.**

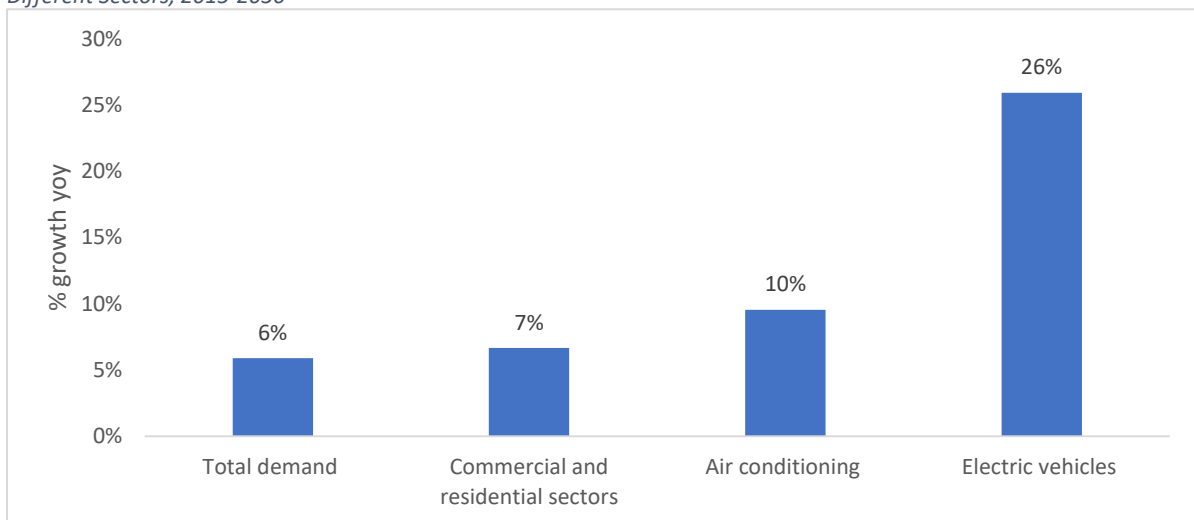
¹ Quoted in R. Gordon (2016), The Rise and Fall of American Growth: The U.S. Standard of Living Since the Civil War, Princeton University Press, Princeton, New Jersey.





In addition to the large absolute growth, the structure of India's electricity demand is expected to become increasingly "urbanised". The share of the residential and services sector in total grid electricity demand is projected to increase to 50% by 2030. More importantly, by 2030 around 10% of total grid electricity demand will come just from air conditioning. Demand growth from electric vehicles (EV) is expected to be even faster (26% year on year), although in absolute terms the sector would still represent a relatively small share of total demand by 2030 (about 2%). Demand from the residential and commercial sectors tends to be more variable than the smoother baseload demand from industry. This variability of demand may pose a challenge for the grid integration of renewables, which are not always available when demand is strong (e.g. at night for air conditioning demand, or EV charging). **India's renewables growth will require a better understanding and management of changing demand patterns.**

Figure 1E: Demand Growth and Transformation of its Structure – Compound Annual Growth Rate for Total Demand and Different Sectors, 2015-2030²



Renewables and Storage Are Cheap and Getting Cheaper

As of today, wind and solar are the cheapest source of new electricity supply in India. Indeed, they are cheaper than about a third of the existing coal-fired fleet in India, even if one considers only the fuel cost of coal electricity and ignores the sunk capital costs. The analysis of this project suggests

² Growth rate for electric vehicles starts from 2020, as they start from such a low base today than any analysis based on today's level produces very high growth rates between now and 2030.



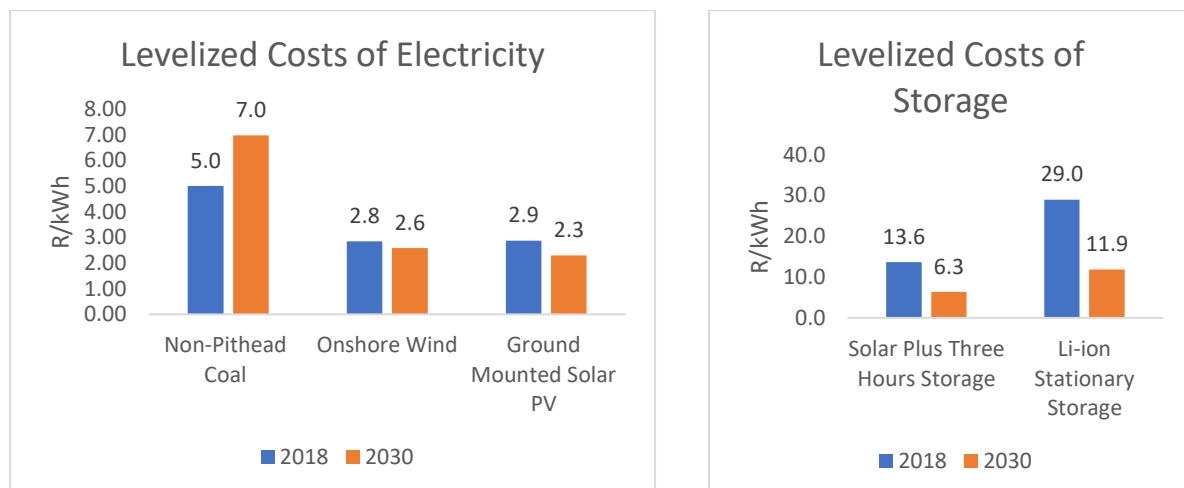


that the costs of wind and solar still have a way to fall. An even more transformational reduction in the costs of stationary storage is projected by 2030, with costs more than halving. By contrast, we project the tariffs of new coal-fired electricity to rise, due to above-inflation increases in coal transport costs and increases in coal plant capital costs to improve efficiencies and reduce local pollution.

By 2030, we project that solar electricity could be as cheap as 2.30 Rs/kWh. Even cheaper solar costs are possible, in the order of 1.90 Rs/kWh, if the widespread deployment of tracking technology raises the capacity utilization factor of new plants above current levels. Likewise for wind, with mast heights increasing from the current level of 80 meters to 100 and even 120 meters, our baseline projection for 2030 for the levelized costs of wind at 2.58 Rs/kWh could be as low as 2.26 for projects with higher capacity utilization factors. By contrast, we project that new non-pithead coal could be as expensive as 6.98 Rs/kWh by 2030, while cheaper pithead coal would be 4.85 Rs/kWh by 2030.

On the other hand, we project dramatic costs reductions in storage technologies. The levelized costs of solar plus three hours of storage could fall from 13.6 Rs/kWh to 6.34 Rs/kWh. The levelized costs of stand-alone storage could fall from around 29.0 Rs/kWh to 11.9 Rs/kWh by 2030. This decline in storage costs could be transformational in terms of facilitating high penetrations of cheap solar in the Indian grid.

Figure 2E: Transformation in the Cost of Electricity Generation and Storage Technologies – Absolute Change in Levelized Cost 2018-2030





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Variable Renewables Can be Around 30 Percent of Generation by 2030, While Coal Falls to Close to 50 Percent

By 2030 in the high renewables scenario developed in this project, the share of variable renewables (wind and solar) reaches 30% of total generation by 2030, and 390 GW of capacity (inclusive of small hydro and biomass, it is 420 GW). The share of all zero-carbon technologies in generation, including large hydro and nuclear, reaches 45%. This represents a rapid decarbonization of Indian power production. The grid emissions factor declines from 733 gCO₂/kWh in 2018 to 555 gCO₂/kWh in 2030, a reduction of 25%. This would make India's power sector as clean as that of Japan today, a tremendous achievement for a country of India's level of income per capita. It would represent a truly unprecedented leapfrog into a cleaner electricity system. The required investments in electricity generation capacities are substantial, at about 1.65-1.75 trillion Rs per year. This is slightly above the rate achieved over the last 10 years, which was around 1.40 – 1.50 trillion Rs per year, and represents a substantial financing challenge given the current stresses on the Indian banking system.

Even Considering Grid Integration Costs, A High Renewables System is Projected to Be Cost-Effective

The intermittency of renewables creates additional costs on the electricity system, known as grid integration costs. As a simple example, if solar electricity is unavailable at night, alternative capacities must be available to meet night-time demand. The cost of these capacities represents the "grid integration" costs of renewables. These costs are known to be increasing with increasing renewables penetration in electricity generation, and they can reach substantial levels.

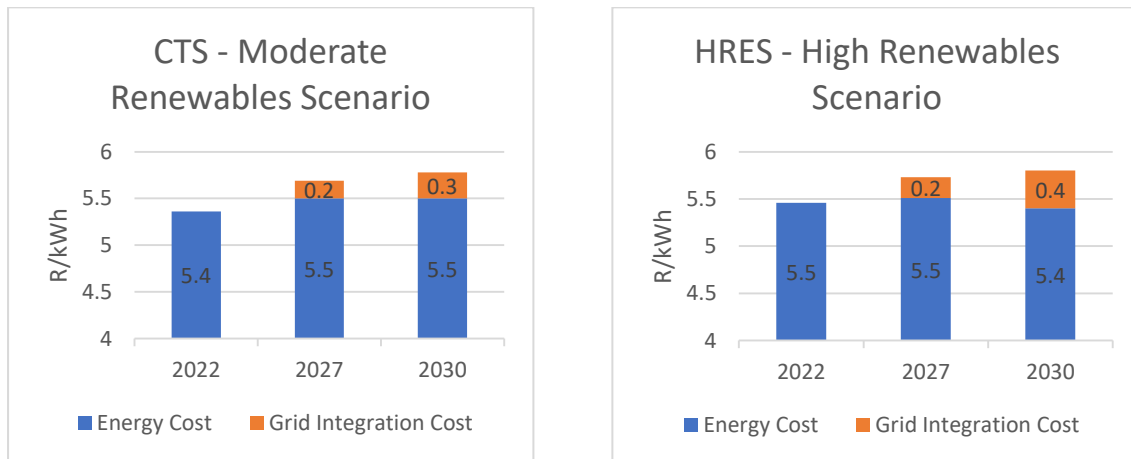
According to the modelling of this project, by 2030 the system costs, excluding grid integration costs, of a high renewables system are projected to be substantially lower than those of a system with moderate renewables penetration. However, the grid integration costs of a high renewables system are higher than those of a moderate renewables system. The net effect of these two factors is that by 2030, the total system costs, including grid integration costs, of a high-renewables and a moderate renewables system are modelled to be essentially equivalent. **Thus, even considering a substantial and conservative increment for grid integration costs, a high renewables electricity system with around 30% of variable renewables generation is found to be cost-effective, and need not raise costs for India's consumers.**



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Figure 3E: The System Costs of a High Renewables System Are Competitive - Low Energy Costs Compensates for Higher Grid Integration Cost



Increasing the Flexibility of the Indian Electricity System is Necessary and Urgent Under Any Scenario: Failure to Do So Will Constrain the Growth of Renewables

Modern electricity systems must balance electricity demand and supply at every instant, and at every location. To continuously match supply with demand, system operators must:

- **Reserve** some powerplant capacity to replace energy lost if a powerplant or transmission line suddenly fails, or to meet an unexpected surge in demand.
- **Ramp** (increase) output fast enough to meet expected sharp increases in demand, such as when the sun sets and consumers turn their lights on at once.
- **Balance daily** demand and supply over the course of each day, for example balancing high solar output at midday against solar output's rapid decline to zero as the sun sets.
- **Balance seasonal** supply and demand to meet seasonal cycles, for instance, when cold winters or hot summers drive up electricity demand, or windy monsoon seasons drive up wind and hydro electricity supply.

The graph below shows the annual growth rate in demand (energy requirement) and peak demand, versus the annual growth rate for the four different kinds of flexibility needs described above. Three scenarios are shown, namely a *current trajectory scenario* with more moderate renewables penetration, a *current policy scenario* reflecting current targets of the Government of India, and a *high renewables scenario*. It can be seen that while the growth rates of flexibility needs are highest in the high renewables scenario, they are nonetheless substantial already in the current trajectory scenario. **According to the**

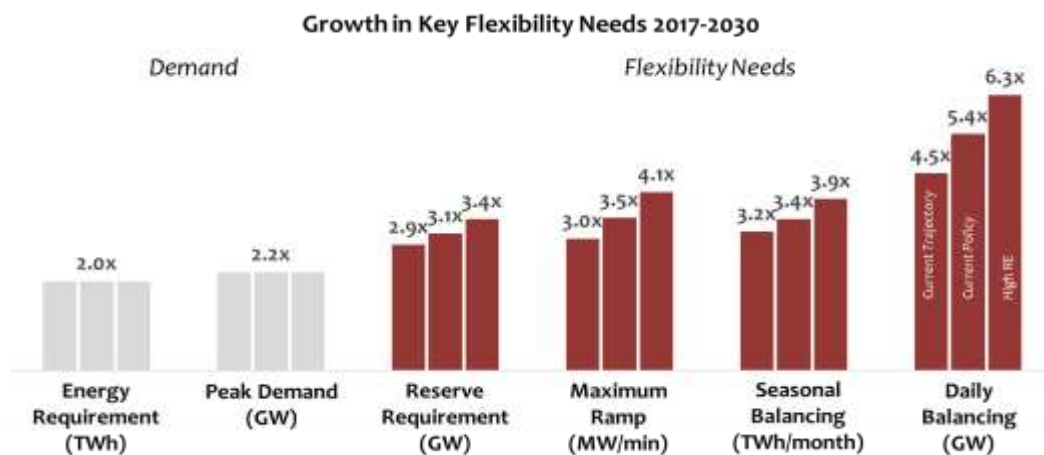




modelling of the project, the need for these four kinds of system flexibility will exceed the capacity of the grid to supply them already by the mid-2020s. This is the case in particular for daily balancing, necessary to integrate large shares of solar electricity with output concentrated at midday.

Increasing the flexibility of the electricity system is therefore urgent and necessary in any scenario. Large-scale outages and unmet demand are no longer politically or economically acceptable: failure to increase the flexibility of the electricity system will be met with a slowdown in the growth of renewables.

Figure 4E: Flexibility Needs Will Grow Faster Than Demand for Energy - Increasing the Flexibility of the Electricity System is Therefore Urgent in Any Scenario



Flexibility Is Not Just About New Power Plants: An Integrated Approach Across Demand, Supply and Storage is Required

If India is to increase the flexibility of the power system, it is not just a question of investing in new power plants. Increasing flexibility needs can be met cost effectively and reliably using a combination of investment, incentives and technologies that:

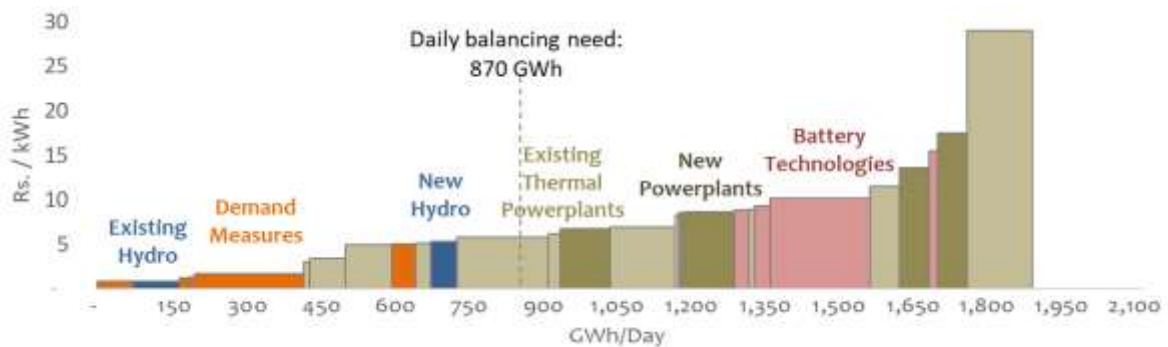
- Change how and when consumers use energy (demand-side management and demand response)
- Increase the flexibility of power generation (supply-side flexibility)
- Encourage development of new energy storage options (storage)





To assess the potential scale and cost of integrating demand, supply and storage-based flexibility options, the project has developed a series of “supply curves” for meeting each of the aforementioned flexibility needs. The figure below shows the example of the supply curve to meet daily balancing needs (e.g. to shift excess solar production to the night through storage, or shift demand to times of excess solar production). The quantum of daily balancing that can be obtained by each option is represented by the width of each block on the horizontal axis, its cost by the height of the block. India has substantial potential supply of daily balancing, exceeding the estimated average need of 870 GWh/day by 2030. **Demand measures and existing hydro provide the cheapest means of meeting this particular need, for example through cycling the output of hydro to balance the daily cycles of solar output, or shifting agricultural pumping to the daytime to match the output of solar. If, on the other hand, demand-side flexibility cannot be tapped at scale, other options such as supply-side flexibility and storage would be required to a greater degree.**

Figure 5E: Flexibility Options Come from Demand, Supply and Storage - An Integrated Approach is Required



A Portfolio Approach Lowers Implementation Risks and Delivers the Lowest Cost Option for Renewables Integration

Figure below shows further detail on the cost simulation runs for the complete system, including a breakdown of renewable energy costs, powerplant costs (both capital and operating costs), the costs of demand flexibility and storage, and, in red, the cost of energy shortfalls that would be met by diesel generation. We have modelled average total system costs (in today’s money), for different portfolios of flexibility options (shown below for the current trajectory and high renewables scenarios).

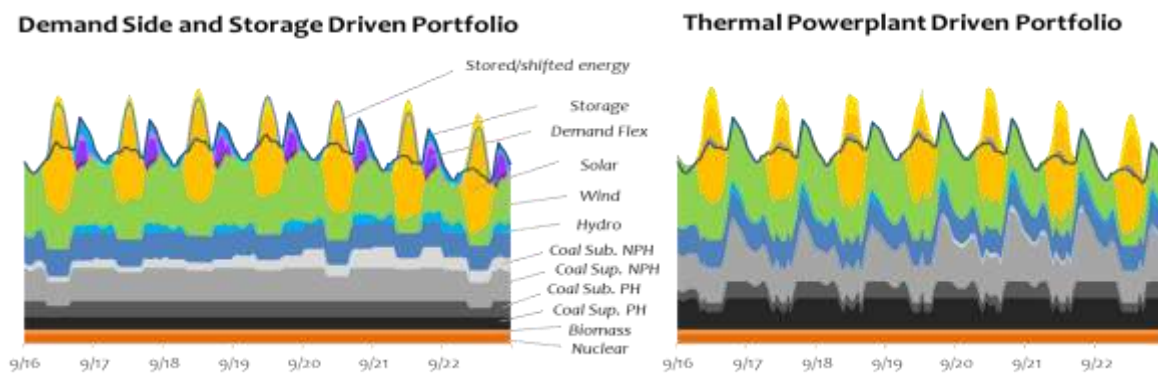
- The base option includes flexibility as it is used today.
- The thermal flexibility meets flexibility through powerplant dispatch, including investments to increase the flexibility of existing powerplants.
- The demand portfolio relies primarily on demand flexibility, but uses existing thermal flexibility to balance the overall system.
- The portfolio approach uses the lowest cost mix of all three options, including storage.





The average system cost for the High RE case is below the current trajectory costs with either the base flexibility, or the enhanced powerplant flexibility. Also, added demand flexibility and storage reduce costs, even at relatively modest renewable energy ambitions. Finally, note that base levels of flexibility lead to energy outages in either scenario, even though enough energy is produced in these scenarios to meet demand.

Figure 6E: A Portfolio Approach to Enhancing the Flexibility of the Power System – Lowering Implementation Risks and Technical Challenges



A Portfolio Approach Lowers Costs – Allowing The System Costs of a High Renewables System to be Competitive

Figure 6E below shows further detail on the cost simulation runs for the complete system, including a breakdown of renewable energy costs, powerplant costs (both capital and operating costs), the costs of demand flexibility and storage, and, in red, the cost of energy shortfalls that would hypothetically be met by diesel generation. We have modelled average total system costs (in today's money), for different portfolios of flexibility options (shown below for the current trajectory and high renewables scenarios).

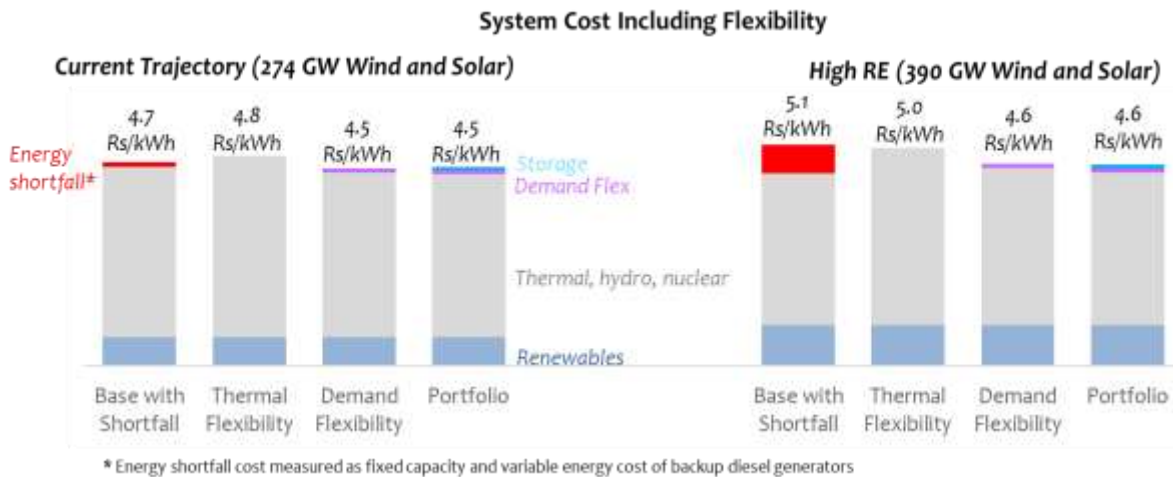
- The base option includes flexibility as much flexibility as is currently in the system.
- The thermal flexibility meets flexibility through powerplant dispatch, including investments to increase the flexibility of existing powerplants.
- The demand portfolio relies primarily on demand flexibility, but uses existing thermal flexibility to balance the overall system.
- The portfolio approach uses the lowest cost mix of all three options, including storage.

If a portfolio of flexibility options can be effectively deployed then the system cost of a high renewables system is essentially no different from that in a more moderate renewables scenario, allowing India to realise the other benefits of increasing renewables but without increasing costs for consumers.





Figure 7E: A Portfolio Approach to Flexibility Lowers Costs - Allowing the System Costs of a High Renewables System to be Competitive



Renewables Policy 2.0 – A “Flexibility Mission”

India’s renewables story thus far has been a huge success. No country of India’s size and low income per capita has done so much to bring the costs of renewables down, or position itself to leapfrog into a cleaner electricity system so early in its development pathway. India’s renewable policy 1.0, initiated notably with the Jawaharlal Nehru National Solar Mission in 2010 and the 175 GW target adopted in 2015, focused on creating the conditions to bring costs down. That has been achieved spectacularly, with the cost of renewables now cheaper than new and much existing coal.

However, India’s renewables transition will stall, coming up against the capacity of the grid to integrate variable renewables while keeping the lights on, unless new policies focus on enhancing the flexibility of the electricity system. Elements of such policy are emerging, through actions of the Power System Operator Corporation (POSOCO), the Central Electricity Regulatory Commission (CERC), Ministry of Power, and the Central Electricity Authority, as well as numerous state and regional level agencies.

What is required now is to initiate a joined-up process of policy formulation for the mid-term (2030), with targets, market reforms, regulatory initiatives, institutional innovations, data and analysis, all considered in holistic manner. The objective should be to come out with a new overarching renewables policy by around 2020 (an electricity system “Flexibility Mission”), in time to provide mid-term clarity and direction to the sector beyond today’s policy targets, which focus on 2022. The



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analysis of this project suggests that India could target 390 GW of variable renewable capacity by 2030, equivalent to 30% of renewable power generation, and 45% of zero carbon generation if biomass, small hydro, large hydro and nuclear are also included.



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