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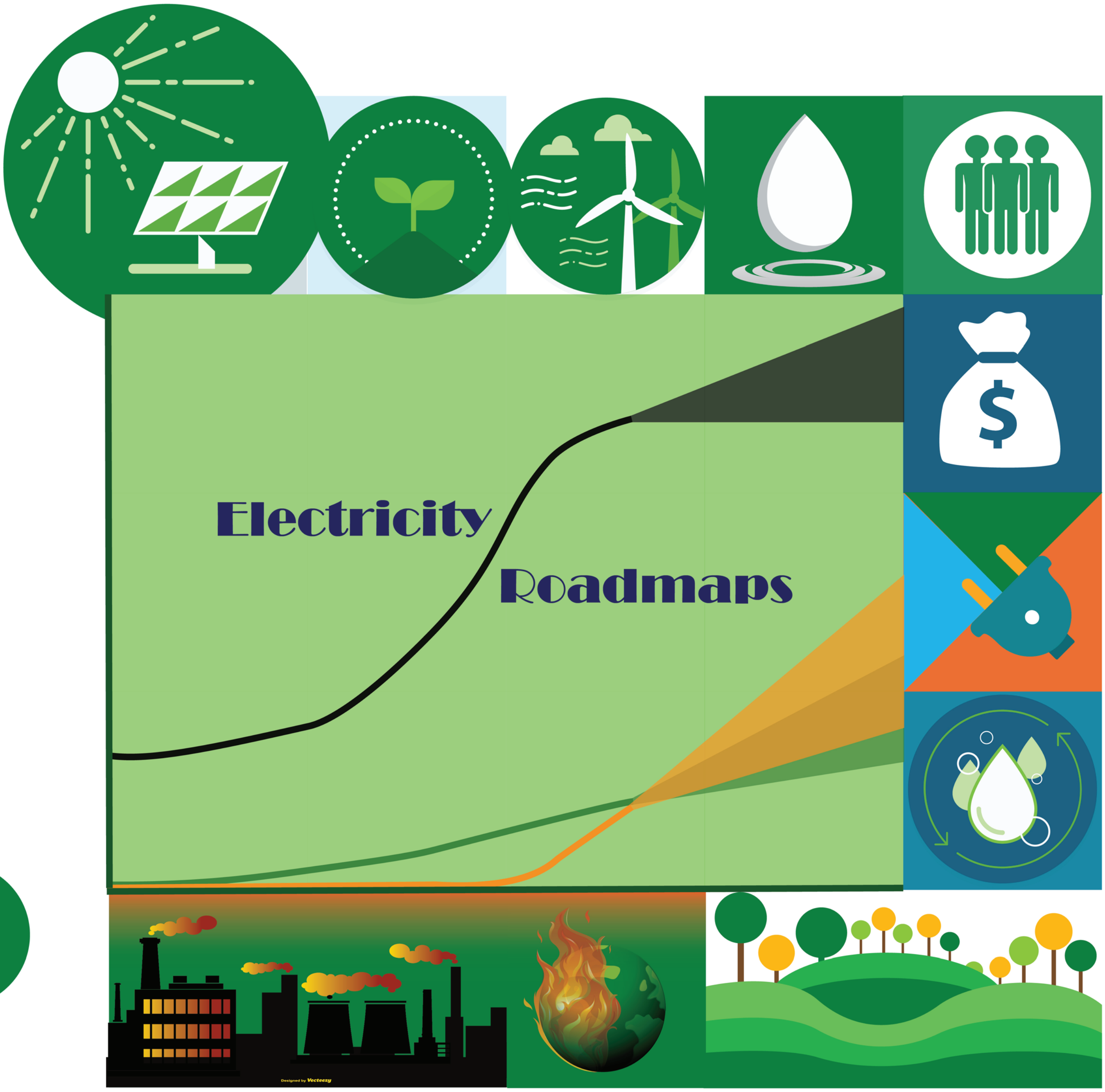
# ELECTRICITY TRANSITION ROADMAPS

## Comparative Evaluation of Long-Term Low Carbon Electricity Transition Roadmaps for India



# Electricity Transition Roadmaps

## Comparative Evaluation of Long-Term Low Carbon Electricity Transition Roadmaps for India: A Supply Side Assessment

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**Shakti Sustainable Energy Foundation** seeks to facilitate India's transition to a sustainable energy future by aiding the design and implementation of policies in the following areas: clean power, energy efficiency, sustainable urban transport, climate change mitigation and clean energy finance.

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# EXECUTIVE SUMMARY

## Background

Low carbon electricity transition roadmaps for future power supply options are valuable tools for developing India's climate mitigation strategies. Electricity system modeling to understand future trajectories and developments of the power sector has become a norm to support the future energy policies of any nation. Various energy system models have been developed in recent years that have different capabilities which are better suited for different purposes. As a result, many modeling studies show significant differences in their predictions and projected future scenarios. Hence, harmonizing, comparing and interpreting the results of different modeling studies within a single framework becomes necessary as they all could share a common objective of modeling the future of India's power system for instance. Further, most of the future roadmaps are developed keeping climate mitigation as their utmost priority and often ignore other socio-environmental aspects of energy transition. Hence, there is a need to evaluate and quantify: (i) the key differences between the major electricity transition roadmaps and scenarios developed for India; (ii) the co-benefits and trade-offs of different electricity transition roadmaps from multiple sustainability perspectives (in addition to climate mitigation); (iii) benchmark India's transition roadmaps with other emerging and developed economies in the world.

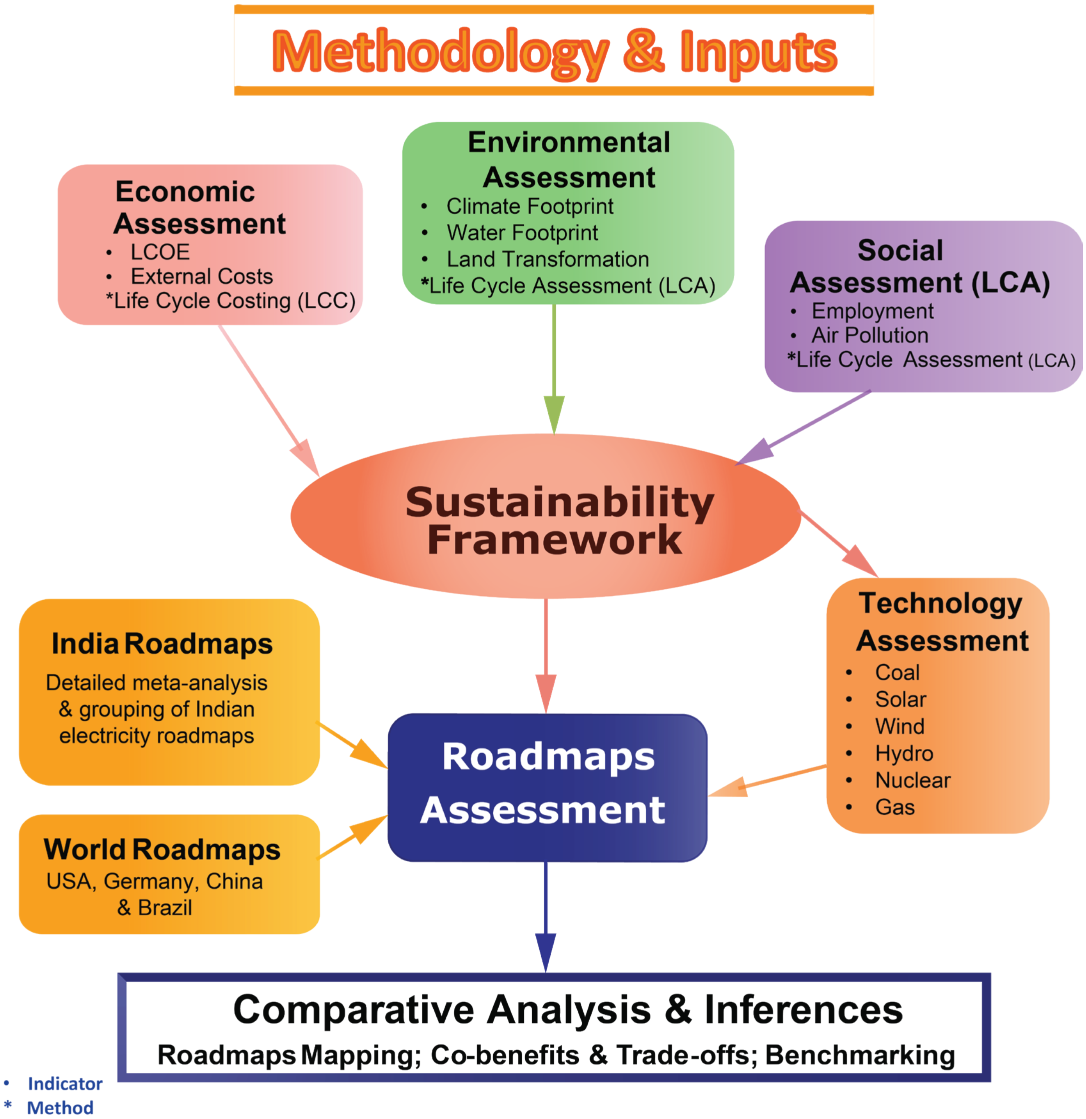
## Objective

This study aims to provide detailed insights into the future electricity-mix anticipated by various India specific modeling studies in the last five years and intends to address the following energy policy relevant questions in an Indian context:

1. What kind of impacts could future electricity-mixes have on multiple sustainability indicators?
2. What are the projections for the major electricity sources in India's future roadmaps?
3. How much increase in renewable energy share is expected across the modeling studies?
4. What types of electricity system models are prevalent in India-specific modeling studies?
5. How do future Indian electricity-mix projections compare with other emerging and developed economies across the world?

## Methodology

In this work, we conducted a comparative review of major low carbon electricity transition roadmaps developed specifically for India from a supply side perspective. Overall, we reviewed 16 India-specific modeling studies with a total of 41 roadmap scenarios; five studies from think tanks and academia each, four studies from international organizations and two studies from governmental or related agencies. We first harmonized the electricity generation-mix predictions for India in 2030 and 2050, and generically compared the electricity supply trends across various electricity modeling studies. A robust sustainability indicator-wise comparison on the performances of the electricity roadmaps was possible only for 2030 due to data availability issues and the short-term focus of most modeling studies in an Indian context. For robust comparison of electricity roadmaps, we adopted a bottom-up scenario analysis based approach wherein a series of indicators from environmental (climate footprint, water footprint, land transformation), economic (LCOE, external costs) and social (employment, air pollution) dimensions were chosen and integrated within our "Sustainability Framework" to assess the multi-dimensional aspects of electricity supply technologies (see graphical representation below). Then, the technology level impacts were aggregated to arrive at the cumulative impacts of India's low carbon electricity transition roadmaps. Lastly, we collected electricity supply data on low carbon electricity transition roadmaps for other emerging and developed economies (China, Brazil, the USA and Germany) from 11 international studies with a total of 27 roadmap scenarios. Through a short international comparative assessment, we provide glimpses on where the future electricity supply trends projected for India stand in comparison to other countries.




**Methodology and Inputs used to assess India's low carbon electricity transition roadmaps.**

## Inferences and Conclusion

### I. Generic Comparative Assessment of India's Roadmaps (comparing median values only)

- The median for alternate roadmap scenarios predict slight increases in coal power capacities during 2020 to 2030 and expect that the coal capacities will slightly drop afterwards and then stabilize around 2020 installed capacities (approx. 205 GW). Further, most roadmaps predict dramatic reductions for coal share in their annual electricity generation-mixes in the alternate scenarios: from over 72% in today's grid to 49% in 2030 to 21% in 2050.
- For nuclear power, the future predictions are very conservative and most alternate scenarios expect that nuclear capacities might stabilize around 17 GW to 20 GW in the coming decades; that is, nearly thrice as much increase in nuclear power capacity as of today (7 GW in 2020). However, the predictions for natural gas based power plants are promising: 45 GW in 2030 to 115 GW in 2050 (compared with 25 GW in 2020); this might be because of their flexible role in balancing and maintaining the grid stability during peak loads and also during non-availability of renewable energy sources in the future power grid, among other reasons.
- For solar power, most alternate scenarios project an ambitious rise in solar capacity by 2030 and 2050 in comparison to today's installed capacity; for example, the median values for alternate scenarios in 2030 and 2050 are higher by a factor of 5 and 15 in comparison to today's solar capacity installations (35 GW), respectively. The same trend holds true for wind power projections, except that their capacity projections are not as dramatic as for solar power. Nevertheless, the median values for alternate scenarios predict 130 GW and 290 GW of wind power capacities by 2030 and 2050, respectively; that is, an increase in the total wind power capacity by a factor of 3 to 8 in comparison to today's wind power capacity (38 GW). The RE share (solar and wind only) in annual electricity generation is expected to rise from 8% in 2020 to 23% in 2030 to 45% in 2050 in alternate scenarios, and the RE share in total power capacity is projected to rise from 20% in 2020 to 39% in 2030 to 59% in 2050 in alternate scenarios. Further, the majority of roadmap scenarios expect large hydro to stabilize after reaching around 70 GW in the coming decades, from 46 GW in 2020.
- Lastly, the predictions for other renewable energies mainly include bioenergy (primarily) and micro/small hydro based electricity generation, and the roadmap scenarios expect higher contributions from these renewable energy sources in the future electricity-mix. However, the possible contributions from prospective renewable energy technologies are ignored or highly underrated in the present modeling studies.

### II. Low Carbon Electricity Transition Roadmaps: Benefits & Trade-offs

- Our comparative assessment of India's future low carbon electricity transition roadmaps finds that the scenarios with a very high share of renewables (solar PV and wind) and lower absolute coal power generation perform not only well in terms of climate footprint, but they could have dramatic co-benefits in terms of water footprint, air pollution, external costs and employment generation indicators. The opposite is true with respect to coal dominated roadmap scenarios. The reason for a strong dependence of the roadmap scenarios on mainly coal, solar and wind electricity sources is because coal power has significant impacts on other sustainability indicators (in addition to climate change) when compared to renewables. For instance, it is estimated that coal emits 36 to 68 times more GHG emissions, consumes 10 to 400 times more fresh water resources and emits 13 to 38 times more particulate matter emissions in comparison to wind and solar, respectively. Hence, the external costs for coal power generation that account for some of the above mentioned environmental impacts indicate that coal is a very expensive electricity source from a socio-environmental perspective and suggests that the external costs for coal power could be 26 to 36 times higher than for wind and solar, respectively. Thus, it becomes evident that the impacts of electricity roadmaps increase 10s of times for every unit of coal power generated in their electricity generation-mix and likewise could decrease 10s of times for every unit of coal power being replaced by renewables.

- The mean system costs for the roadmaps with very high renewables are optimal in comparison to coal dominated roadmaps. The cost savings resulting from the lower LCOE of renewables (in comparison to coal power) and the significantly avoided climate damage costs associated with coal (e.g., carbon costs) in future electricity markets could be utilized to build a strong support infrastructure for a very high penetration of renewable energies in India's future power grid.
- The employment indicator favors the roadmaps with higher absolute renewable power generation contribution in the total electricity-mix, particularly solar power as it would create 5 times more jobs than coal for the same amount of electricity generation.
- Coal power accounts for nearly 92% of the total cumulative GHG emissions during 2020 to 2030 (comparing median values). Hence, we highlight that reducing the dependence on coal power generation more ambitiously – e.g., adopting the best performing roadmap scenarios instead of the pathway suggested by the median roadmap - could yield considerable "emission space" for GHGs from other sectors in India, for example heavy metal industries and other essential industries wherein there are often no alternatives for emission reductions (in the short run). Further, we underscore again that a shift towards renewables could help the country to reduce GHG emissions by 36 to 68 times for every unit of coal electricity being replaced.

### III. Electricity-Climate-Water Nexus

- We recommend a radical shift in modeling future electricity roadmaps for India wherein the water footprint should be given its due place and must be considered as one of the key criteria, along with climate change and cost optimization. If direct integration of water criteria into the existing models is difficult in the short run, then we suggest that the projected low carbon roadmap scenarios should be re-evaluated for freshwater consumption optimization through scenario based bottom-up approaches (like this study). We further caution the policy makers that ignoring the water footprint indicator during electricity system modeling and policy design could also favor sub-optimal clean technologies that might not become practically scaled-up on-the-ground in future India owing to the strong influence from water scarcity issues. Moreover, we underscore that a responsible action towards conserving India's freshwater resources will certainly benefit the country directly; unlike climate mitigation efforts that often need concerted action across the globe and whose benefits are often indirect and circuitous.
- Moreover, we underscore that accounting for water footprint in electricity modeling and energy policy studies not only helps in fine-tuning and filtering the climate friendly technology-mix to meet on-the-ground India-specific requirements, but could also greatly support in directing the development of India's future electricity sector towards water conservation and efficient water utilization in the coming era of water scarcity and global warming.

## IV. Electricity Modeling in India

- Although the electricity models used in India-specific studies ranged from simple excel based simulation type models to large scale simulation and optimization models to integrated models based on computational general equilibrium, we observed that the open source modeling tools have not yet found their place in India's modeling community. We call for attention from energy modelers in the country to the application of open source based tools and data sets in modeling India's future electricity system.
- In general, we found that the modeling granularity, data and assumptions used for projecting 2030 scenarios are more reliable than 2050 scenario projections, and also that most of the India-specific modeling studies have a short-term focus on prospective electricity and storage technologies. This could be because of the lack of Indian-specific detailed future technological studies on different electricity sources and prospective technology types till 2050. In addition, we encountered serious data availability issues (India-specific) while quantifying the technological impacts on the different sustainability indicators chosen in this study. We certainly recommend more policy oriented research in this direction.

## V. Benchmarking India's Roadmaps

- Benchmarking India's electricity transition roadmaps with other emerging and developed economies highlights that the alternate scenarios for India's future expect ambitious reductions in the coal share and significant escalations in the RE share in comparison to other countries as well as to India's present status-quo. Further, the median projection for India's RE share by 2030 (23%) is second only to Germany (55%) and India outperforms all the other three countries that were studied.
- Lastly, we observed that India is lagging behind other countries, especially when compared to developed economies (Germany and the USA), in terms of the development of open source based electricity modeling tools and their applications in an Indian context.