WRI INDIA

CONFERENCE PROCEEDINGS

Pathways for India's low-carbon and climate-resilient development

RESEARCH AND CAPACITY-BUILDING NEEDS

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EXECUTIVE SUMMARY

WRI India, in collaboration with Indian Institue of Management (IIM) Ahmedabad and Institute for Sustainable Development and International Relations (IDDRI), organized a multistakeholder dialogue on February 12, 2024, in New Delhi titled "Pathways for India's Low-Carbon and Climate Resilient Development." The dialogue was designed to facilitate discussions on the strategic transitions outlined in India's long-term low-emissions development strategy titled "Long-Term" Low-Carbon Development Strategy," henceforth referred to as India's LT-LEDS, and identify research and capacity-building needs so that climate planning and implementation could be supported and strengthened. The dialogue brought together 60 participants representing national, state, and local governments; research institutions; think tanks; industry; and teams from WRI India and IIM Ahmedabad. The dialogue included group visioning exercises and group discussions for key sectors.

This document synthesizes key insights into policy and financial intervention needs and entry points for research and capacity-building that emerged from the discussions. We hope that this synthesis will serve as a useful reference for climate policy researchers and practitioners, helping them prioritize policy-relevant research and capacity-building initiatives in India over the next three to four years.

We summarize the key insights from the discussions, including priorities for research and capacity-building.

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This conference proceedings reflects the presentations and discussions of the participants and does not necessarily represent the views of WRI India or other participating institutions.

Development is at the core of India's LT-LEDS, and planning is needed across time horizons

Greater horizontal and vertical institutional coordination is needed to implement long-term climate action.

The dialogue highlighted the following development priorities: poverty eradication, increasing employment, energy needs for development, improving energy access and security, economic growth, and sustainable development. In each of the thematic sessions on electricity systems, industry, transport, urbanization, agriculture, and the land sector, the participants envisioned and articulated development goals for the long term. For example, access to clean, affordable, and reliable electricity could be one of the indicators for the successful transition of India's electricity system.

The discussions highlighted the potential implications of the low-carbon transition on people and livelihoods across sectors and emphasized the need to plan for and implement a "just" energy-economy transition. India's development pathway is marked by the need to plan and align interventions over the short, medium, and long terms, considering targets such as the Sustainable Development Goals (SDGs), updated first Nationally Determined Contribution (NDC) by 2030, updated NDC targets for 2035, and the net zero target of 2070 as well as its aspirations of being an energy-independent and developed nation by 2047.

Institutional coordination and clarity on the role of states are needed to implement long-term climate action

The implementation of India's LT-LEDS will need to be carried out at multiple levels: the national, state, and local levels. This will require institutional coordination across multiple sectors and multiple levels of governance. At the state level, the state action plans on climate change (SAPCCs) have been mandated, prepared, and revised since 2011–12. With the SAPCCs articulating short-term climate action for five years at the state level and the LT-LEDS outlining long-term climate action at the national level, there is a need for an institutional framework and guidance for long-term climate planning and action by state governments. More recently, a few states such as Bihar and Tamil Nadu voluntarily articulated either long-term net zero targets or initiated long-term strategies for low-carbon and climate-resilient development. There is a need for capacity-building at the state and city levels to plan for and implement long-term climate actions.

Engagement, capacity development, and low-cost finance are required for the private sector, especially small industries

India's industrial sector is an important contributor to the national gross domestic product (GDP) and employment, but it also has a critical role to play in mitigating emissions from hard-to-abate sectors such as cement and steel as well as from micro, small, and medium enterprises (MSMEs).

Capacity-building needs for MSMEs and their workforce for the low-carbon transition were highlighted. Stakeholder engagement was emphasized to understand and address challenges related to small industries. Training programs will be required for the workforce while they transition to a circular economy.

Low-cost international finance is critical for decarbonization and for transitioning to a circular economy across sectors.

Sustainable urban development that integrates climate action needs improved planning, governance, and partnerships

Integrating climate action into urban development requires revisiting processes and institutions for long-term city planning. Urban policies need to be updated to take into account climate change in planning, implementation, and data collection. Small and large cities have have different needs and capacities, and appropriate capacity development of urban line departments is needed.

Further, partnerships with the private sector and civil society can unlock new avenues for financing and implementing urban climate action. The discussions also noted the need for instituting learning processes through which city governments can share their ideas, innovations, challenges, and experiences on climate action with other cities.

Infrastructure is needed to support the transition to low-carbon pathways

In addition to policies and behavior change, supporting infrastructure is needed for the scale-up of low-carbon technologies such as electric vehicles (e.g., charging facilities) and green hydrogen (e.g., storage and distribution infrastructure). It is also important to facilitate a modal shift in transportation from air and road toward rail and water (where possible). Infrastructure also needs attention in order to improve last-mile connectivity for freight and public transport, and pedestrians and cyclists.

Innovation opportunities should be tapped

Technological innovations such as waste heat recovery and utilization in industries, and alternative building materials are needed across sectors.

Innovations are also important in the context of urban and transport solutions. Integrated and innovative approaches to electric vehicle charging infrastructure, Battery-as-a-Service models, as well as solutions for last-mile transport connectivity were identified as important needs.

Transitioning to a circular economy is important

Strengthening material value chains, transparency in material composition, and incentives for the transportation of end-of-life products can support a transition to a circular economy along with financial interventions and capacity-building of the large informal workforce. The discussions highlighted multiple opportunities for the utilization, recycling, and repurposing of materials ranging from construction and demolition waste, e-waste, and batteries to decommissioned wind turbine blades.

Energy-economy models play a role in informing long-term low-carbon development scenarios

The dialogue recognized the importance of energy-economy models in developing long-term scenarios toward net zero emissions while understanding the impact of key decarbonization policies at the economy-wide and sectoral levels. The economic development assumptions underlying the models, climate mitigation ambition, and timing of climate action will be important considerations for alternative long-term development scenarios.

Although energy-economy models exist at the national level, there is a clear need for developing such models at the state level to inform long-term low-carbon development pathways.

A land sector roadmap is needed for India's low-carbon and climate-resilient development

The land sector is crucial for India's 2070 net zero target and other commitments such as biodiversity targets and combating desertification. Considering the multiple competing uses of land, it is important to assess land-use trade-offs and integrate them into planning. For state government officials, a key capacity-building need identified is related to planning for agriculture, while aligning land strategies with the net zero emissions target.

The discussions also noted the need for research on the role and contribution of biofuels in the long-term decarbonization pathways.

INTRODUCTION

WRI India, in collaboration with IIM Ahmedabad and Institute for Sustainable Development and International Relations (IDDRI), organized a multistakeholder dialogue on February 12, 2024, in New Delhi titled "Pathways for India's Low-Carbon and Climate-Resilient Development." The dialogue brought together 60 participants representing national, state, and local governments; research institutions; think tanks; and industry. A list of participants is provided at the end of the document.

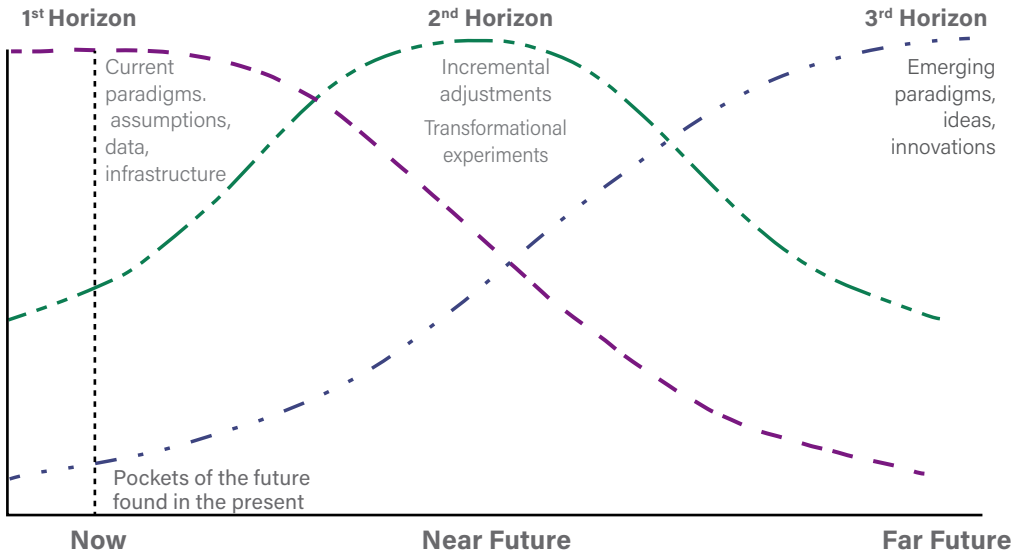
The discussions focused on the strategic transitions outlined in India's Long-Term Low-Carbon Development Strategy (LT-LEDS). The dialogue was designed to identify short-term research and capacity-building needs toward strengthening climate planning and implementation. WRI India and IIM Ahmedabad facilitated group visioning exercises among the participants that centered on five themes contextualized to the strategic transitions in India's LT-LEDS:

1. Low-carbon development of electricity systems
2. Efficient, innovative, low-emission industrial systems
3. Sustainable urbanization
4. Integrated, efficient, low-carbon transport systems
5. Agriculture, land use, and carbon dioxide removal

The group visioning exercises were inspired by and adapted from the Three Horizons Framework (ITC n.d.), a tool to help people think about possible and desired futures collectively while recognizing current assumptions about the world and emerging opportunities (see Figure 1):

- Horizon 1: The current state of play
- Horizon 3: The envisioned future
- Horizon 2: Transition opportunities and interventions

FIGURE 1 | Group visioning exercises inspired by and adapted from the Three Horizons Framework



Source: ITC n.d.

In each thematic session, the discussions began with Horizon 1, where the participants noted and discussed key assumptions underpinning the current state of play and barriers hindering the transition to an improved future. Then, the participants were requested to envision a desired future in the long term (Horizon 3) related to the theme of the session. For example, what would be the key indicators defining a low-carbon, high-growth industry sector after 2050? Following this, discussions were facilitated on identifying transition opportunities and interventions (Horizon 2) from our current state toward the envisioned future. The idea was to encourage participants to think of how we could transition toward the envisioned low-carbon and climate-resilient development future through interventions on different fronts, such as capacity development, research to address knowledge gaps, financing requirements, and governance changes.

FIGURE 2 | Group visioning exercises with the participants based on the Three Horizons Framework

Photo credit: WRI India.

BOX 1 | Key research needs identified during the sectoral group visioning exercises

Low-carbon development of electricity systems

- Case studies and innovative alternative business models for electricity subsidies offered by distribution companies offer.
- Field-based studies on the impacts of large-scale renewables such as utility-scale solar on natural resources and local communities.
- Detailed analyses of the role of demand-side management, which could minimize both the financial and environmental cost of expensive storage options in variable renewable-energy-rich scenarios.
- Electricity sector scenarios that explore higher dispatch of nuclear power and/or carbon capture and storage-retrofit fossil-based power plants.
- Sectoral electrification studies that can inform the ambition of future sector-specific low-carbon targets or pathways.

Efficient, innovative, low-emission industrial systems

- Sectoral and geographical studies on the potential impacts of the industrial transition; recommendations to plan and implement a just transition.
- Mapping and quantification of low-cost finance for the development and scale-up of emerging and innovative low-carbon technologies.
- Policy brief on recommendations for green taxonomy standards for industrial sectors such as cement and steel.
- Research on the role and contribution of biofuels in India's long-term decarbonization pathways.
- Research on the financing requirements of MSMEs and potential instruments they can use to adopt and scale low-carbon technologies.

Sustainable urbanization

- Comparative study on climate-sensitive planning in peri-urban India and policy recommendations.
- Pilot or demonstration studies on climate budget tagging in urban planning across selected cities.
- Compendium of urban climate innovations from Indian cities.
- Needs assessment for specific capacity-building required in metropolitan cities and smaller urban areas.
- Case studies on behavioral nudge interventions toward sustainable urban lifestyles in sectors such as waste management and transportation.

Integrated, efficient, low-carbon transport systems

- Case studies from Indian cities highlighting experiences in innovative financial approaches toward low-carbon transport.
- Behavioral nudges that could enable the adoption of low-carbon transport in India.
- Mainstreaming battery circularity within the electric vehicle ecosystem.
- Policy briefs on the decarbonization potential of various freight policies in India.
- Case studies exploring the potential of inland waterways to decarbonize the transport sector.

Agriculture, land use, and carbon dioxide removal

- State- and region-level studies on changes in land-use patterns due to climate action and climate change, to inform subnational roadmaps for the land sector.
- State-level case studies on the role and effectiveness of nature-based solutions (NbS) in building climate resilience.
- Studies on the impact of sustainable agriculture on building resilience, sustaining livelihoods, and increasing income in the sector, especially for women and marginalized communities such as landless laborers.
- Synthesis of recent evidence from land-related impacts of climate change and climate action, to inform land-use policy and planning at the national and state levels.

IMPLEMENTING INDIA'S LT-LEDS

India submitted its LT-LEDS to the United Nations Framework Convention on Climate Change (UNFCCC) in November 2022 under the Paris Agreement. This serves as India's long-term climate strategy commitment for adopting low-carbon development pathways toward net zero emissions and strengthening adaptation measures in the context of a changing climate.

The LT-LEDS identifies seven strategic transitions to low-carbon development pathways. These are low-carbon electricity, transport, and industrial systems; sustainable urbanization; climate-resilient and efficient buildings; carbon dioxide removal; enhancement of forest and tree cover; and the need for substantial low-cost international climate finance.

Development is at the core of India's LT-LEDS

Although the LT-LEDS underlines India's commitment to a low-carbon future, it also recognizes the national development priorities of poverty eradication, increasing employment, energy needs for development, and improving energy access and security while ensuring continued economic growth and sustainable development. Moreover, the strategy emphasizes that India's low-carbon transition will be proceed at a pace and scale that is nationally determined and does not compromise its development future.

The dialogue emphasized the need for low-carbon, sustainable, and inclusive development focusing on poverty eradication, improved living standards, and affordability to all. The transition to low-carbon development needs to be just while avoiding adverse environmental impacts.

India aims to fulfill the development goals articulated in the Sustainable Development Goals (SDGs) by 2030 and aspires to be a developed nation by 2047. However, this will entail a quantum increase in emissions to meet development goals, considering India's current low per capita electricity consumption (IEA n.d.-a). Therefore, it is imperative to choose development pathways that are less emission-intensive, while being cognizant of the social and economic aspects of such transitions.

Energy-economy models play an important role in creating low-carbon development scenarios based on policy and technology interventions. Long-term scenarios toward net zero emissions help explore the potential impacts of key decarbonization policies at the economy-wide and sectoral levels. Co-creation of long-term low-carbon scenarios with key stakeholders, including policymakers, will help assess how different climate policies and technology choices will affect India's development future.

In this context, the economic development assumptions underpinning the models are very important. GDP growth rate assumptions impact estimations of future energy demand. Modeling assumptions regarding the structure of the economy in terms of the shares of the agriculture, industry, and services sectors; the rate of urbanization; and the level of climate mitigation ambition will impact sectoral energy demand and emissions. These considerations are critical for long-term scenario-based planning toward a low-carbon future as outlined in India's LT-LEDS.

Development planning is required across multiple time horizons and targets

India's development is challenged by the need to plan and align interventions over different time horizons leading to India's 2070 net zero target.

Over the short term (i.e., until 2030):

- India has articulated its climate commitments to the UNFCCC through its Nationally Determined Contributions (NDCs). Globally, the NDCs are expected to be updated in 2025, with sectoral targets being outlined for 2035
- India is undertaking development interventions to meet its SDGs by 2030

- States in India have created state action plans on climate change for five-year periods. Several states have updated their SAPCCs, fixing the implementation timeline before 2030

In the medium term, India aims to be an energy-independent and developed nation by 2047. Fossil fuels met 75 percent of India's primary energy demand in 2020 (IEA n.d.-b), and India's fossil fuels are largely imported (MoPNG 2022, 2023)

The key challenge is to plan for India's development considering multiple time horizons. This entails transitioning to a low-carbon economy while building resilience to climate change

Energy-economy models help understand the implications of the timing of climate action. Early decarbonization measures would entail higher costs to the economy but avoid lock-in to emission-intensive pathways and stranding of fossil-fuel-based assets. Late decarbonization measures would potentially reduce technology costs but could impact trade competitiveness through external climate policies such as the European Union (EU) Carbon Border Adjustment Mechanism (CBAM)

Institutional coordination and clearly defined state roles are required

The LT-LEDS was prepared through a consultative process led and coordinated by the Ministry of Environment, Forest and Climate Change (MoEFCC) as the nodal agency. This process involved ministries, state governments, research institutions, and industry. Going forward, the implementation of the LT-LEDS will require institutional coordination across multiple sectors and deeper engagement between national, state, and local government entities.

Whereas the LT-LEDS is a long-term strategy document at the national level, the SAPCCs plan for short-term climate action at the state level. Although states have the responsibility to implement climate action through the SAPCCs, they are not subject to any directives or mandates to develop state-level net zero or long-term strategy documents. There is currently gap, namely, the lack of an institutional framework and guidance for state-level implementation of LT-LEDs and for climate planning that ensures alignment between the center and the states to be in alignment. Action needed at the state level in the context of long-term climate action emerged as a clear gap that needs attention.

State-level capacity development is needed for long-term climate planning and action

At present, a capacity gap at the state level hinders the implementation of net zero climate actions. There is a significant need for capacity development at the state level for government officers on multiple aspects of planning for low-carbon and climate-resilient development, such as what the LT-LEDS is and how strategies and policies can be aligned to move toward net zero emissions. Further, in the context of existing national and state policies, there is a need to understand the states' resource requirements for a low-carbon transition.

Although national-level energy-economy models such as the India Energy Security Scenarios (IESS) 2047 (IESS n.d.) and the TIMES model (IEA-ETSAP n.d.) exist, there is a need for developing models to inform long-term climate planning at the state level.

Ongoing initiatives such as the NITI Aayog's State Support Mission (NITI Aayog n.d.) can be leveraged to build the capacity of state governments toward development planning up to 2047 and strengthen institutionalized engagement between the center and the states.

Access to finance will be critical for India's low-carbon and climate-resilient development

India's LT-LEDS recognizes that low-cost international finance is essential for low-carbon development. Across the thematic sessions, access to low-cost finance was noted as an enabler for decarbonization and the transition to a circular economy. Different kinds of finance instruments, such as blended finance and grants, are needed.

There is a critical need for quantifying low-cost finance requirements at a more granular level through analyses that uncover specific needs and outline potential financing mechanisms.

The quality of finance available is a challenge considering that loans from international funders are not cost-competitive for developing countries, whereas developed countries have access to relatively low-cost finance.

STRATEGIC TRANSITIONS IN KEY SECTORS

Low-carbon development of electricity systems

India has a total installed power generation capacity of 415 GW (as of March 2023). Of this, coal-based capacity is 51 percent, and it accounts for about 73 percent of total electricity generation (CEA 2023). Renewable capacity (solar and wind energy) has grown rapidly in recent years (MoEFCC 2022a), contributing to India's early achievement of its original NDC target of 40 percent of installed electricity capacity from nonfossil fuel sources (MNRE 2021).

India's per capita electricity consumption from utilities is about 25 percent of the global average. Based on progress with universal access to household electricity, the current priority of the government is to improve the quality and reliability of supply (MoEFCC 2022a). By 2050, India's electricity demand could increase to over four times the present demand because of rising incomes, urbanization, and electrification of other sectors (Swamy et al. 2021). Considering that India's overall average per capita electricity consumption is expected to grow in the coming decades, the challenge is to transition to a low-carbon electricity system while being cognizant of the important role of coal and other fossil fuels in the economy. In this context, the LT-LEDS outlines the following broad pathways for the development of a low-carbon electricity system:

- Expansion of renewables and strengthening of the grid
- Other low-carbon technologies, such as nuclear power, and emerging technologies
- Demand-side management measures
- Rational utilization of fossil fuels

Current policies and initiatives

Several government policies and incentives aim to expand renewables. The recently announced Pradhan Mantri Suryodaya Yojana aims to provide incentives to 1 crore (10 million) households for adopting and installing rooftop solar (MNRE 2024a).

- The ongoing Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyaan (PM KUSUM) scheme incentivizes the solarization of irrigation pumps (GoI n.d.). This scheme also provides for feeder-level solarization. Because electricity supply for agriculture is provided at night in some states, access to daytime supply of solar-based power for irrigation pumps will play a role in the decarbonization of the agriculture sector
- Renewable energy is encouraged through "must run" status for renewable sources and renewable purchase obligations (RPOs) for distribution companies, open-access consumers, and captive power plants (MoEFCC 2022a)

- Renewable generation obligation (RGO) has been mandated for new coal- or lignite-based thermal power plants since 2023. The plants need to generate (or purchase) a minimum of 40 percent of their capacity from renewable energy sources (MoP 2023a)

Universal household access to electricity was initiated through the Pradhan Mantri Sahaj Bijli Har Ghar Yojana or Saubhagya scheme in 2017. The scheme has been reported to provide electricity connections to all willing households through last-mile connectivity (MoP 2023b). However, because last-mile connectivity through a centralized grid is not guaranteed, there is a need for local off-grid options such as decentralized renewable energy for remote households.

Transition challenges

Affordability

India's energy transition entails the challenge of providing affordable electricity to consumers, taking into account fluctuations in the price of electricity and fuels. Despite subsidies to support higher uptake of clean electricity, there is uncertainty regarding the feasibility of subsidies over the long term. Further, considering that energy storage systems are expected to play an important role in the medium to long term, the high cost of energy storage technologies will have implications for electricity prices until economies of scale drive down prices. The key concern is the expected impact on access to affordable electricity.

Technological challenges

The transition to a low-carbon electricity system entails several technological challenges and uncertainties:

- The share of renewables capacity in the energy mix increased rapidly from 39 GW in 2015 to 110 GW in 2022 (MoEFCC 2022a). It will be difficult to meet peak electricity demand in the future if the energy mix is heavily reliant on renewables (even with storage technologies)
- Current systems are not designed to cater to decentralized renewable energy. Although the physical infrastructure of the grid is sufficient, mechanisms to balance supply from renewable energy sources are lacking

Energy demand forecasting and planning

Long-term energy demand assessments are based on projections of past use. However, this approach may not yield accurate estimates because systemic, economy-wide shifts that are part of the energy transition are not reflected in past trends.

Resource dependence

At COP26 in 2021, India presented its ambition to increase its nonfossil energy capacity to 500 GW by 2030 (MoEFCC 2022b).

The transition to renewables, such as solar photovoltaics and wind power, supported by battery energy storage systems, involves dependence on critical minerals, such as lithium, nickel, cobalt, and copper, and rare earth metals. These minerals are available only in a few countries, creating a global dependence on them. India does not have the critical minerals required for its energy transition.

Considering the global dependence on, and the increasing demand for, scarce critical minerals, India's transition to renewables is contingent on their availability. There is a risk of supply chain disruptions due to import dependence.

Financial challenges

The transition toward renewables-based power generation entails financial challenges:

- New investments in thermal power increase the risk of stranded assets (Srivastava 2023), which can have adverse financial implications through nonperforming assets (MoEFCC 2022a)

- The viability of renewable energy projects is gauged using variables such as cost, price, and value, which are used interchangeably. Viability estimation using variables such as the levelized cost of electricity (LCOE) does not account for the fact that renewable energy generation varies in time and across regions

The envisioned future

The participants were asked to identify indicators that define a successful transition to a low-carbon electricity system.

Electricity for development

The participants envisioned a low-carbon development future that is inclusive and just, ensures decent living standards, and provides affordable access to basic services, including energy.

Access to clean, affordable, and reliable electricity emerged as an important indicator for the successful transition of India's electricity system.

Energy security

India aims to be energy independent by 2047. For the government, this is an important indicator in the context of India's energy transition. Initiatives such as the National Green Hydrogen Mission aim to enhance India's energy security while decarbonizing the economy. Diversifying energy sources to include green hydrogen could reduce fossil fuel imports such as crude oil (MNRE n.d.-a).

Transition opportunities and interventions

Reforms to support electricity distribution utilities

Because electricity distribution companies (discoms) are in debt, there is a need for reforms to improve their financial health. This is important in the context of the ongoing transition, where larger consumers are migrating to alternative power supply options such as open access and captive power. New models for subsidizing electricity must be explored to replace the current cross-subsidy model.

Further, establishing alternative, bankable business models for distribution utilities can prevent overreliance on subsidies. The subsidies can then be channeled to new technologies such as battery energy storage to drive down the total cost of procurement and the cost of electricity.

Just energy transition

India's energy transition necessitates a phased reduction in the share of coal in the electricity sector (MoEFCC 2022a). Given that coal mining and allied activities and thermal-based power generation employ millions of people directly and indirectly, the energy transition must be planned and implemented in a just manner, ensuring that people with coal-based livelihoods are not left behind. Further, repurposing land in coal-based regions will be a challenge.

Also, as utility-scale solar is scaled up, the ongoing expansion of renewables will need to be supported by comprehensive planning and resource adequacy assessments to mitigate potential adverse impacts on natural resources and local communities. Examples of such adverse impacts are land-use conflicts in the context of solar and wind and displacement of local, indigenous communities for hydropower generation.

Further, the potential for renewable energy (solar and wind) is not uniform across states. Some regions have better solar and wind potential than others. Therefore, interstate coordination and regulations that incentivize a higher volume of interstate trade in clean energy are essential.

Capacity development for new job opportunities

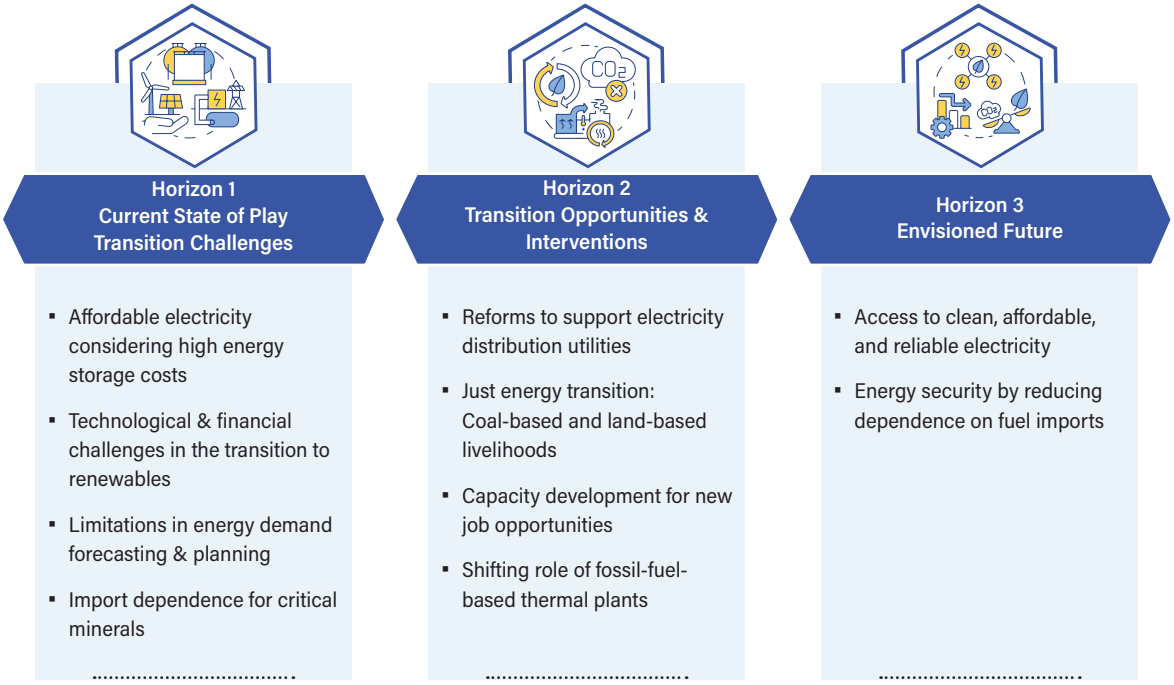
The energy transition presents India with an opportunity to emerge as a global leader in the manufacture and production of emerging green technologies. Examples of such technologies are green hydrogen and nuclear power from alternative fuel resources such as thorium. Research and development and capacity-building on these fronts can foster the creation of new jobs and ensure energy independence in addition to decarbonizing energy use throughout the economy.

The role of fossil-fuel-based thermal capacity

Although there is a risk of stranded assets, fossil-fuel-based thermal capacity may still retain its utility in the medium–long term, with carbon capture, utilization, and storage (CCUS) either functioning as a backup or shifting its role from supplying baseload to enabling flexibility.

Figure 3 summarizes the discussion on transition challenges, transition opportunities and interventions, and the envisioned future for low-carbon development of electricity systems in India.

FIGURE 3 | Low-carbon development of electricity systems in India



Efficient, innovative, low-emission industrial systems

India's industry sector is an important contributor to economic growth and development (~26 percent gross value added in 2020–21). India aims to expand industrial production by increasing the share of domestic manufacturing in its GDP. This will result in increased energy consumption and significant additional demand for hard-to-abate steel and cement in the medium to long term (MoEFCC 2022a).

In this development context, India's LT-LEDS notes the need to decouple economic growth from emissions through an efficient, innovative, and low-emission industrial system. The LT-LEDS outlines broad pathways for industrial decarbonization:

- Improvements in energy and resource efficiency
- Process and fuel switching, electrification in the manufacturing sector
- Enhancement of material efficiency and recycling, which will strengthen the circular economy
- Promotion of green hydrogen technology and infrastructure

The strategy emphasizes the need for sustainable and low-carbon development of both hard-to-abate sectors and MSMEs. It also recognizes the need for maintaining employment and repurposing assets within a transitioning economy that involves sectors such as mining, petroleum, refining, and manufacturing. The strategy also recognizes the presence of a large informal workforce in the economy.

Current policies and initiatives

The Make in India initiative (MoCI 2023a) by the Government of India (GoI) aims to boost domestic manufacturing by facilitating investments, encouraging innovations, and instituting policy measures such as production linked incentive (PLI) schemes (MoCI 2023b). An example is the PLI scheme for promoting domestic manufacturing of high-efficiency solar photovoltaic modules (MNRE n.d.-b).

The GoI is planning an Indian Carbon Market (ICM), to accelerate the transition to a low-carbon economy and progress toward India's NDC goal of reducing the emissions intensity of its GDP by 45 percent by 2030 when compared to 2005 levels. This will entail developing greenhouse gas (GHG) emissions intensity benchmarks and setting targets for specific energy sectors and the trading of carbon credits (MoP 2023c). This will be implemented through the Carbon Credit Trading Scheme (CCTS) notified in 2023, progressing bulding upon the energy savings achieved through the Perform, Achieve, and Trade (PAT) scheme.

The National Mission for Enhanced Energy Efficiency (NMEEE) (MoP 2022), under the National Action Plan on Climate Change (NAPCC), has aimed to improve energy efficiency through the PAT scheme since 2012. The PAT scheme is a regulatory instrument with a market-based mechanism for reducing specific energy consumption in energy-intensive industries. This allows for the certification and trading of excess energy savings by industries.

The government has initiated the National Green Hydrogen Mission to develop and scale up green hydrogen production capability for energy self-reliance and export green hydrogen and its derivatives. India has set a target of producing 5 million tonnes of green hydrogen per annum by 2030 (MNRE n.d.-a). The mission currently supports pilot projects on green methanol in shipping, direct reduced iron (DRI) steel, and hydrogen-powered internal combustion engines.

Transition challenges

There are multiple challenges in transitioning to efficient, innovative, and low-emission industrial systems.

Increasing the energy efficiency of production

There are limits to improvements in the energy efficiency of production. The challenge is to identify and tap into energy efficiency opportunities beyond low-hanging fruit, such as raw material optimization, ore beneficiation, and energy auditing.

Feasibility of nascent low-carbon technologies

The adoption of low-carbon technologies is challenged by the relatively high cost and limited or uncertain feasibility of these technologies in industry. Long-term industrial decarbonization hinges on the assumption that nascent technologies such as green hydrogen and CCUS will become feasible and play a critical role in the future. At present, green hydrogen is not commercially feasible, and significant research and development (R&D) on geological carbon storage is needed before its feasibility can be established.

Switching to cleaner fuels

There is great dependence on coal as a fuel in production processes. The transition from coal to cleaner fuels is hindered by the high price of alternative fuels. For example:

- The price of biomass has increased significantly in the last two decades
- Electrification of kilns is a very expensive process, slowing the transition toward electrification of production processes

Incentives for low-energy-use products

At present, there are gaps in financial incentives for transitioning to low energy or low carbon use in production. Further, low-energy-use products have limited offtake in the market. Standards defining green products are yet to be developed, further inhibiting demand creation. This limits transitions toward reduced energy consumption and carbon emissions in production.

International trade policies

The cost of accessing and trading in lead international markets is impacted by policies such as the EU CBAM, which would come into effect from 2026. The competitiveness of Indian industries in the global market will depend on the timing and pace of its decarbonization relative to that of Europe and other developed economies.

Sustainable development of MSMEs

The development of MSMEs entails a twofold challenge. First, MSMEs need improved access to reliable and uninterrupted grid power supply. Second, balancing decarbonization efforts with maintaining competitiveness is a challenge. At present, there are gaps with respect to (a) mapping and measuring emissions and (b) small-scale technologies for emissions reduction through energy efficiency and waste heat recovery. Limited awareness and aggregation within the MSME sector also limit its ability to transition to low-carbon pathways.

The envisioned future

The participants were asked to identify indicators that define what a low-carbon, high-growth industrial sector should look like in the distant future—after 2050, for example.

Decarbonization and energy efficiency

The participants envisioned a low-emissions and energy-efficient future for large industries and MSMEs. Energy intensity and emissions intensity would be the indicators used to assess industrial decarbonization. Life Cycle Assessment (LCA) methodology will be used to assess GHG emissions.

- Hard-to-abate industrial sectors such as steel and cement will achieve net zero emissions targets
- MSMEs will have access to a reliable supply of power and heat

Manufacturing pathway and circular economy

In the envisioned future, India will have a higher share of global manufacturing. Also, there will be a transition to a circular economy involving industrial systems, and the recycling industry will play an important role in this economy.

Transition opportunities and interventions

Job creation

As India transitions to a low-carbon economy with a focus on manufacturing, there will be a need for reskilling. There are emerging opportunities in the renewable energy sector and in the manufacturing of green hydrogen and its derivatives, for which the workforce needs to be prepared.

Further, it is important to ensure that the transition within the industrial sector is just. The focus on just transition needs to expand beyond the coal economy to include the industrial sector and the economy at large.

Circular economy

The transition to a circular economy will require strengthening material value chains with regular collection systems for components as well as transparency in material composition for tracking and repurposing. Interventions are needed for waste recovery and for transportation of waste or end-of-life products. There is also a need to formalize material streams.

For example:

- There is a need for transparent information on the composition of appliances and components in the e-waste value chain and recycling
- In the cement sector, construction and demolition waste can be utilized as raw material. There are opportunities to recycle decommissioned wind turbine blades as raw material and fuel in the cement industry
- Waste generated by municipalities could be channeled to industries by establishing appropriate value chains
- There is a need to explore opportunities to collect and channel used cooking oil for biofuels
- Because the quantum of scrap is expected to increase with economic growth, it is necessary to begin formalizing scrap collection

Training and finance are required for creating jobs in the circular economy. For example, opportunities exist in steel scrap recycling, concrete reuse, and manufacturing fly ash bricks. Capacity-building is required for the following:

- The primarily informal sector workforce engaged in recycling
- Quality assessment of waste streams, which could be recycled for industrial use

Innovation, research, and development

Industrial R&D plays a critical role in India's energy-economy transition toward low-carbon development. Technological innovation is needed on different fronts. Further, it is necessary to adopt and scale up innovative technologies.

For example:

- Opportunities for innovation exist in simple waste heat recovery and utilization in industries such as cement and fertilizers
- Over the next few decades, with economic growth and urbanization, the demand for infrastructure and housing will be high. The majority of building stock (infrastructure and housing) is yet to be built. There is therefore a need to reduce the demand for cement and steel, which are hard-to-abate industries, and an opportunity for research and innovation in alternative building materials
- Innovations to reduce process emissions are needed
- Considering the potential, yet uncertain feasibility, of CCUS in decarbonization, R&D on this front is also important

Policy and regulatory interventions

Operationalizing the ICM requires a clear policy direction regarding the recently notified CCTS and clarity regarding the transition from the PAT scheme to CCTS.

Enabling the development and scale-up of green hydrogen production capability in India requires policy support and incentives on multiple fronts:

- Support for R&D and pilot projects
- Indigenous manufacturing of electrolyzers
- De-risking hydrogen production through blended financing models
- Creation of hydrogen production and consumption hubs
- Public procurement policies to incentivize green steel and green cement

Policy direction is required to prioritize decarbonization pathways in different contexts, such as electrification versus CCUS. Policy measures are required to scale and commercialize CCUS technologies for large industries. The costs of implementing CCUS need to be reduced.

India's energy transition planning needs to consider national and state priorities and capacities:

- Considering the demand for scarce land resources, regulatory measures on resource utilization are required
- Planning needs to recognize who should bear the burden of carbon taxation and carbon pricing in order to ensure that the energy transition is just and equitable

Since 2007, India has implemented the Energy Conservation and Building Code (ECBC) to improve energy efficiency in new commercial buildings. The discussions indicated that there is an opportunity to extend the ECBC to industrial buildings. Further, industrial spaces can have preassigned spaces for solar power generation.

Green standards in India are outdated and require review and revision.

Financing

The development and scale-up of low-carbon and innovative technologies are contingent on adequate financial support. This requires quantification of low-carbon investments. Further, low-cost finance needs to be made available for large industries as well as MSMEs.

For MSMEs, concessional financing with viability gap funding will be required from the government. Catalytic capital, blended finance, grants, sustainability-linked bonds, and loans could serve as potential financing mechanisms to help MSMEs transition to low-carbon measures.

Financing opportunities include raising large-corporate-led sustainability-linked capital and low-cost international finance from multilateral development banks.

Financial institutions will need to measure and incorporate climate risk. In this context, there is a clear need for India to develop green taxonomy standards.

Capacity-building

Implementation of the CCTS will require significant capacity-building within the country. This is also important for industrial competitiveness within the global market. Further, capacity-building needs to incorporate a good understanding of global instruments in the context of climate mitigation.

In-country expertise and skill development are required on various topics such as lifecycle assessments and marginal abatement cost curves.

MSMEs

For MSMEs, interventions on multiple fronts can enable their transition to low-carbon and sustainable development:

- Improved access to power supply enabled through subsidized electricity rates
- Energy auditing (especially in hard-to-abate industries) and incentives for energy efficiency ratings
- Access to adequate finance for decarbonization
- Formalization of MSMEs. For the benefit of the large workforce in MSMEs, there is a need to register the workforce as MSME workers. Streamlined certification processes and capacity-building are required to enable this

For MSMEs to remain competitive and trade in global markets, potential interventions include, the following:

- Simpler compliance mechanisms through integrated processes that avoid multiple windows for clearance and approval
- Access to a shared pool of resources to prepare for international changes such as the EU CBAM

In addition to the above measures, stakeholder engagement with small industries is required to understand challenges and plan interventions. Further, clear policy direction and support are needed for MSMEs to remain commercially competitive.

Bioenergy

Bioenergy is a nonfossil fuel alternative that could contribute to India's renewable energy targets. It can also serve as a nonfossil fuel alternative for industrial process heat. For example, bamboo-based biochar was mentioned as a potential option to reduce carbon dioxide emissions from steelmaking.

Because the energy efficiency of biofuels is lower than that of fossil fuels, there is a need for research on the role and contribution of biofuels in the context of long-term decarbonization pathways.

Also, there is a need to improve biomass supply chains and further incentivize bioenergy. Biomass-based alternative fuels should be derived only from waste residues.

Renewable energy generators have the option of utilizing renewable energy certificates (RECs) and trading them at the national level. To incentivize certain renewable energy technologies, REC multipliers have been designed that enable multiple RECs to be associated with the electricity produced from such technologies. Although the REC multiplier value is the highest for bioenergy projects, there is potential for further increasing the REC value of bioenergy projects.

Transition to cleaner fuels and natural resource management

Industrial decarbonization through electrification will require higher renewable energy integration in the grid. For large industries, there is a need to explore opportunities for on-site renewable energy integration and implement them to reduce transmission losses and emissions.

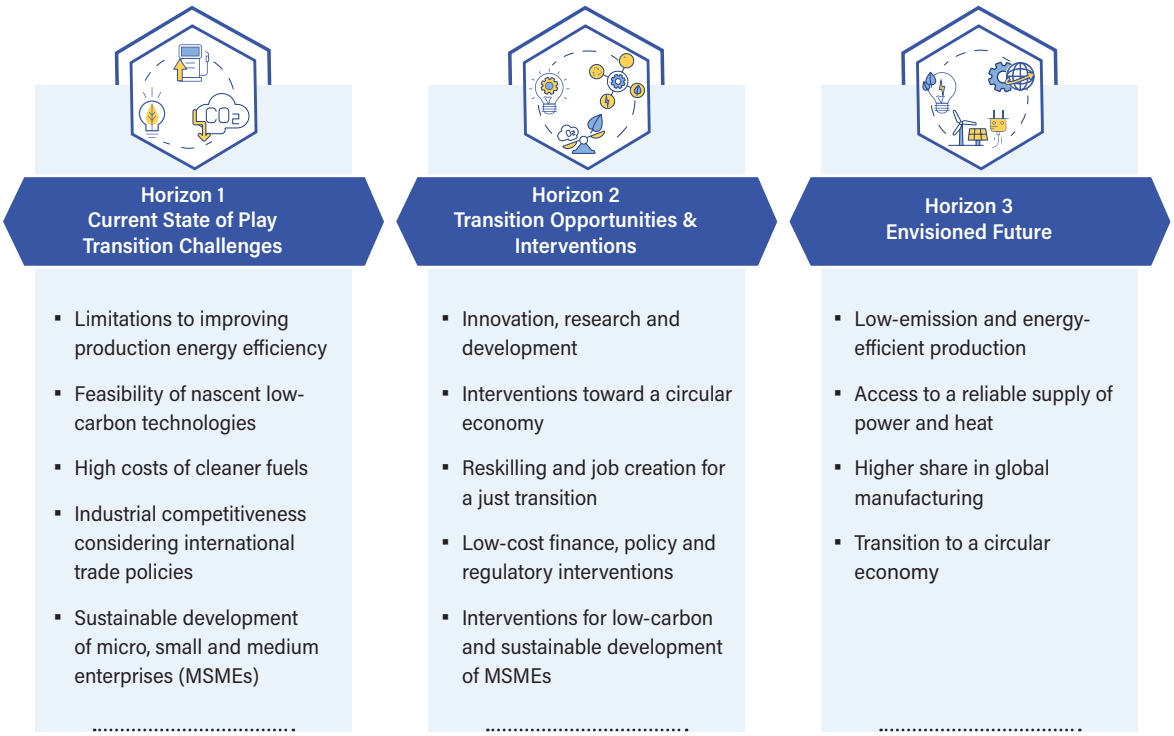
In cases where electrification is not possible, a potential pathway for industrial decarbonization is through green hydrogen, green ammonia, and ethanol. Green hydrogen is considered the fuel of the future and can be utilized in the fertilizer, cement, and steel sectors.

Also, there are emerging opportunities for concentrated solar power (CSP) within India's renewable energy ecosystem.

Considering the increasing demand for limited land resources, less carbon-intensive land-use patterns for industrial development need to be promoted. Also, wastewater reuse needs to be incentivized.

Figure 4 summarizes the discussion on transition challenges, transition opportunities and interventions, and the envisioned future for efficient, innovative, low-emission industrial systems in India.

FIGURE 4 | Efficient, innovative, low-emission industrial systems



Sustainable urbanization

Although there is a clear recognition of the urgent need for cities globally to address the impact of climate change on local communities and ecosystems (IPCC 2022), in India, this is especially important considering the vulnerability of cities to the increasing number and frequency of extreme weather events (MoEFCC 2022a).

On the other hand, cities contribute significantly to global carbon dioxide emissions, especially in India, where rapid urbanization is projected to double the urban population by 2050 while also generating 75 percent of the country's GDP.

India is at a critical juncture in urban development. Estimates indicate that the urban population is projected to grow to 600 million by 2030 from about 377 million according to Census 2011 (MoEFCC 2022a). The challenge for Indian cities and towns is achieving sustainable urban development while building resilience to the impacts of climate change and taking scalable climate action to mitigate urban emissions.

India's LT-LEDS underscores sustainable urbanization as one of the seven key strategic transitions for low-carbon development. Three broad pathways toward sustainable urbanization are outlined:

- Mainstreaming adaptation measures in urban planning
- Promoting climate-responsive and resilient buildings
- Promoting low-carbon municipal service delivery through resource efficiency and water management

Current policies and initiatives

Policies and initiatives aimed at fostering clean and livable urban environments underpin efforts toward sustainable urbanization. Municipal services and urban missions form the backbone of these efforts, covering critical aspects such as water supply, sanitation, provision of clean and adequate public spaces,

enhancing public transport networks, and improving green cover. These initiatives are further supplemented by the ECBC and other initiatives on energy usage in cities aimed at improving energy and material efficiency in buildings.

Transition challenges

Uneven urbanization

One of the key challenges to sustainable urban development is uneven urbanization across cities and towns. This not only strains metropolitan cities but also limits climate action in smaller urban centers. Smaller cities often lack the necessary attention and resources required to plan for sustainable development. Moreover, the rapid expansion of peri-urban areas, characterized by unplanned growth and reduction of green spaces, threatens urban biodiversity.

Capacity

There are significant capacity constraints at the local level that limit adequate planning for climate action.

Despite initiatives aimed at improving urban infrastructure, including planning documents such as masterplans, there is often a disconnect between the plan objectives and initiatives and their impact on citizens' well-being and quality of life. Further, improvements in citizens' environment and well-being are not measured in urban projects' indicators of success.

The lack of quantification of economic losses due to climate change impacts in cities (such as flooding due to erratic rains, heatwaves) hampers careful adaptation efforts.

Governance

Fragmented governance structures and inadequate coordination between various departments and agencies further compound the challenges in implementing climate action in cities.

The envisioned future

Amid the urban challenges, the participants collectively envisioned a desired future for Indian cities.

Holistic and equitable urban development for the well-being of citizens

The envisioned future is characterized by holistic and equitable urban development that prioritizes the health and well-being of all citizens. Accessible and affordable services to all citizens, including basic amenities such as water supply and sanitation, as well as governance structures that prioritize citizen participation and engagement are critical.

Further, the participants envisioned a future where citizens adopt lifestyles that rely on public transport, use and nurture green spaces, and actively participate in maintaining and improving the city.

Improved urban ecosystems

Central to the vision of holistic urban development is maintaining and improving the health of urban ecosystems through mitigation of air pollution, improved green cover, and promotion of active and public transportation modes. Additionally, in future, cities will support greater urban biodiversity, harvest more water, and adopt cleaner energy sources such as rooftop solar power.

Interactions between cities and surrounding regions

Going forward, cities will need to rethink how urban areas currently interact with their larger regions in terms of waste production, food systems, and resource use. There will be an improved relationship between cities and their surrounding regions with respect to waste, water use, and food systems.

Transition opportunities and interventions

Realizing the vision of sustainable urbanization in India necessitates not only concerted efforts to address existing development challenges but also interventions to realize emerging opportunities for urban climate action.

Improved urban planning, updated policies, and governance

There is a need to revisit the processes and institutions of long-term planning, such as urban development authorities, and their role in incorporating environmental sustainability in city planning. It is critical to incorporate environmental and ecosystem concerns within developmental works planned for the city. This can be done by building adequate capacities in line departments. This also entails rethinking traditional approaches to infrastructure development and incorporating NbS that mitigate climate risks and improve overall urban livability.

For example, there is an opportunity to create green public spaces and foster a sense of ownership among urban residents, thereby promoting community participation. Further, tools such as transferable development rights (TDRs) need to be explored to create more public spaces. Ultimately, cities need to recalibrate their measures of success to include citizens' well-being and the health of urban ecosystems.

At the same time, considering that vulnerable urban populations are disproportionately affected by the adverse impacts of climate change such as heatwaves and floods, there is an urgent need for climate-resilient urban planning and adaptation measures.

States need to update their urban policy to incorporate climate change, in terms of planning, implementation, capacity-building, and data collection, acknowledging that the requirements of large cities differ from those of smaller but fast-growing urban areas. Smaller but fast-growing parts of urban India may face increasing sustainability challenges in the coming years; hence, policies should focus on providing solutions to uneven urbanization.

Urban policy in states needs to incorporate climate-sensitive planning, specifically for fast-developing peri-urban areas of cities. Further, although building design policies such as the ECBC offer significant potential for enhancing energy efficiency, their widespread adoption and enforcement require concerted efforts from the relevant stakeholders.

Further, it is vital to leverage information and data across departments and parastatal agencies for comprehensive climate action planning. Coordination would play an important role in quantifying losses from climate change impacts such as urban floods and environmental challenges such as air quality; coordination would also be needed to plan for adaptation. Planning documents such as masterplans need to be drafted carefully, and concepts such as budget tagging for masterplans need to be explored to improve their implementation.

Partnerships for urban climate action

Fostering partnerships with the private sector and civil society can unlock new avenues for financing and implementing climate action initiatives in cities. By scaling up corporate social responsibility (CSR) efforts for public spaces and developing viable business models for urban climate projects, cities can ensure the long-term viability of their initiatives.

By developing learning processes, city governments should be able to share their ideas and innovations for solving climate and environmental challenges with other cities.

State governments can leverage urban climate action to generate livelihood opportunities in cities.

An integrated, efficient, low-carbon transport system

India's transport sector contributes 12 percent of the country's energy-related carbon dioxide emissions (IEA n.d.-c). At present, road transport meets 90 percent of domestic transport energy demand (MoEFCC 2023). Road transport represents 87 percent of passenger traffic and 60 percent of freight movement (MoRTH n.d.). India's freight demand is projected to quadruple by 2050, and decarbonizing freight transport will be pivotal because it currently accounts for more than a third of road transport emissions despite comprising only 3 percent of the on-road fleet (NITI Aayog and RMI 2022; MoEFCC 2022a).

India's LT-LEDS highlights four key pathways for transitioning to an integrated, efficient, and low-carbon transport system:

- Improved fuel efficiency, leading to reduced fuel demand and thereby lower GHG emissions
- Phased adoption of cleaner fuels
- Modal shift toward public transport and less polluting modes of transport
- Electrification across multiple modes, including EVs and railways

Current policies and initiatives

There are several national-level initiatives for transitioning to electric mobility:

- The national interim budget 2024–25 mentions that the government aims to expand India's EV ecosystem by supporting charging infrastructure and e-buses for public transport (Mukherjee 2024)
- The Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME India) Scheme Phases I & II have played an important role in promoting the manufacturing of electric and hybrid vehicles since 2015 (MoHI 2019; MoHI 2023)
- The PM e-Bus Sewa Scheme launched by the Indian government in 2023 aims to deploy 10,000 electric buses through public-private partnership models (MoHUA 2023)

State-level initiatives include state policies on EVs and efforts to promote the adoption of compressed natural gas (CNG).

Transition challenges

Addressing the challenges within the transportation sector would necessitate a direct approach to various systemic issues.

Transitioning to low-carbon transportation and developing supporting infrastructure

The high costs and early development stage of low-carbon transportation technologies present major barriers to their adoption. Challenges include a lack of infrastructure such as inadequate charging facilities, limited public awareness, and people's lack of willingness to adopt electric vehicles (EVs). There is a clear need for subsidies or alternative funding models. Also, setting stringent fuel economy standards would help transition manufacturing from fossil-fuel-based vehicles to clean transport options such as EVs.

The transition from internal combustion engine (ICE) vehicles to EVs will entail a shift from crude-oil-derived products to electricity in transportation. Although this could reduce India's crude oil imports, it would increase imports of critical minerals such as lithium for EV batteries.

Although there is a focus on biofuels because they are cleaner fuel sources, there are uncertainties regarding adequate availability, challenged by limited land with multiple competing uses. There are also technological uncertainties associated with second- and third-generation biofuels.

There are also uncertainties associated with the scale-up of green hydrogen as a clean source of fuel. These include the nascent stage of the technology and the absence of storage and distribution infrastructure. It is noteworthy that the government has recently issued scheme guidelines for implementing pilot projects for the use of green hydrogen in the transport sector in India (MNRE 2024b).

The high up-front costs of hydrogen fuel cells and EVs, concerns over battery lifecycle and recyclability, and the complexity of making sustainable mobility economically viable and environmentally sound add to the difficulties. Issues such as EV range anxiety and the trade-off between battery and vehicle weight, especially for freight transport, highlight the complex nature of transitioning to sustainable transportation.

Enabling last-mile connectivity with freight transport

Decarbonization of freight transport will entail a shift from road to railways for freight. However, this is challenged by the limited last-mile connectivity of railway freight networks.

Passenger transport challenges

Urban areas in India, specifically cities, face certain challenges in planning for and implementing solutions to improve local transport systems. Limited financial capacities and human resources in municipal governments and local transport utilities and the absence of unified urban transit authorities make it difficult to integrate different modes of transportation.

However, there is a critical need for integrating public transportation modes and increasing mass transit occupancy. This is also challenged by the fundamental inclination toward private motorized mobility with limited attention to providing connected paths for pedestrians and cyclists and a lack of measures to disincentivize traditional private ICE vehicles. The potential rise in single-occupancy private vehicle use, compounded by traffic congestion, presents further challenges.

Across cities, improvements in the transport sector are hindered by unclear regulations that prevent the implementation of new shared mobility solutions. Further, lack of data on travel behavior in smaller cities inhibits the efforts to address these challenges effectively.

In the context of rural transport, the heavy reliance on private operators points to a systemic need for reform.

The envisioned future

A vision for the long-term future underscores a commitment to sustainability, innovation, and equitable access to transport services, shaping a potentially transformative trajectory for India's transport sector beyond 2047.

Increased reliance on railways and waterways

The participants envisioned a strategic shift toward greater reliance on rail and waterways for freight transportation, with electrified water metros and the potential adoption of roll-on/roll-off (RORO) ferries in coastal shipping. Increased utilization of inland waterways is foreseen, marking a departure from traditional modes of transport.

High-speed rail networks and the widespread penetration of regional rapid transit systems (RRTSs) will revolutionize intracity and intercity connectivity, serving millions of people.

There will also be a transition away from short-haul flights to high-speed rail.

Transition to cleaner fuels

In the long term, the participants envisioned that hydrogen would play an important role in the decarbonization of the shipping and aviation sectors. On the other hand, CNG might not play a role in the long term.

Transition to a circular economy

In the long term, there will be a highly evolved circular economy framework that will focus on maximizing resource efficiency and minimizing waste, especially by ensuring the circularity of batteries and fuel cells.

Innovations in end-of-life battery management, battery standardization, and interoperability are anticipated, fostering greater efficiency and sustainability in EV ecosystems.

Improved urban mobility

The discussions indicated that integrated city planning strategies, coupled with transit-oriented development (TOD) principles, would streamline urban mobility, potentially reducing the number of trips and enhancing overall efficiency in transport systems.

Transition opportunities and interventions

Considering the current challenges and the envisioned future of India's transport system, a range of transition opportunities and interventions emerge. Through concerted efforts and strategic interventions, these opportunities can unlock the transformative potential needed to realize the long-term vision of an integrated, efficient, low-carbon transport system in India.

There is an overarching need for institutional coordination and capacity-building to enable the transport system transition in India.

Decarbonization of the transport sector

A four-point approach to decarbonize the transport sector includes the following:

- Increasing efficiency
- Adoption of cleaner fuels, the transition to EVs. For example:
  - The metric of success should prioritize the electric miles achieved over the number of EVs produced
- Transition to cleaner modes of transport for both public transport and freight, for example, from air and road to rail and water—the last wherever available
- Optimizing the available capacity in existing transport, for instance, reducing the empty space in moving vehicles
  - There is potential for information technology (IT)-based platforms in transport capacity optimization

Considering the important need for freight transport decarbonization, technological advancements, notably in battery and hydrogen fuel cell technologies, can play an important role in paving the way for more sustainable solutions.

Improved access to transport through last-mile connectivity

There is a need for innovative solutions for last-mile connectivity through intermediate public transport (IPT) solutions with multiple nodes and points. Alternative transport modes ranging from rail and waterways to cable cars and ropeways emerge as promising avenues to alleviate congestion and improve accessibility.

Innovative approaches

Innovative approaches can further incentivize the transition to EVs. For example:

- An integrated solution based on a synergetic approach between solar rooftop schemes and EV charging infrastructure will optimize resource utilization and support the ongoing transition in the automotive sector

- Battery-as-a-Service models for EVs to reduce the up-front cost

Innovative interventions such as parking reforms can disincentivize the use of private vehicles and encourage a shift to public transport.

The creation of low-emission zones in cities incentivizes the adoption of public transport systems and encourages pedestrian-friendly movement in select zones within cities.

As the transport sector continues to evolve, initiatives such as improved non-motorized transport (NMT) infrastructure and strategies for freight electrification will play an important role.

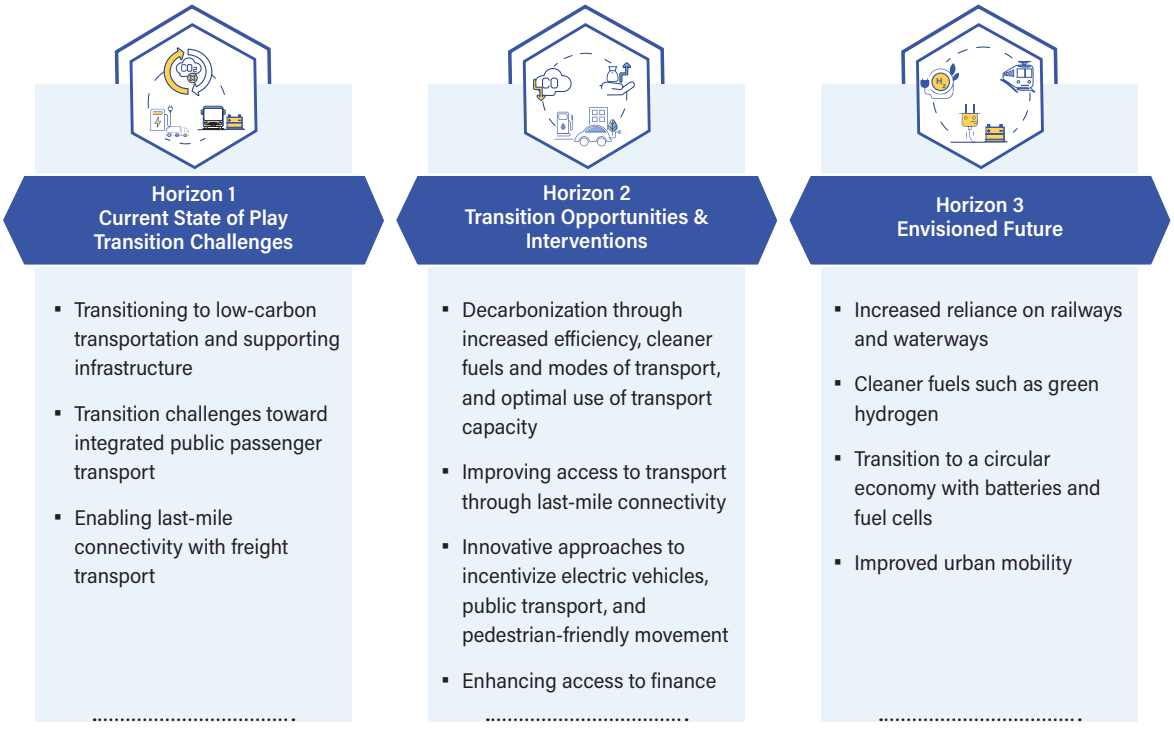
Financing opportunities

Enhancing access to finance can promote the adoption of clean transport solutions. Finance-related opportunities include leveraging financial mechanisms such as concessional financing and credit guarantees to catalyze private sector investments in new energy vehicles and infrastructure development.

Implementation of fossil fuel taxes and sustainable policies for freight transport, such as fuel efficiency standards for heavy-duty commercial vehicles, scrappage policy for vehicles, and logistics plans for urban freight is necessary to reduce emissions.

Figure 5 summarizes the discussion on transition challenges, transition opportunities and interventions, and the envisioned future for an integrated, efficient, low-carbon transport system in India.

FIGURE 5 | Integrated, efficient, low-carbon transport system



Agriculture, land use, and carbon dioxide removal

Management and governance of land is a critical challenge in the context of India's development, involving multiple competing demands for food, fiber, and oilseed production; ecosystem services through forests, grasslands, and other types of land cover; land for human settlements, industry, and infrastructure; and rising demand for electricity generation through land-based power plants such as solar photovoltaic, on-shore wind, and nuclear. The need to balance competing demands for multiple uses on limited land has been well recognized across countries and is reflected in the recent UNFCCC LT-LEDS synthesis report (UNFCCC 2023). At the same time, land degradation due to deforestation, soil erosion, overgrazing, and excessive use of fertilizers is a serious concern. This degradation will be exacerbated by climatic change, leading to heat stress and flooding.

India's NDC aims to create an additional carbon sink of 2.5–3 billion tonnes of carbon dioxide equivalent through additional forest and tree cover by 2030. Further, India's LT-LEDS considers increasing forest and tree cover as one of the seven strategic transitions required to achieve long-term, low-emissions development. The LT-LEDS outlines two pathways toward this: improving the density and quality of forests and increasing the area under trees outside forests through agroforestry and urban forestry.

India's LT-LEDS outlines the priorities and actions in the agriculture sector in the context of strengthening adaptation measures and building resilience.

With this context, the dialogue aimed to generate discussions on the challenges related to the multiple competing demands for land resources and land availability, vulnerabilities associated with land-based livelihoods, opportunities related to models of land co-utilization, and ways to address knowledge and capacity gaps.

Current policies and initiatives

India's land sector needs to achieve its targets under the following global conventions:

- India was one of the earliest signatories of the Convention on Biological Diversity (CBD) and became a party to it in early 1994. India has outlined 12 national biodiversity targets (NBTs) in line with the 20 global Aichi Biodiversity Targets, which were developed under the CBD (MoEFCC 2018)
- The Bonn Challenge is a global pledge under the United Nations Convention to Combat Desertification (UNCCD) to restore 150 million hectares of deforested and degraded land by 2020 and 350 million hectares by 2030. The GoI made a Bonn Challenge pledge to restore 26 million hectares of degraded land by 2030 (MoEFCC 2019)

Transition challenges

Several challenges associated with land use and agriculture affect the transition to a low-carbon and climate-resilient future.

Limited land availability due to competing uses, land degradation, and climate change impacts

Although India has progressed in increasing its forest cover in the last three decades (FSI 1991, 2021), further increase is limited by land constraints, that is, the reduction in availability of marginal land that can be brought under additional forest cover. India, which is about one-third the size of China or the United States, has the highest population globally. Therefore, the competition for land is very high. For example, the construction of highways and expansion of roads place a significant demand on land.

In India, 30–45 percent of land is degraded, caused by soil, water, or wind degradation. This includes agricultural land, affecting food production.

In addition to land degradation, the impacts of climate change on food production are a concern. Currently, India does not have a diversified genetic stock of different crops. The predominant practice of monocropping increases the vulnerability of food systems to climate change.

Further, some regions within the country, such as the Western Ghats and the Eastern Himalayas, are extremely vulnerable to climate change. Also, much of the grasslands, which are home to rich biodiversity and play a role in soil conservation, have been underinvested for years and are especially vulnerable to climate change impacts. The challenge, therefore, is to build the resilience of people, communities, and ecosystems.

Agricultural economy and nutritional self-sufficiency

The economic contribution from the agriculture, fisheries, and forestry sectors has come down from about 38 percent of the total gross value added in 1994 to around 17 percent in 2019 at basic prices (MoF 2023). At the same time, the share of India's workforce that is engaged in agriculture and allied sectors remains unchanged between 1994 and 2019 (NSSO 1998; MOSPI 2023). However, their real wages have been stagnant since 2015-16.

India's per hectare application of fertilizers is among the highest in the world, especially Punjab's, which is higher than that of many developed countries (FAO n.d.). Although India is self-sufficient in food grains, it still depends on imports for pulses (MoAFW 2022) and edible oil (MoAFW 2023). Hence, the challenge is to become nutritionally self-sufficient by increasing the productivity of land and crops without increasing the use of chemical fertilizers, which is already very high, while also ensuring that real rural wages rise above their current levels.

Agriculture and livestock emissions

India's total emissions from agriculture and land use, land-use change, and forestry (LULUCF) were approximately 30 percent of national net emissions as of 1994 (MoEF 2004). At present, these sectors contribute net negative emissions. However, emissions from agriculture are rising, although the share of emissions from the agriculture sector has been progressively decreasing over the years (MoEFCC 2023). Also, carbon dioxide removal from forests has increased, explaining the net negative emissions.

At the micro-level, shifts in cropping patterns can also impact agricultural emissions. For example, paddy cultivation has been increasingly replacing soya bean cultivation, thereby increasing emissions.

The proportion of livestock emissions in India's agriculture, forestry, and other land use (AFOLU) sector is about 50 percent (MoEFCC 2023). India has the highest livestock population globally; however, it is characterized by low productivity. Thus, the challenge is to increase livestock productivity while reducing their numbers as well as reducing the per capita enteric fermentation in cattle and other ruminants.

Data and governance

At present, data are either inadequate or too poor in quality to answer questions related to land:

- Land under food production that can be converted to other uses
- Land that can be used to meet India's renewable energy targets
- Land that can be used for carbon sequestration for India to reach net zero by 2070

Enabling a just transition

As noted earlier, in India, the agriculture and allied sectors account for nearly 46 percent of total employment (MOSPI 2023). Going forward, despite urbanization, the share of agriculture in employment is not likely to decrease to levels comparable to those in developed countries. The transition toward a low-carbon economy therefore needs to take into consideration the large number of agricultural workers and their livelihoods linked to land.

For farmers, the transition to climate-resilient agriculture or regenerative agriculture practices is a challenge in different ways:

- Insufficient infrastructure and safeguards to de-risk farmers' crop productivity losses during the transition
- Difficulty in changing crop choices, especially for subsistence farmers
- Insufficient information and capacity to adopt alternative models such as agroforestry

With changing land use, reversing land use is very difficult and is dependent on social and political factors.

The envisioned future

In the long term, the participants envisioned a desired future for India's land use, forests, and agriculture.

Forests and land use

The participants envisioned improved quality of forests with high-density forest cover. In the future, there will be a policy framework to address the issue of fragmentation of forest land.

Agriculture

There will be a transition to climate-resilient agriculture in the long term. Crop choices will be better informed by water use and water availability.

Transition opportunities and interventions

Road map for the land sector

The land sector is crucial for India in planning for its 2070 net zero target, meeting biodiversity targets. and combating desertification. There is a need for elevated action, drawing from a land sector road map aligned with India's NDC and guided by its LT-LEDS.

Land-use planning

As India plans for its long-term low-carbon and climate-resilient development, there is a need to consider costs holistically, including financial, socioeconomic, and environmental costs. At the same time, trade-offs in terms of land use need to be assessed and integrated into planning, considering socioeconomic and development goals. Further, there is a need for safeguards that not only protect forests but also other habitats and ecosystems, such as wetlands and grasslands.

There is a need for relevant government ministries and departments to arrive at a common nomenclature and taxonomy system to improve the definition of various land-use classes to ensure policy coherence.

Clear land-use and zonal plans at the national level are required to sequester carbon dioxide in soils, protect biodiversity and protect land from degradation, as well as to protect wastelands, grasslands, and other specific habitats.

At the same time, there is a need to bring the renewable energy infrastructure under environmental impact assessments while improving the quality of such assessments through compliance monitoring and evaluation.

Also, the wasteland available in India needs to be assessed for appropriate land uses such as, growing crops like bamboo for bioenergy.

Improving the quality of forest cover and increasing tree cover

India's NDC aims to create an additional carbon sink of 2.5 to 3 billion tonnes of carbon dioxide equivalent through additional forest and tree cover by 2030. Interventions for increasing forest cover alone will not be adequate to meet the NDC target. It is critical to expand trees outside forests (ToF). For example, there is an opportunity to increase and optimize tree cover, especially on bunds.

As outlined in India's LT-LEDS, it is important to improve the quality and density of forest cover by reducing forest fires and invasive species. The key challenge is finding ways and means of achieving this. Along with the expansion of forest area, improvements in forest quality and density need to be prioritized, because this provides an opportunity for improved carbon sequestration with relatively less investment than that required for forest expansion.

Investments in NbS

There is a need to invest in NbS that allow for livelihood diversification, land restoration, diversified food production, soil erosion control, and afforestation. Existing funding channels such as the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS) need to be mapped to NbS for improving the quality of forests. Also, there is a need for India to make its stand clear on NbS as a strategy for climate change adaptation and mitigation.

Capacity-building

There is a need for capacity-building interventions in the context of the agriculture, forests, and land sectors. For state government officials, the key capacity need identified was planning for agriculture, while aligning land strategies and policies with the net zero emissions target.

Further, there is a capacity-building need for agriculture extension services that serve farmers. Also, the capacity of forest officers on the ground needs to be upscaled to protect and conserve forests. The Compensatory Afforestation Fund Management and Planning Authority (CAMPA) funds can be utilized to conduct such training programs for front-line forest staff.

NEXT STEPS

The multistakeholder dialogue titled "Pathways for India's Low-Carbon and Climate-Resilient Development" facilitated discussions on the strategic transitions outlined in India's LT-LEDS. Short-term research and capacity-building needs for supporting and strengthening climate planning and implementation were identified.

The thematic discussions and group visioning exercises on electricity systems, industry, transport, urban development, and land highlighted the myriad multidimensional challenges in transitioning to a low-carbon economy while identifying enablers and opportunities that can effect change. With the participation of national, state, and local government representatives, industry, research institutions, and think tanks, we believe that the discussions and exchanges have contributed to the current policy discourse in the context of implementing India's LT-LEDS.

WRI India and the collaborating institutions will continue to engage with multiple stakeholders on pathways to implement India's LT-LEDS and inform future updates to this "living document". Building on the learnings from this dialogue, we identify the following entry points as the next steps in stakeholder engagement and research related to pathways for low-carbon and climate-resilient development:

- Convening smaller national-level thematic group discussions on key topics of policy relevance for India's LT-LEDS
- Facilitating exchanges between state and local government stakeholders on climate-planning experiences, challenges, and interventions
- Undertaking deep-dive studies on specific key issues in the context of low-carbon development

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WRI India, an independent charity legally registered as the India Resources Trust, provides objective information and practical proposals to foster environmentally sound and socially equitable development. Our work focuses on building sustainable and livable cities and working towards a low-carbon economy. Through research, analysis, and recommendations, WRI India puts ideas into action to build transformative solutions to protect the Earth, promote livelihoods, and enhance human well-being. We are inspired by and associated with World Resources Institute (WRI), a global research organization. Know more: www.wri-india.org.

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