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Is net zero net positive? – Opportunities and challenges for pursuing a socio-economically sensitive net-zero transition for India

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ABSTRACT
At COP26 in Glasgow, India announced a long-term ambition to achieve net-zero greenhouse gas emissions by 2070. Existing emissions-economy modelling studies highlight that India's emissions show no sign of peaking before mid-century and will not reach net zero by 2070 in a business-as-usual scenario with current policies. Using a mixed methodology of expert elicitation and system dynamics modelling, this article examines the policy gap that needs to be bridged for India to realize its net zero by 2070 commitment. The study discusses a socio-economically sensitive policy mix that could set India on a trajectory to peak its emissions in a decade and zero out its carbon dioxide (CO_2) emissions by mid-century, leaving about one gigaton of other greenhouse gases to be decarbonized by 2070 to meet India's net-zero goal. The policy mix realizes this goal while maintaining the government's fiscal stability, and increasing employment and GDP beyond business-as-usual. The trajectory reported here is one of many possible low-carbon development pathways that could potentially be a net socio-economic positive for India. However, barriers such as the country's lack of clean energy innovation and industrial policies, the gap between its domestic manufacturing capacity and deployment requirements, individual sector readiness for decarbonization, and the distributional implications of government revenue shifts through the energy transition remain significant challenges that need to be addressed to realize these potential socio-economic benefits of decarbonization.

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Net zero; policy pathways; socio-economic benefits; technology opportunities; green industrial policies; climate finance

Key policy insights

- Near-term action is crucial to achieve India's long-term 2070 net-zero goal. 'Readiness policies' in this decade, followed by post-2030 levers such as phased retirement of coal power plants, electric vehicle mandates, electrification, and hydrogen use, may lead to timely decarbonization.
- India needs strategic green industrial policies to bridge the clean energy manufacturing-deployment gap and reap economic benefits from the transition.
- A pragmatically sequenced and fiscally-manageable policy mix could generate net-positive employment and GDP gains above business-as-usual.
- A tax shift, modelled in this study as a carbon tax starting after this decade, may likely compensate for falling future government revenues from fossil-fuel taxes. Appropriate utilization of such tax revenues may enhance GDP growth and job creation while keeping government fiscal health in check.

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- International climate finance, particularly in the coming decade, could help bridge the transition finance gap before domestic mobilization of climate finance materializes.

1. Introduction

India announced a 2070 net-zero goal at COP26 in Glasgow (Press Information Bureau, 2021). India also announced a target to deploy 500 GW of non-fossil capacity by the end of this decade and updated its NDC targets accordingly in 2022 (see Appendix A). Despite these targets and other policies, several modelling studies show that on a business-as-usual (BAU) trajectory with existing policies implemented, India's emissions are unlikely to peak and decarbonize towards the 2070 net zero goal (see Figure S1 of the supplementary information). The challenge is to identify an emissions pathway that balances climate commitments with national socio-economic development priorities. Drawing inspiration from the co-benefits approach to policymaking (Dubash, 2013), this article explores a policy scenario that could put India on a low-carbon development pathway consistent with its net-zero goals. The study uses a mixed methodology of expert elicitation and system dynamics modelling (Gallagher et al., 2019) to elucidate a policy mix that brings India's CO_2 emissions close to zero by mid-century. This leaves one gigaton of non-CO_2 greenhouse gas emissions (GHGs) to be zeroed out between 2050 and 2070.

The policy mix is (1) sequenced and scheduled, keeping in mind expert views on policy implementation, technology cost, and deployment trajectories for India; (2) fiscally manageable and thereby politically viable; and (3) generates net-positive employment and GDP gains above business-as-usual growth projections. The scenario identified in the study is not optimized for any particular criterion or combination of criteria, and it is only one among many possible pathways to reach net-zero CO_2. Instead, the article illustrates the possibility of a low-carbon development pathway consistent with India's net-zero timeline and certain key economic priorities, and uses this as a starting point to discuss the potential opportunities, trade-offs, and challenges involved in realizing it.

The article is organized as follows: Section 2 reviews the existing modelling studies for India and highlights the knowledge gap this article aims to address. Section 3 describes the mixed methodology approach followed in this study. Section 4 reports key results from the 'Raising Ambition' policy scenario explored in this study. Sections 5 and 6 discuss the opportunities and challenges of pursuing a socio-economically positive net-zero pathway for India and distill key policy findings and implications.

2. Background

Several prior multi-sectoral emissions-economy modelling studies have proposed potential pathways to decarbonize India's economy. These studies use models including the E3ME global macroeconomic model from Cambridge Econometrics (Asia Society Policy Institute, 2022), the integrated assessment model GCAM (Chaturvedi & Malyan, 2021), CSTEP's bottom-up cost optimization IMRT5 model (CSTEP, 2018), a global computable general equilibrium (CGE) model with a combination of end-use cost optimization for energy supply and energy demand (Gupta et al., 2020), the International Energy Agency (IEA) partial equilibrium model (IEA, 2021), and the McKinsey decarbonization scenario explorer which aggregates emissions arising from underlying sectoral activity levels (Gupta et al., 2022). A recent study also used the India Energy Policy Simulator (EPS) (Energy Innovation, 2022), the system dynamics model used in this study, to identify long-term decarbonization pathways for India until the mid-century (Swamy et al., 2021).

Many modelling studies diverge significantly in their emission trajectories for India due to varying input assumptions about GDP growth, rate of urbanization, economic structure, technology costs, and other factors (Centre for Policy Research & IIT Delhi, 2022) (see Figure S1 and S2 of supplement). The modelling studies generally converge on the following policy interventions: (1) coal phase-down by mid-century, (2) significant ramp-up of renewable energy capacity beyond the 500 GW target set currently by 2030 and greater than 1500 GW by 2050 depending on the input growth assumptions, energy efficiency improvements, and battery storage additions, (3) reduction in the industrial energy intensity of GDP by more than 50 percent, and (4) significant penetration of green hydrogen in industrial energy use (Asia Society Policy Institute, 2022; Chaturvedi & Malyan, 2021; Gupta et al., 2022; Swamy et al., 2021). Studies generally concur that, given the cost of carbon capture and storage (CCS) and green hydrogen, the industry sector will be the hardest and last to decarbonize – for example, the IEA estimates that nearly 60 percent of India's GHG emissions after 2030 will come from infrastructure and industrial machinery that do not exist today (IEA, 2021). Some of these studies identify socio-economic opportunities in the transition, such as lower cost of power supply, additional farmer income, foreign exchange savings, household energy cost savings, additional jobs, and additional GDP growth. They also provide a wide range of estimates on the cost of decarbonization and emphasize that it will be significant – estimates include 2.8–4.4 percent of GDP (Chaturvedi & Malyan, 2021), 3.5–6 percent of GDP (Gupta et al., 2022), and $10 trillion over the coming five decades (Asia Society Policy Institute, 2022).

This article adds to the existing state of knowledge in three ways. First, published modelling studies either put India on trajectories that require an immediate ratcheting up in policy enactment and implementation or on trajectories that are unlikely to reach net zero by 2070 (see Figure S2 of supplement). There is a need for a policy mix that can realistically schedule and sequence policy implementation while being compatible with India's net zero commitment. Second, while some existing studies highlight the potential future losses in fuel tax revenues, they do not discuss the resulting fiscal strain that ambitious decarbonization may cause for the government, and its political implications. Finally, this article's approach to viewing India's energy transition as a 'development pathway' with economic opportunities and challenges, aims to move the discourse beyond a set of technology options. Instead, it reveals the sectoral challenges in scaling to the levels required, clarifies the fiscal implications of decarbonization, and demonstrates that socio-economic gains in GDP and employment are crucially tied to these factors. However, given that emissions-economy model insights vary significantly based on the input data and assumptions that go into them, the article limits its scope to avoid the impression that the scenario explored here is by itself a complete decarbonization solution. Instead, the article contributes to the existing and emerging literature that uses modelling studies to discuss the possibility frontier for India's low-carbon development, with the hope that policy recommendations can be synthesized from a meta-analysis across these several modelling studies in the future.

3. Methods

This study used a mixed methodology involving qualitative and quantitative analysis. First, a climate policy inventory was developed, documenting all significant national policies implemented by the Indian government after 2000. The database contains more than 100 national-level climate policies in India, classified by sector, policy type, policy goal, and whether they directly or indirectly contribute to GHG emissions reductions. The inventory of India's climate policies is available online at [https://www.climatepolicylab.org/national-climate-policy-inventories].

Second, an expert elicitation was conducted to understand the effectiveness of key policies from the 'policy inventory' in peaking and decarbonizing India's economy (see Appendix B for details). The study then used expert opinion to reconfirm model assumptions and reinforce the policy choices made to develop a possible net-zero scenario. The utility of expert elicitation is well-recognized in providing qualitative input on policy-relevant questions, particularly when robust quantitative evidence of the current and projected impact of policies is still emerging. Combining qualitative insights with quantitative modelling is also recognized in the literature (Colson & Cooke, 2019; Cooke & Probst, 2006; Gallagher et al., 2019). System dynamics modelling allows for a quantitative examination of interactions, synergies, and trade-offs between technological, economic, and emissions trajectories. However, responsible modelling requires the grounding of inputs in normative criteria (in this case, selecting policies to combine/balance emissions reduction and economic development), which is subsequently tested, reinforced, and modified by expert opinion.

In parallel to expert elicitation, the study's co-authors developed a 'system dynamics' model, India Energy Policy Simulator (India EPS), in collaboration with the World Resources Institute (WRI) India (Energy Innovation, 2022). Subsequently, policies identified in the policy inventory were mapped to the policy levers in the EPS model that interact with each other to project India's emissions pathway. The India EPS system dynamics model conceptualizes relationships between economic and environmental variables using stocks and flows, feedback loops, and time delays. The model framework captures many important interactive effects of a single or multiple climate regulations/policies on model variables. It assumes the economy is in non-equilibrium, thereby enabling the analysis of both pricing and non-pricing policies. The model includes local optimization in specific sectors, as vehicle sales, capacity additions, and generation are determined through least-cost optimization. The model groups 'energy use' and 'emissions' in slightly different ways than the National Inventory Reports to suit the required structure to internally track energy consumption and policy interventions. For example, policies applied to the oil and gas, or coal mining industries are implemented in a similar way to other industrial policies, so they are tracked within the model's 'industry sector' alongside other manufacturing instead of in a broader 'Energy' category. The complete model and all the accompanying input data and assumptions are available for download at https://india.energypolicy.solutions/docs/. Table C1 of Appendix C provides data on a few basic input assumptions related to macrostructural variables and technology costs.

The India EPS model complements its system dynamics framework with a fully integrated input-output macroeconomic model, following standard input-output modelling principles. The input-output component estimates the number of jobs, type of jobs, and the GDP generated above or below BAU for different climate policy mixes. The model tracks the first-order changes in cash flow due to policies and then feeds these changes into an input-output module to calculate direct, indirect, and induced changes in jobs and GDP for 38 different industrial classification codes. The indirect and induced changes are fed back into each sectoral module in the following timestep to calculate the energy use and emissions associated with indirect and induced economic activity.

The model's BAU scenario is based on historical data and the results of other studies and models. Policy scenarios created by users can include a mix of non-market and market-based instruments, and changes in public spending priorities – all of which have independent implementation schedules and can be applied on a sector-by-sector basis or be economy-wide. The EPS captures how policy affects prices, demand, and infrastructure across sectors, and avoids double counting policy effects with a tailored approach that handles each policy with either a price-driven floor or ceiling or an additive effect that can more easily capture non-price barriers.

4. Results

The study constructed a 'Raising Ambition' scenario that zeros out CO_2 emissions by 2050, leaving 1.167 $GtCO_2e$ of other GHGs to be decarbonized post-mid-century. The study only identifies policies to zero out CO_2 emissions as the EPS model is limited in its ability to capture non-CO_2 GHG reduction (key policies summarized in Table C2 of Appendix C). Expert elicitation (see Appendix B for expert opinion) was used to reconfirm the policy assumptions and reinforce (1) the policy settings for existing climate policies in India, (2) additional policies included in the scenario to achieve net-zero CO_2 emissions by 2050, and (3) the implementation timeline settings for the policies by taking advantage of the model's unique ability to allow policies to take full effect over specified time periods. The resulting Raising Ambition scenario illustrates the potential for India to co-achieve climate and development objectives, and clarifies the scope of additional policies and effective implementation needed. Four sectoral policy interventions beyond those recommended by experts are included to achieve net-zero CO_2 by 2050, indicating the gap between what experts believed was needed for net-zero and what the model requires to reach net-zero – (1) an EV mandate in the transport sector, (2) coal phase-out and CCS in the electricity and industry sector, (3) electrification and green hydrogen adoption in the industry sector, and (4) forestry and land-use policies. Finally, a 'carbon tax' is added to the policy mix as a fiscal proxy to ensure stable government revenues in the transition and enhance GDP and job outcomes.

4.1. Decarbonization outcomes

Under BAU (i.e. with India's current climate policies), India's emissions continue to rise to 4 $GtCO_2e$ in 2030 and 6 $GtCO_2e$ by 2050, with no peak in sight (see Figure 1). Persistent coal use in the electricity sector and a fossil-fuel-dependent transport sector are exacerbated by the expansion of emissions from the industrial sector (Figure C1 (a) of Appendix C). Continuing this trajectory for the coming decade and attempting to move to a 2070 net-zero

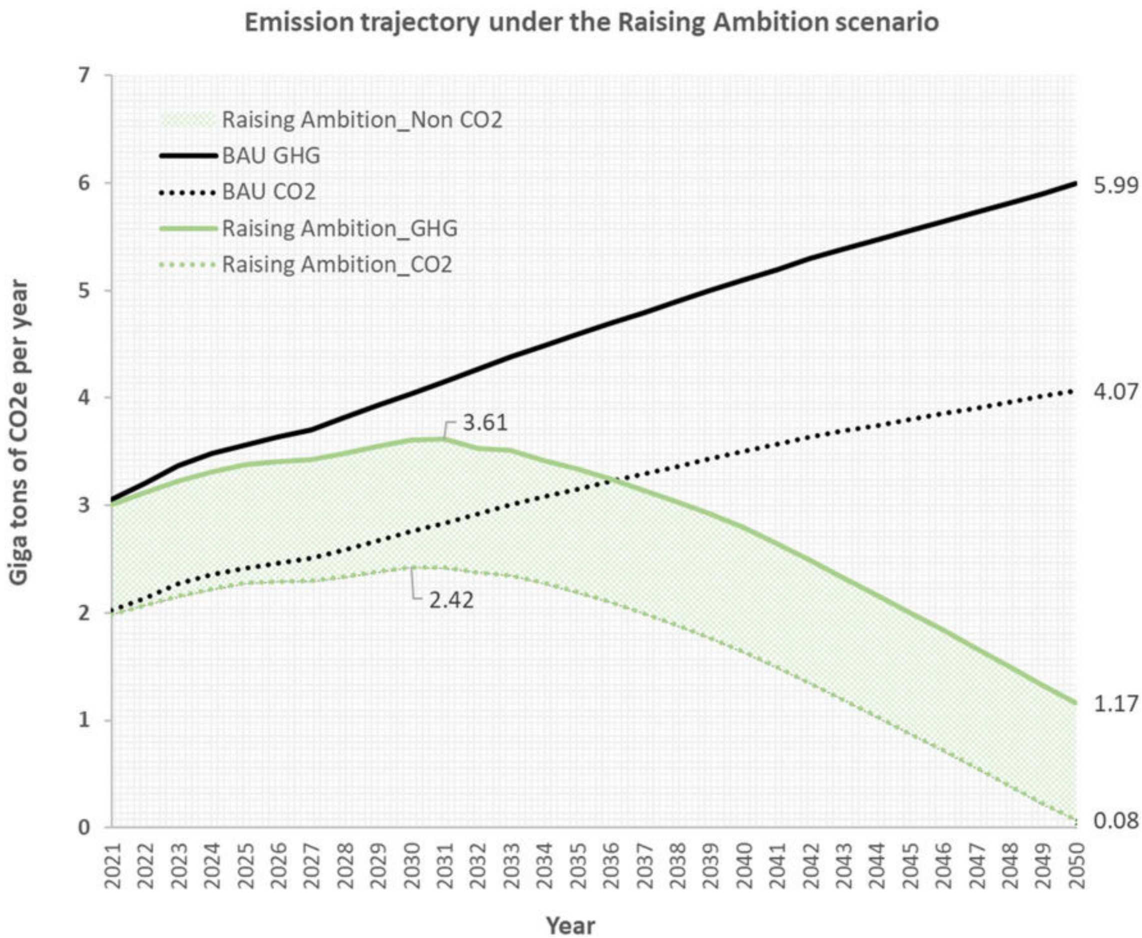

Figure 1. Emission trajectories under the BAU and Raising Ambition scenarios.

trajectory later is difficult, as confirmed by the experts. Despite India's non-fossil power generation capacity reaching 76 percent by 2030 in the BAU scenario (Figure C2(a) of Appendix C), 69 percent of the power generated is likely to come from non-fossil fuel sources. It is important to note that these projections indicate that India's updated NDC (see Appendix A), in terms of both the emissions intensity of GDP and non-fossil power generation capacity targets, are, in effect, not a deviation from the pre-NDC update trajectory.

The 'Raising Ambition' scenario is the study's assessment of the most ambitious policy mix India could implement that would balance emissions reductions with socio-economic priorities. In this scenario, emissions peak at 3.6 GtCO_2e in 2031 (i.e. 10 percent below BAU) and reduce to 1.2 GtCO_2e in 2050 (i.e. 89 percent below BAU). Carbon dioxide emissions peak at 2.4 GtCO_2e in 2030 and are zeroed out by 2050 (see Figure 1). GHG emissions peak and reduce after 2031 as green hydrogen deployment starts to decarbonize the hard-to-abate industry sector emissions (Figure C1(b) of Appendix C), while non-fossil power generation capacity reaches 98.6 percent by 2050 (Figure C2(b)). The scenario consists of several sectoral policies aimed at decarbonization, keeping in mind factors such as the uncertainties around sector readiness, employment implications of sunset policies such as coal retirement, and government revenue implications of decarbonization policies (see Figure 2). The study chose the sequencing, timeline, and rate of implementation of different policy instruments to balance these objectives (see Table C2, Appendix C).

In the electricity sector, near-term readiness policies that increase transmission capacity, reduce transmission and distribution losses, increase grid flexibility, improve demand response, and reduce power plant downtime

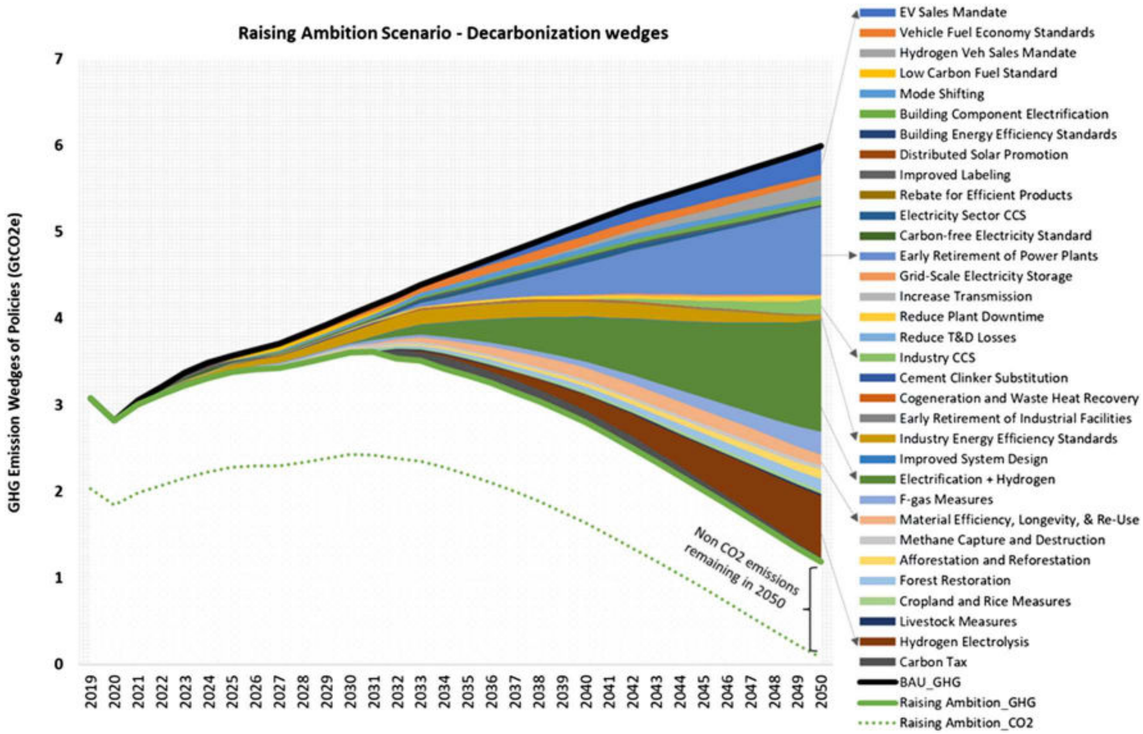

Figure 2. Emission wedges created by policies under the 'Raising Ambition' scenario.

are crucial for sector readiness. In terms of key decarbonization levers, early retirement of coal power plants starting in 2030, implementation of a carbon-free electricity standard alongside 178 GW of storage capacity by 2050, and policies that cause a 60 percent reduction in building energy consumption below BAU levels by 2050 are crucial (see Figure 2). Coal retirement ramps up from 0 GW in 2030 to 11.75 GW annually by 2040 and stays constant until 2050, phasing out coal capacity by mid-century compared to 200 GW capacity under BAU (see Figure 3). Implementing carbon-free electricity standard increases grid-scale and distributed solar capacity to 801GW and 144GW by 2050 under the 'Raising Ambition' scenario, 60 percent and 10 times higher than BAU, respectively. Onshore wind increases to 582GW, 55 percent higher than BAU. Offshore wind capacity increases to 98GW by 2050 compared to negligible deployment under BAU.

In the transport sector, India has articulated some ambitious national targets, including achieving 30 percent of private cars, 70 percent of commercial cars, and 80 percent of two and three-wheeler sales to be electric by 2030 (Khan, 2022). While not legal mandates, these goals are supported by producer and consumer subsidies, production-linked incentives, tax exemptions, and permit exemptions under two key policy frameworks – the second phase of the Faster Adoption of Manufacturing of Hybrid and Electric Vehicles Scheme (FAME-II) scheme, and the National Mobility and Storage Mission. However, the effect of these existing policies falls short of the stated goals in the BAU scenario. Transport emissions under BAU increases 40 percent by 2030 and doubles by 2050 (from 0.45 to 0.9 $GtCO_2e$).

Under 'Raising Ambition,' electric vehicle charging infrastructure is a crucial readiness policy. EV sales mandates (up to 90 percent for passenger cars), mode-shifting policies (30 percent shift to public transportation) to increase public transportation, and an increase in fuel economy standards (60 percent increase from BAU) are key policies that substantially decarbonize the sector (see Figure 2). In terms of the technologies deployed, ICE car fleet reduces by 70 percent while EVs increase by 67 percent than BAU (see Figure 4). In two and three wheelers, ICE reduce by 78 percent while EVs increase 140 percent than BAU. In freight, ICE reduces by an order of 10x while EVs increase 6x than BAU. A total of 21 million light-duty

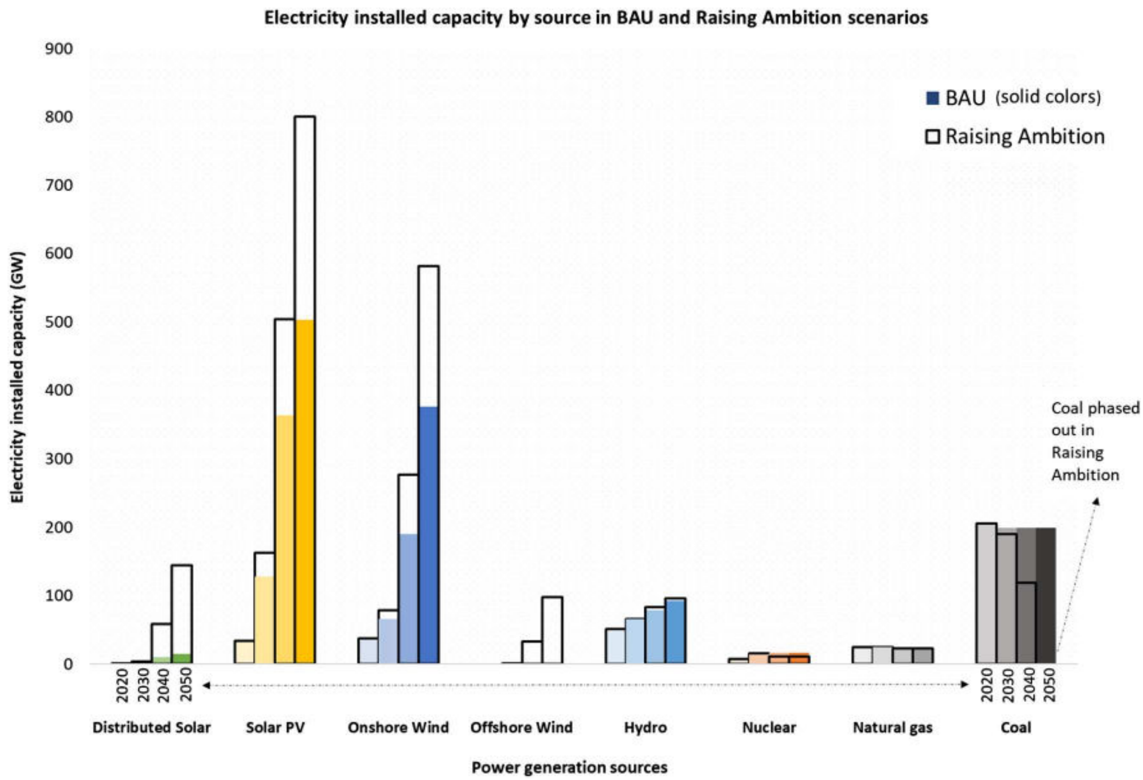

Figure 3. Electricity capacity by technology in the BAU and Raising Ambition scenarios.

freight EVs and 13 million heavy-duty hydrogen freight vehicles are deployed in the 'Raising Ambition' scenario compared to only 3.5 million light-duty freight EVs and no hydrogen freight vehicles under BAU, respectively.

In the industry sector, adopting industrial energy efficiency standards (up to a 30 percent increase from BAU), material efficiency, reuse, and recovery are important near-term decarbonization policies as they ensure that industries are better prepared to absorb a future carbon tax within India and remain globally competitive under an emerging EU CBAM regime. Electrifying energy inputs as much as possible and using green hydrogen starting in 2030, improving material use efficiency further across sub-sectors, and phasing in a CCS mandate to reduce process-related emissions are interventions crucial to peak and decarbonize India's GHG emissions.

The 'Raising Ambition' scenario also includes a carbon tax on the industry sector that will gradually increase from INR 0 to 6000 ($70 in current prices) from 2030 to 2050. For comparison, the IMF recommends a Paris-compatible carbon price of $25/ton in India and $75/ton in developed economies starting in 2030 and continuing at the same level (Parry et al., 2021). While this policy encourages some decarbonization in the industry sector (Figure 2), it primarily acts as a fiscal policy that offsets future fuel tax revenue losses in the 'Raising Ambition' scenario as fossil-fuel use reduces significantly. The India EPS model applies a carbon price by adding the appropriate $/BTU amount to business-as-usual (BAU) fuel prices, according to the carbon intensity of the fuel. For instance, in the demand sectors (transportation, buildings, industry), the model applies elasticities of demand with respect to fuel price to project changes in fuel consumption. For the transportation sector in particular, changes in fuel price due to a carbon tax also affect the calculated lifetime vehicle cost, which affects vehicle purchasing decisions.

The study sets the level and schedule for the carbon tax to be 'revenue neutral', i.e. completely offset the loss of fuel tax revenue from decarbonization by the year 2050. The carbon tax revenue is redistributed (through the

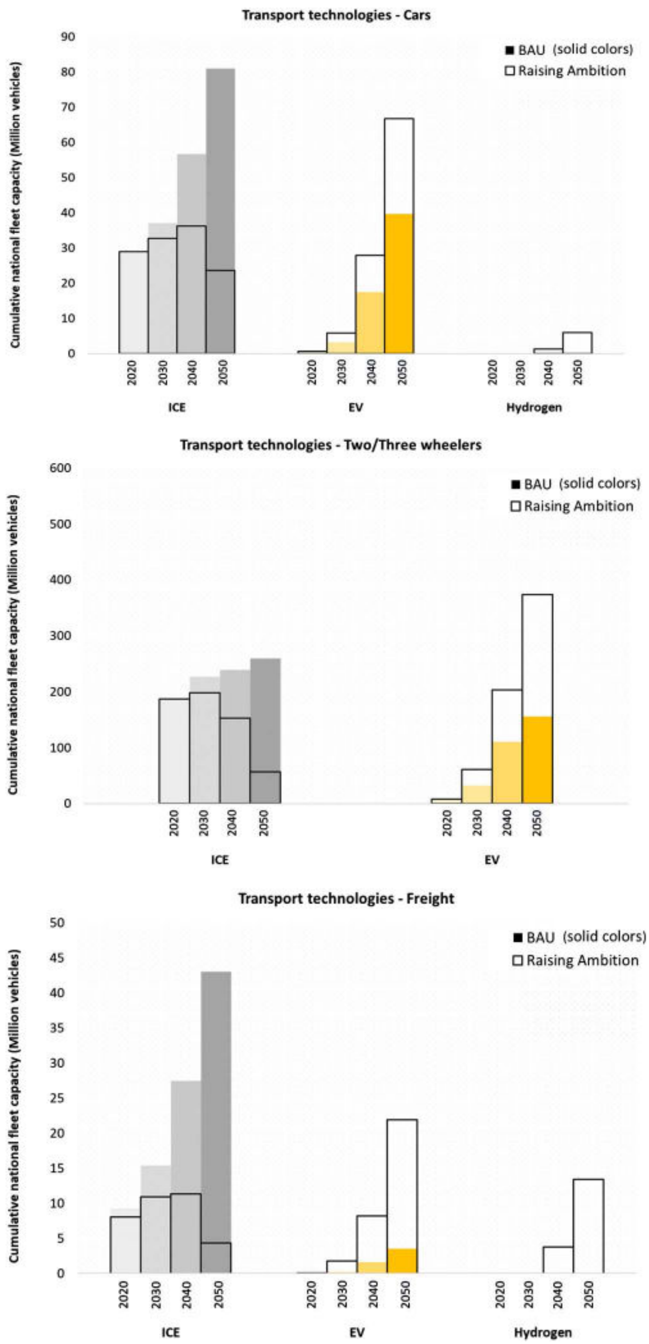

Figure 4. Transport deployment by technology in the BAU and Raising Ambition scenarios.

model settings) to offset household, payroll, and corporate tax burdens, increase government social spending, and pay down the national debt. It is important to note here that the government could offset fuel tax revenue losses through other revenue-generating options such as monetary policy, reducing government spending, public-private finance frameworks, or international climate finance sector – the study includes the carbon tax in the policy mix as one potential revenue source. Without an alternative revenue-generating mechanism (in this case, a carbon tax), a sharp drop-off in government cash flows (and a corresponding increase in national debt) would make the enhanced ambition scenario less politically viable and more suboptimal from a socio-economic point of view due to reduced welfare spending alongside reduced employment and GDP gains from the transition.

4.2. Fiscal implications

The total government burden in this transition (i.e. 'government cash flows without alternative tax revenue generation' in Figure 5, which includes fuel tax revenue losses, green subsidy costs, national debt, and debt interest) reaches INR 27.2 trillion (US$390 billion) annually by 2050. This cost would have to be borne through international and domestic climate finance. To raise domestic public finance, revenue mechanisms outside of the energy sector and/or a carbon tax are needed.

A few caveats are important to elucidate here. The clean energy transition is marked by a transition from a fuel/operating expenses heavy energy system to a capital-intensive one with minimal fuel costs. With tax revenues tied to operating expenses like fuel consumption, shifting the tax burden to capital purchases, like a value-added tax, can remedy this problem and create a more progressive tax policy. Indian consumers already pay one of the highest fuel taxes in the world. Hence, coordinating carbon and fuel taxes is critical to ensuring politically and economically feasible climate policy by preventing excessive tax burdens and securing government revenues for socioeconomic priorities. Through the phasing and scheduling mechanism built into the model, the study constructed the 'Raising Ambition' policy mix to be approximately revenue-neutral to the government by 2050. This is achieved through a 'carbon tax' proxy in the model. Keeping the already high fuel taxes and sector preparedness in mind, the carbon tax is phased in – starting at zero in 2030 and rising to INR 6000/ton (~USD 70 in current exchange terms) in 2050 on industrial emissions in the 'Raising Ambition' scenario. This intervention stabilizes government cash flows while contributing to additional decarbonization,

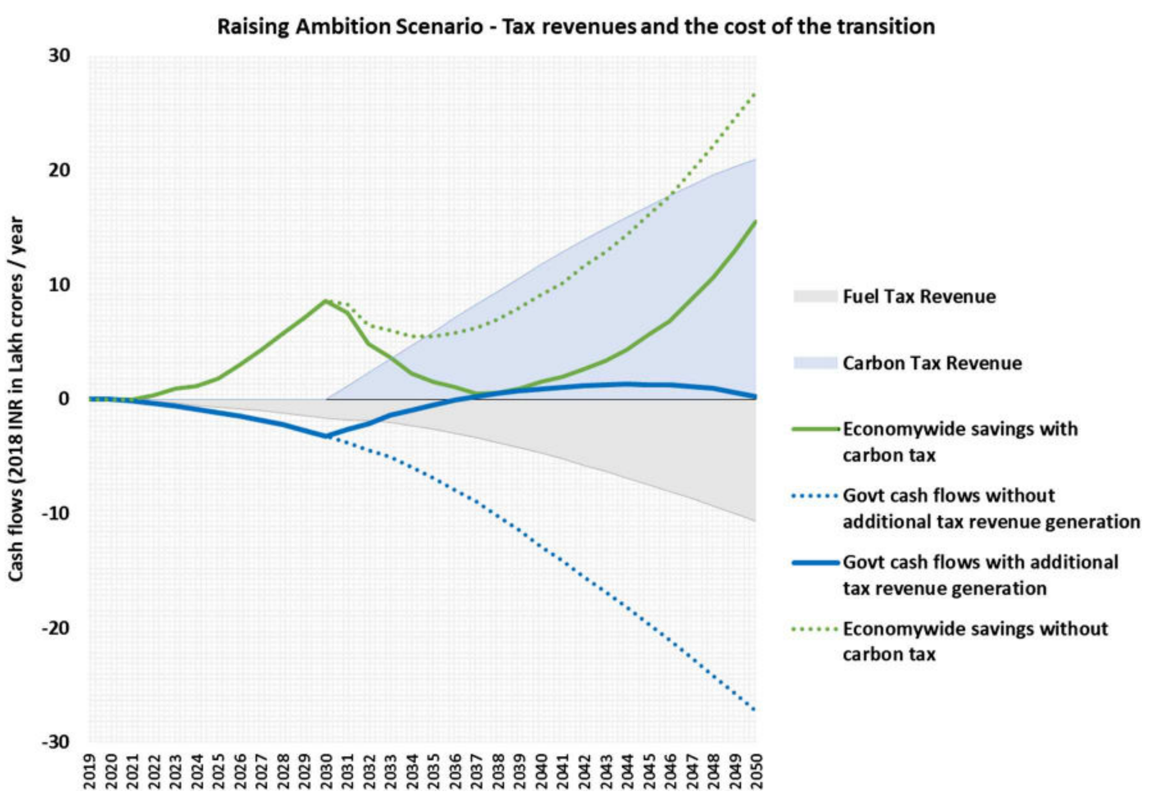

Figure 5. Tax revenues and the cost of the transition.

job creation, and GDP gains. Government deficit resulting from 'Raising Ambition' before 2030 could be supported through international climate finance mechanisms to kick start India's energy transition.

In terms of fiscal benefits, the 'Raising Ambition' scenario results in net economy-wide savings compared to BAU. The increase in capital expenditure resulting from the policy package is offset by the increase in fuel savings over time. Annual economy-wide private savings with and without a carbon tax policy will reach INR 15.5 trillion (US$222 billion) and INR 26.7 trillion (US$383 billion) by 2050. While the carbon tax policy helps stabilize government cash flows and increases the political viability of the transition, it results in reduced private economy-wide savings. Nevertheless, net private savings are still significantly above BAU levels.

4.3. Socio-economic implications

With alternative revenue generation, the 'Raising Ambition' policy mix increases GDP growth above business-as-usual by around 0.2 percent in 2030, 2.8 percent in 2040, and 2.2 percent in 2050 (Figure 6). Net consumer surplus due to increased fuel savings results in increased consumer spending on food and education by a large portion of society currently burdened by higher energy costs as a share of their monthly income. Thus, the 'Raising Ambition' decarbonization scenario also adds more jobs than the non-decarbonizing BAU, cumulating to more than 6 million new jobs by 2030 and 30 million jobs by 2040 (Figure 7). Here, jobs are measured in job-years (i.e. one job for one year). It is important to note that these are net job numbers with some sectors benefiting and others losing jobs in the transition. For instance, approximately a million fossil-fuel sector jobs (primarily coal) will be lost by 2050 and these will be geographically concentrated in some regions of India.

Key open questions for future research include the mix between direct, indirect, and induced job creation and policy mixes that simultaneously improve job creation and income (i.e. 'Direct jobs' in clean energy infrastructure build-up, manufacturing, and services; 'Indirect jobs' in the allied sectors; and 'Induced jobs' from welfare spending of carbon tax revenues and consumer energy savings). The 'Raising Ambition' scenario

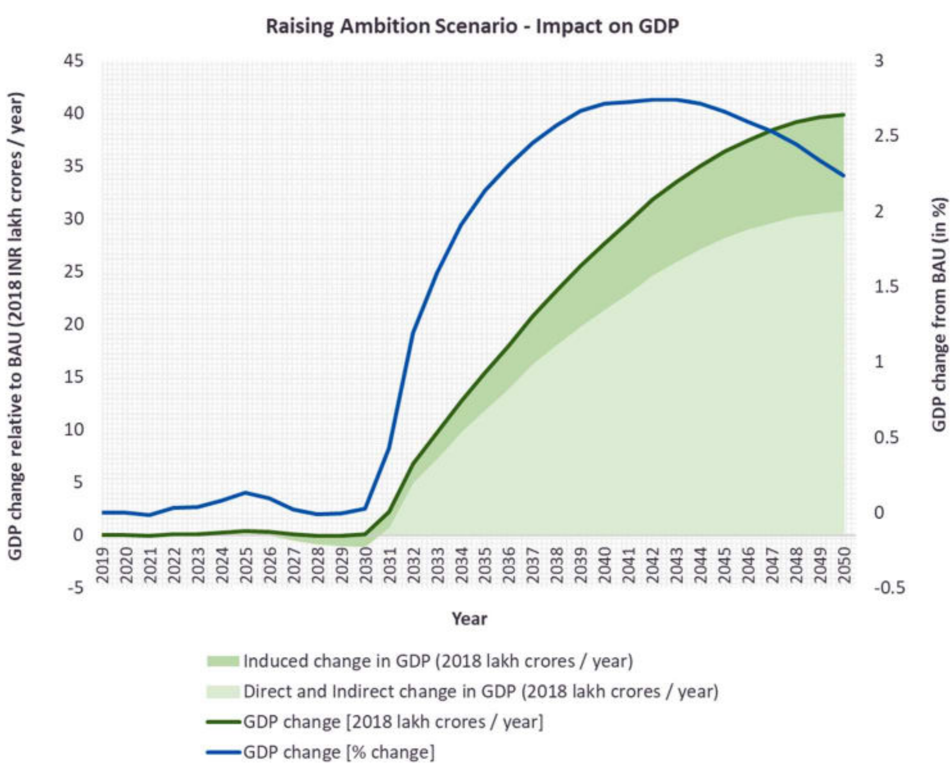

Figure 6. GDP impact of decarbonization policies in 'Raising Ambition' scenario.

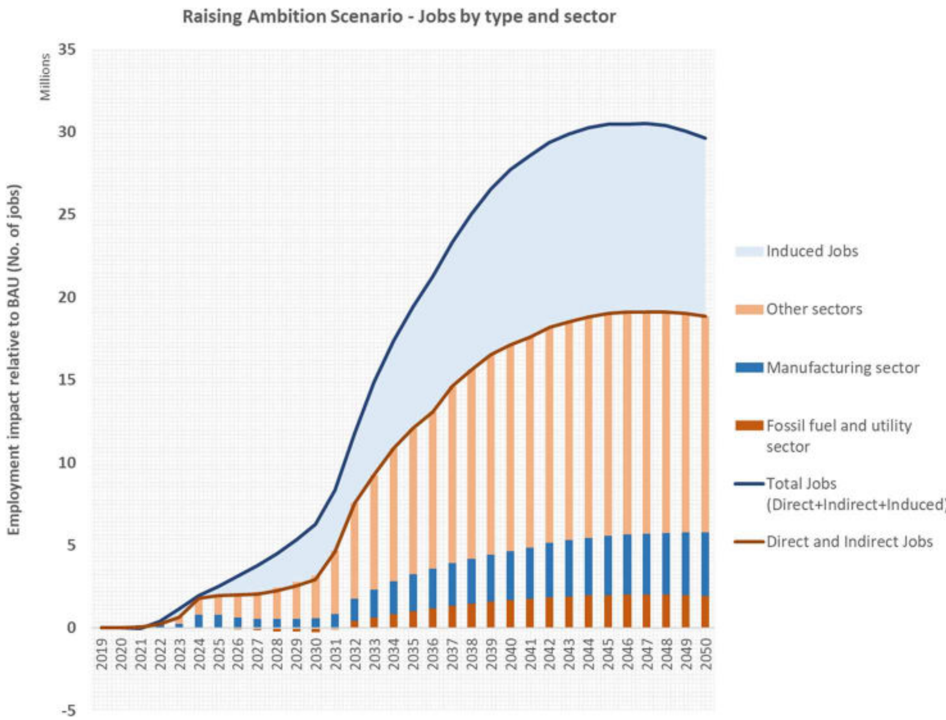

Figure 7. Jobs impact of decarbonization policies in the 'Raising Ambition' scenario.

adds nearly 19 million direct and indirect jobs in the economy at its peak before 2050, along with around 11 million induced jobs. Beyond headline job creation numbers, the types and quality of jobs will affect the political favorability of implementing climate policies needed for a net-zero transition. Job types are susceptible to the relative allocation of government revenue across priorities such as corporate tax reduction, payroll tax reduction, household tax reduction, budget deficit reduction, and increasing government spending. Besides, job types depend on the balance of sectoral policies, which was not explored by this study.

5. Discussion

Study results reveal a possibility frontier for India's net-zero ambition. However, it is important to note that model insights are sensitive to assumptions (see Table C1 of Appendix C for key model assumptions) and, at best, a starting point for further research and deliberation on the opportunities and challenges involved in putting India on a net-zero pathway. There are three key takeaways that emerge from this modelling exercise. First, model results show that decarbonization and socio-economic prosperity may not be inherently at odds – in other words, the potential for ambitious climate policies in India that also deliver positive socio-economic outcomes exists. Nevertheless, there are several challenges that currently keep India from fully exploiting these economic opportunities. Second, results highlight the importance of near-term ambitious action for achieving India's 2070 net-zero goal. Third, embarking on a net-zero pathway imposes a significant burden on government revenues, and offsetting it using alternative revenue generation mechanisms is crucial to creating economic benefits and ensuring continued political support. These takeaways aim to provide a guiding framework for further policy deliberation and emphasize the need for a strategic policy approach to India's energy transition.

5.1. Net-zero as a net socio-economic positive?

The 'Raising Ambition' scenario presents potential net socio-economic benefits over BAU. This result brings additional evidence to inform an ongoing concern in Indian policy discourse that long-term decarbonization is difficult to reconcile with near-term development priorities, as reflected in the views of experts who were interviewed, as well as the literature. If managed carefully, the transition could create up to 30 million new jobs and 2.8 percent higher GDP growth than business-as-usual. Nevertheless, this opportunity frontier is constrained by several challenges, otherwise assumed as possible in the model, that need to be addressed for India's net zero to be a net socio-economic positive.

In terms of technological opportunities, model results project a needed deployment of 1625 GW of grid-scale and distributed solar; onshore and offshore wind by 2050 (~60 GW per year); 178 GW of storage by 2050 (~7 GW per year), more than 200 GW of hydrogen electrolyzers between 2030 and 2050 (>10 GW per year), 67 million electric cars, 375 million two and three-wheelers, 18 million EV light duty freight and 13 million hydrogen freight vehicles (see Figures 3 and 4). However, these requirements vastly exceed India's clean energy manufacturing capacity (Sinha, 2022), a challenge that could be turned into an economic opportunity with careful sequencing of innovation and industrial policies. Given that most of the value creation in clean energy technologies is concentrated upfront in innovation, component manufacturing, project development and construction, and piloting/market-testing, a strategic approach to green innovation and industrial policies becomes pertinent.

India's recent attempt to encourage domestic clean energy component manufacturing through the production-linked incentives (PLI) scheme is a step in the right direction. In the last three years, India's manufacturing capacity in mature technologies like solar modules and cells has risen significantly (from 15GW and 3GW, respectively, in 2020 to 38GW and 6.6GW, respectively, in 2023). Given this trend, it is likely that India will reverse its heavy dependence on solar components from China to become self-sufficient by 2026 (IEEFA, 2023). The PLI policy aims to localize the manufacturing of various technology components while improving India's export competitiveness through advanced industry performance requirements in exchange for incentives.

However, India's lack of clean energy RD&D investments and existing capabilities in manufacturing high-performance technology components has meant poor uptake of the PLIs provided for emerging technologies such as battery storage (Sachdev, 2023). Currently, most of India's public energy RD&D spending goes towards nuclear and fossil fuel technologies and is highly mismatched with future technological needs for decarbonization (Zhang et al., 2021). Besides, India's annual renewable energy RD&D spending was only \$110 million in 2018, compared to China's doubling its annual spending from \$4 to \$6 billion between 2015 and 2020 (Myslikova & Gallagher, 2020). While the EPS system dynamics model does not capture and highlight the marginal impact of green industrial policies and innovation policies on GDP and employment gains/losses, the aforementioned numbers illuminate the challenges involved in India capturing the high value-added jobs and economic opportunities in the net-zero transition.

In terms of job creation and GDP growth, the model results show that pursuing a net-zero transition could possibly lead to net-positive GDP growth and job creation than business-as-usual. However, it is important to note that this article's findings are at the national-level and they do not address the spatial and distributional inequities of transitioning to net-zero across India's states. For instance, the coal retirement policy implemented in this model is likely to result in significant stranding of coal assets after 2030 (~199 GW and associated mining assets), beyond what will naturally result from market-driven push towards renewables without any retirement policy (~16 GW). These estimates are in line with recent estimates from studies focusing on stranded assets in the energy transition (Malik et al., 2020). Livelihoods associated with these coal assets are mostly concentrated in a few coal-dependent states such as Jharkhand, Orissa and others. Scholars show that these regions that currently host coal power and mining may not necessarily benefit from renewable energy, unless justice is embedded in transition. Without policy support, people employed in sectors such as coal mining cannot be seamlessly transitioned to sectors that benefit from the transition (Bedi, 2022; Blankenship et al., 2022; Haldar et al., 2023; Malik & Bertram, 2022: Roy & Schaffartzik, 2022).

Lastly, the model presumes that consumption preferences are based primarily on prices and availability. This elides the importance of recent policies such as the Mission LiFE (Lifestyles For the Environment) that aims to modify consumption through culture, behavioural change, and other non-price information. Future efforts at modelling economy-wide trajectories could draw from agent-based modelling of this important policy concern (e.g. Chaudhari et al., 2018; Chen et al., 2020; Karimi & Vaez-Zadeh, 2021).

5.2. Net zero 2070 as a signal for near-term ambition

There is a concern that net-zero pledges 'postpone into the future critical action that needs to take place now' (UN, 2022). As one of the latest net-zero goals announced, India's 2070 deadline is particularly vulnerable to this charge without a defined pathway (Climate Action Tracker, 2023). In addition, this study's results show that India's updated NDC is incompatible with its 2070 net zero goals, as the targets are insufficient to peak India's emissions even by mid-century. In this regard, this analysis emphasizes the need for more near-term ambition leading up to 2030 for India to meet its 2070 net-zero goals.

To achieve net-zero CO_2 emissions by 2050 and possibly net-zero GHG emissions by 2070, the 'Raising Ambition' scenario highlights the importance of near-term 'readiness policies' that prepare various sectors for deep decarbonization, followed by policies that effectively decarbonize while enhancing the GDP, creating additional jobs, and maintaining fiscal balance. Specifically, in the electricity sector, near-term readiness policies that increase transmission capacity, reduce transmission and distribution losses, increase grid flexibility, improve demand response, and reduce power plant downtime are crucial for sector readiness. Similarly, electric vehicle charging infrastructure in the transport sector is a crucial readiness policy, with the EV mandate implemented over time.

In the industry sector, industrial energy efficiency standards, material efficiency, reuse, and recovery are important near-term decarbonization policies as they ensure that industries are better prepared to absorb a future carbon tax within India and remain globally competitive under an emerging EU CBAM regime. Further production-side measures are possible, particularly in the steel and cement sub-sectors with high managerial, technical, and financial capacity (Bataille et al., 2023). The perception around the feasibility of industrial decarbonization is also rapidly evolving. Transition to green hydrogen use in heavy industry implemented in a phased manner starting in 2030 provides the largest decarbonization wedge for the industry sector in the model. While green hydrogen was considered decades away from cost competitiveness (Yadav et al., 2022) until recently, India's newly announced National Green Hydrogen Mission, generous subsidies under the US Inflation Reduction Act (IRA), and the EU hydrogen strategy all point to a brighter future for green hydrogen deployment.

5.3. The role of climate finance

The technological opportunities and policy prescriptions discussed under the 'Raising Ambition' scenario significantly burden government revenues absent an alternative revenue generation mechanism. Reduction in fuel tax revenues and the cost of decarbonization policies will likely lead to an annual government cash flow deficit of $46 billion by 2030 and $390 billion by mid-century, rendering the transition package fiscally and politically infeasible. Fiscally, India's central and state governments are heavily dependent on transportation fuel tax revenues. More than 13 percent of tax revenues raised by the central and state governments come from taxation on various fossil fuels (Bhandari & Dwivedi, 2022; Gambhir et al., 2021), a source of revenue that is likely to deplete as the economy decarbonizes. Thus, mobilizing international climate finance alongside managing a domestic tax shift from transportation fuel taxes towards carbon or other types of taxation is crucial to ensure the fiscal health of the central and state governments in the transition.

With a tax shift from fuel to carbon, as designed in the model scenario, from 2030 to 2050, fuel tax revenue losses and decarbonization costs are compensated for, essentially stabilizing government cash flows to BAU levels by 2050. An important caveat here is that the model sets carbon prices in a way that leaves the share of imports and domestic consumption constant, i.e. it presumes that border tax adjustments are in place for imports into and exports out of India, zeroing out the impact of a carbon tax on trade competitiveness. This is a challenging assumption but also a potential area for negotiating cross-border policy linkage or coordination, particularly under the emerging EU CBAM regime.

Revenues from carbon taxes in the scenario are redeployed in the economy as carbon dividends – to households, workers, and companies – and to spending on government programmes or reducing the deficit. This is a significant driver of additional induced jobs created from increased consumption among lower-income groups that benefit from government welfare programmes and carbon dividends financed from the carbon tax. The absence of a carbon tax in the 'Raising Ambition' scenario until 2030 (to allow for industry sector readiness) results in a $46 billion government cash flow deficit before it is brought back to BAU levels by 2050 (Figure 5). Mobilizing international climate finance to compensate for this near-term deficit is crucial to kick-start India's transition laid out in the 'Raising Ambition' scenario. Conditional on international climate finance mobilization and the careful use of domestic carbon tax revenues, economy-wide private savings will likely rise to $222 billion annually by mid-century alongside GDP growth and job creation, making a case for raising India's climate ambition beyond business-as-usual.

6. Conclusion

India's challenge is decarbonizing while simultaneously creating millions of new jobs, increasing incomes, and improving its economic output in the next few decades. The task is a monumental one. India's youth constitute about one-third of its 1.4 billion population. The prevailing youth unemployment rate is 32 percent, and its per-capita GDP ($2256) continues to lag major economies and several emerging economies. In this developmental context, this study identifies a possible scenario that may zero out India's CO_2 emissions by 2050 while generating new additional jobs and higher GDP growth than business-as-usual. However, for this scenario to materialize, India must initially implement several readiness policies in the coming decade, followed by policies that provide the most emissions reduction in each sector. The article also notes that it is financially and, hence, politically impossible to put India on a net-zero pathway without international climate finance to kick-start India's energy transition and domestic revenue generation mechanism compensating for the declining fossil-fuel tax revenues due to decarbonization.

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