The Coalition
of Finance Ministers
for Climate Action

# How system dynamics models can inform India's low-carbon pathways


## World Resources Institute (WRI)

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## India's economy-wide climate challenge

India aspires to be a developed country by 2047. However, India's per capita energy consumption of 1,255 kWh is low, at about a third of the global average (Ministry of Power, 2022a). This means that as India develops, its energy consumption will increase, and it is expected to double by 2047 to meet its development goals.

On the other hand, India has communicated a long-term climate target to reach net zero emissions by 2070 under the Paris Agreement at COP26 in 2021 (Ministry of Power, 2022b). It has also set ambitious short-term climate targets by 2030 through its updated Nationally Determined Contribution (NDC)—i.e., to achieve 50% of its cumulative electric power installed capacity from non-fossil fuel energy sources, to reduce the emissions intensity of its GDP by 45%, and to create an additional carbon sink of 2.5 to 3 billion tons of carbon dioxide equivalent through additional forest and tree cover (Government of India, 2022).

At the same time, India is among the 50 most climate vulnerable countries globally and is highly vulnerable with respect to healthcare, freshwater availability, and food security through decreased crop yields.[1] Moreover, it is estimated that more than 80% of India's population resides in districts highly vulnerable to extreme hydrometeorological disasters (Mohanty and Wadhawan, 2021). Recent observations indicate that heatwaves in India are getting stronger and more frequent with climate change (Coleman, 2024). This means that it is critical for India to urgently invest in adaptation measures and build resilience to climate change.

The challenge before India is massive, multidimensional, and unprecedented. The country will require a rapid scale-up of renewables such as solar photovoltaics and wind power, a shift to electric vehicles, and deep industrial decarbonization through emerging low-emission technologies and fuels, including green hydrogen, and green buildings. This will entail just energy transitions toward renewables, skilling the workforce for changing energy and economic needs, integrating adaptation measures in development planning, and investing in social protection measures. It will be possible only if India has access to adequate finance and investments to realize this transition.

## Finance and fiscal space for decarbonization and development

India's finance requirement for climate mitigation is estimated to be in the order of tens of trillions of US dollars by 2050 (Ministry of Environment, Forest and Climate Change, Government of India, 2022). But as the share of fossil fuels in India's energy basket decreases, its public revenue from taxation of fossil fuels—currently about a quarter of the total tax revenue (Gambhir et al., 2021)—will also decline. This will constrain the availability of public resources to invest in basic public infrastructure, human capital, and the achievement of the UN Sustainable Development Goals. This will especially impact coal-producing states in India, which incidentally also lag on infrastructure and human development indicators (Swamy and Agarwal, 2023; Upadhyay and Agarwal, 2024).

On the other hand, the energy-economy transition resulting from climate mitigation interventions will impact jobs and livelihoods across regions and sectors. It may disproportionately affect the informal workforce and marginalized groups, who might be unable to access new green jobs. Significant financial support will be required to plan and implement a just transition and provide safety nets for vulnerable groups at risk from the jobs transition.

Climate change adaptation will also require substantive finance. India's adaptation-related expenditure has been significant at 5.6% of its GDP in 2021/2022, but the adaptation gap is estimated at ~US$870 billion until 2030 (UN Climate Change, 2023).

While domestic public finance can support initial investments in decarbonization, India will require careful financial planning to prioritize and allocate limited public finance for multiple critical needs such as adaptation, just transition, and sustainable development. It will also be imperative to mobilize

1 https://gain-new.crc.nd.edu/country/india#vulnerability

substantive and timely international finance, particularly in the form of grants, to tackle the scale of the challenge (Bhushan, 2023).

## Policy insights from new systems dynamics models

Energy-emission modeling is useful to guide policy decisions related to long-term decarbonization. However, traditional modeling approaches based on optimization of individual parameters (e.g., technology costs) can only answer limited policy relevant questions (EEIST, 2024). Optimization models do not always account for cross-sectoral feedback and policy design to tackle the multidimensional nature of India's development challenge. This necessitates complementary approaches that model the dynamics of interlinked systems including energy, the economy, and the environment. System dynamics offers a simulation-based approach to model the long-term interactions between these systems and can provide useful insights to finance ministers.

This contribution uses two system dynamics simulation models—the India Energy Policy Simulator (EPS) and the Green Economy Model for India (GEM). The former has a more granular representation of the power, transportation, and industry sectors, whereas the latter has greater detail in agriculture, land-use, water, and critical minerals. Combined, these two models aim to enable a comparative assessment of the macroeconomic and resource-use implications of alternative climate policy scenarios for India. While both models provide insights into public finance, as well as other co-benefits of climate action, they differ in their approaches.

The EPS simulates changes in the economy with respect to an exogenous baseline, accounting for the direct, indirect, and induced impacts of mitigation policies calculated using a fully integrated national input-output table that divides the economy into 36 sectors. This provides granular insight into changes in output, investment, and employment across economic subsectors in response to climate policies. However, the main limitation of this approach is that the structure of the economy is assumed to remain static, i.e., the interdependencies between economic subsectors are assumed to stay constant over time.

The GEM, on the other hand, endogenously models production in the economy. This gives the model the capability to account for effects on economic output and employment of changes in technology, energy prices, and improvement in human capital over time. While this allows a more dynamic representation of structural change in the economy compared with the EPS, the trade-off is limited sectoral disaggregation, with the economy being divided into three sectors—agriculture, industry, and services. The model also has a limited capability to incorporate labor market frictions and interactions between wages and employment. However, the model has further details on natural resources, with disaggregated representation of land and agriculture driven by demand from population, GDP, energy, and urbanization. The model increases understanding of the impact of decarbonization policies on water use and critical minerals as well as the land and agriculture sectors.

### Fiscal impacts

Both models suggest that the low-carbon transition will create economic gains, overall, with higher GDP and employment in the decarbonization scenarios compared with the reference scenario (business as usual). In terms of public finance, the shift to cleaner forms of energy and electric mobility will likely reduce the tax revenue from petroleum products—the authors estimate that in a net zero 2070 scenario, tax revenue will be US$130 billion lower in 2050 than in the reference scenario. However, it is found that if a new carbon tax is introduced, linearly increasing to about US$50 per ton of $CO_2$e by 2050, it could offset the revenue loss by 2050 by widening the tax base to all fossil fuel use in energy and industry, including industrial process emissions (EEIST, op. cit.).

Explicit fossil fuel subsidies accounted for just under 5% of the tax revenue in FY2022/2023. With increased spending expected on renewable energy and other cleaner fuels across sectors, the state of the fiscal deficit is important to consider. The models suggest that the fiscal deficit will likely be higher in the net zero 2070 scenario compared with the reference scenario. In the long term, however, with economic growth and taxes from non-energy sources, the cumulative public debt will likely recover and be lower than the public debt in the reference scenario.

It is estimated that the low-carbon public investment for the transition is about US$90 billion higher than in the reference scenario, annually, between 2024 and 2070. By 2070, this amount is estimated to be about US$300 billion in the net zero 2070 scenario compared with about US$100 billion in the reference scenario.

This is for three major reasons:

- Clean energy investments, including power generation as well as fuel switching policies in the transportation and industry sectors as well as investments in green hydrogen production
- The high cost of carbon capture and storage (CCS)
- The cost of land-based interventions, including afforestation, reforestation, and sustainable agricultural practices.

### Trade impacts

As well as having public finance consequences, the long-term low-carbon transition portends profound trade implications. The models suggest reduced spending on oil imports by about US$270 billion by 2050 and increased spending on mineral imports for solar panels and lithium-ion batteries by about US$100 billion by 2050 (Arpan et al., 2022; EEIST, 2024).

India's balance of payments, trade relationships, and import dependence will likely shift from OPEC countries to mineral rich countries such as China, Australia, and Argentina. Reducing these dependencies will require increased efforts around recycling and reuse of materials used in solar panels and vehicle batteries.

### Employment impacts

These economic shifts will also likely have an economic impact on jobs. In the net zero 2070 scenario, the economy is estimated to gain an additional 3.5 million jobs overall (Swamy and Agarwal, 2023). The highest gains are in construction, utilities, and services sectors, with smaller gains in the manufacturing sector and losses in mining and raw material extraction sectors. The fossil fuel sector sees job losses in oil and gas extraction, refining petroleum, and coal mining, while the manufacturing sector sees job losses in cement and basic metals due to recycling and material efficiency. However, clean energy expansion and switching to cleaner fuels in the industry and transportation sectors require specialized manufacturing, thereby creating job gains in sectors such as fabricated metal products and electrical and electronic goods.

These job gains, however, only signify an increasing labor demand and will require skilling/reskilling the workforce to enable access to these jobs. Moreover, the impact on the informal sector, which the models are unable to accurately account for, will be much larger and will need much more focus on welfare/social protection schemes. This will require Government interventions to enable the transition in a just manner (Swamy and Agarwal, 2023).

### Land impacts

While assessing the economic consequences of the low-carbon transition for public finance, trade, and employment, resource-related impacts are often overlooked. Land, in economic terms, is deemed an important part of the capital cost and will likely be squeezed due to demands from urbanization, food security, and energy, as well as for carbon sequestration. Water, for industrial and energy sectors, would be a part of the operating costs, and scarcity could lead to dire consequences for both residential and agricultural users. The models also connect resources such as land and water use with the economic and decarbonization outcomes, allowing the study of policy trade-offs such as whether the biofuel target is detrimental for food security or whether the target for adding sinks is possible given the constraints on forest land conversion. Such an analysis can help identify policy options that can conserve resources while meeting intended targets (Golechha et al., 2022). In the model, changes in land use are demand-driven and dependent on population, GDP, and policy choices, with competing uses from urbanization, a rising population, and their food and energy requirements.

These models bring together mitigation-heavy sectors such as power, industry, and transportation and link them with the economic and resource-use consequences of their decarbonization. While these models may not answer questions relating to the labor market or at a subnational level, they can provide insights on growth, public finance, employment changes, land use, demand for critical minerals, technological and efficiency shifts, etc. These models are therefore equipped to demonstrate the multidimensional nature of the challenges that India will face en route to net zero.

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