



PATHWAYS FOR DECARBONIZING INDIA'S ENERGY FUTURE: SCENARIO ANALYSIS USING THE INDIA ENERGY POLICY SIMULATOR

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EXECUTIVE SUMMARY

Highlights

- This working paper explores two climate policy packages for India through 2050 using the India Energy Policy Simulator (EPS), an open source, systems dynamics model. The analysis considers:
 - The NDC-SDG Linkages (NDC-SDG) scenario: Policies that leverage interconnections between India's climate actions and Sustainable Development Goals (SDGs) for 2030.
 - The Long-Term Decarbonization (LTD) scenario: Policies with high potential for greenhouse gas (GHG) emissions abatement in the long term.
- In the NDC-SDG scenario, GHG emissions are reduced by 24 percent by 2030 and 37 percent by 2050, compared to business-as-usual (BAU) levels. In the LTD scenario, the corresponding emissions reductions are 30 percent by 2030 and 65 percent by 2050. A small number of policies are responsible for most emissions reductions.
- Both scenarios yield health co-benefits from a reduction in air pollution. Relative to BAU projections, from 2020 to 2050, 5.7 million premature deaths from air pollution could be avoided in the NDC-SDG scenario and 9.4 million in the LTD scenario.
- Both scenarios lead to net cost savings in the medium to long term and show a positive impact on employment and output, relative to BAU. A carbon tax is an essential policy lever in realizing these positive impacts.

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Working Papers contain preliminary research, analysis, findings, and recommendations. They are circulated to stimulate timely discussion and critical feedback and to influence ongoing debate on emerging issues.

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- Policies focused on long-term ambition deliver greater emissions reduction and co-benefits in both the medium and long terms, as compared to policies focused on medium-term ambition. However, there is greater uncertainty involved in translating long-term policies into action.

Context

For emerging economies like India, effective climate policy must deliver on the twin objectives of reducing GHG emissions while enabling the achievement of development-related goals. An integrated assessment of sectoral policy options over varying timeframes, along with their macroeconomic implications, can help in the design of effective policy packages that meet India's medium- and long-term climate targets while also delivering economic growth, ensuring the efficient use of resources, and avoiding the lock-in of carbon-intensive behavior and technologies.

About This Paper

We analyze two climate policy packages for India corresponding to differing medium- and long-term decarbonization objectives and their implications for the economy and resource-use, using the India EPS, an open source, system dynamics model. The NDC-SDG scenario is a combination of sectoral decarbonization policy levers featured within the EPS that simultaneously align with goals within the country's first Nationally Determined Contribution (NDC) and the targets within the 17 Sustainable Development Goals (SDGs) under the 2030 Agenda for Sustainable Development. Most policies in this scenario are implemented linearly, reaching full strength of implementation by 2030. On the other hand, the LTD scenario explores sectoral decarbonization policy levers that exhibit high potential for GHG abatement over the long term and sets ambitious targets for implementation by 2050. This scenario includes

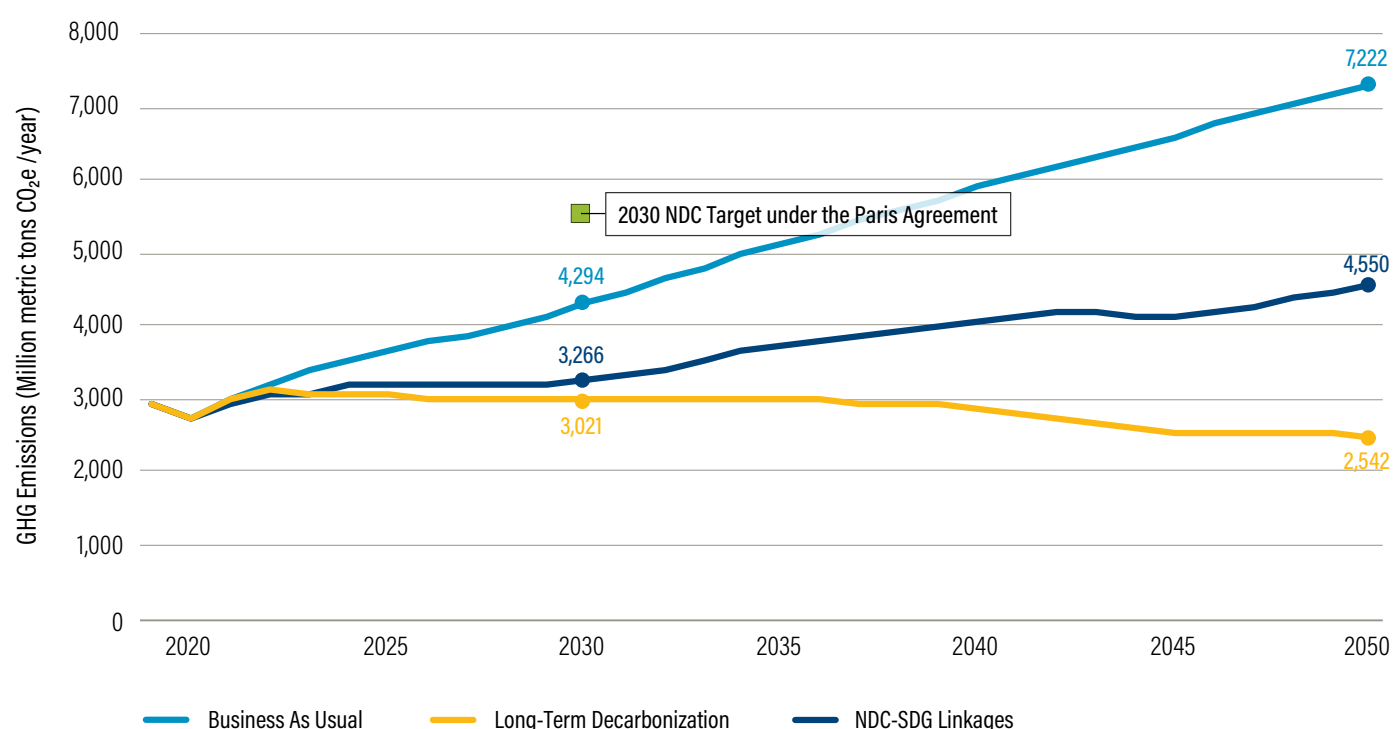
the use of currently nascent technologies, such as hydrogen, battery storage, and to a smaller extent, carbon capture and storage (CCS). The policies with proven technologies are phased in linearly from 2020 until 2050, while those relying on nascent technologies are phased in starting from 2025 through 2030.

The analysis enables the identification of cost-effective policy options across different economic sectors and timeframes for low-carbon development in India, as well as potential trade-offs and co-benefits between climate policies and development priorities. This analysis uses a system dynamics modelling framework, which allows for more realistic representation of the inherent complexity in energy systems than conventional modelling approaches by capturing outcomes that arise from market failures, non-optimizing behavior by economic actors, and non-linear feedback effects of policies across sectors. However, the results of our analysis are limited to aggregate outcomes at the national level and do not capture distributional impacts of those outcomes across different regions or population subgroups, such as socioeconomic, gender, or age groups.

Key Findings

Judiciously designed policy packages can boost the ambition of climate commitments by delivering significant emission reductions. India's economy-wide target of reducing emissions intensity of the gross domestic product (GDP) by 33 to 35 percent over 2005 levels by 2030 is surpassed in the BAU scenario itself. However, it can reduce up to 61 percent by 2030 in the NDC-SDG scenario and further to 87 percent by 2050 in the LTD scenario. Total GHG emissions in the three scenarios are depicted in Figure ES-1.

Figure ES-1 | GHG Emissions (Including Land-Use) in BAU, NDC-SDG, and LTD Scenarios



Source: Authors, using India EPS 2021.

Both the NDC-SDG and LTD scenarios gradually reduce dependency on fossil fuels for primary energy generation over the long term. Relative to BAU, primary energy consumption from fossil-free sources such as wind, solar, hydro, and nuclear increases by 14 percent and 93 percent in 2050 in the NDC-SDG and LTD scenarios, respectively.

A small subset of policies contributes to most of the emission reductions in the medium

and long terms. In the NDC-SDG scenario, about 67 percent of the total GHG emissions reductions in 2030—equaling 690 million metric tons (Mt) of carbon dioxide equivalent (CO₂e)—can be achieved by implementing just three key policies. Similarly, in the LTD scenario, nearly 47 percent of the total GHG emissions reductions in 2050 (equal to 2,200 MtCO₂e) can be achieved through three policies (Table ES-1).

Table ES-1 | Key Policies Contributing to Emissions Reduction in the NDC-SDG and LTD Scenarios

NDC-SDG SCENARIO		LTD SCENARIO	
Policy	Relative Contribution to Total Emissions Reduction in 2030	Policy	Relative Contribution to Total Emissions Reduction in 2050
Industrial carbon tax	30%	Industrial fuel-switching from fossil fuels to electricity and hydrogen	22%
Industrial energy efficiency standards	25%	Hydrogen production via electrolysis (supported by carbon-free electricity generation)	12%
Demand reduction for cement, steel, and wastewater through material efficiency, longevity, and re-use	12%	Early retirement of coal power plants	12%

Source: Authors.

In addition to GHG mitigation, both the NDC-SDG and LTD scenarios yield co-benefits in terms of cost savings, reduction in harmful air pollutants, and reduction in water usage. Both scenarios lead to increasing net cost savings over time relative to the BAU scenario. The NDC-SDG scenario shows net cost savings as early as 2024, while the LTD scenario shows cost savings from 2028 onwards and results in higher savings compared to the NDC-SDG scenario from 2037 to 2050. In both scenarios, one of the most cost-effective policies with considerable emission abatement potential is the mode-shifting policy in the transport sector due to the resulting savings in fuel costs. Most policies that yield GHG emissions reductions within the NDC-SDG and LTD scenarios also reduce air pollution and associated premature mortality. In the LTD scenario, owing to the ambitious policy settings for early retirement of coal power plants, water withdrawals and water consumption by power plants in 2050 are projected to be 89 percent and 80 percent lower than BAU levels, respectively.

Deep decarbonization in the economy is possible, while also boosting GDP and employment. The NDC-SDG scenario sees a 1 percent increase in GDP and 29 million additional jobs by 2050, relative to BAU. In the LTD scenario, this grows to a 1.5 percent increase in GDP and 39 million additional jobs.

Policy Implications

Policy interventions should consider complementarity between policies, and the analysis concludes that efficacy of certain policy interventions is enhanced if combined with supportive policies that bolster their impact. For example, shifting hydrogen production to electrolysis (from the conventional production pathway using natural gas) enhances the emissions mitigation potential of the policy lever involving industry sector fuel switch

to a mixture of electricity and hydrogen. Meeting the electricity demand for industrial use, or hydrogen electrolysis through a grid reliant on fossil fuels, precludes these policies from realizing their mitigation potential, so it is critical to simultaneously implement clean electricity generation policies.

These crucial combinations of policies should be implemented with targeted investments and the development of time-bound implementation roadmaps. We find, for example, that delaying the first year of implementation of the industrial fuel switching policy to electricity and hydrogen from 2030 to 2035 in the LTD scenario would result in a 6.5 percent increase in emissions by 2050, as compared to the original scenario. Timely uptake of nascent technologies like hydrogen, which are key to decarbonization in the long term, will require the creation of supporting infrastructure and policy incentives for technology investments in the private sector. Supporting infrastructure may include, for instance, grid improvements and development of distribution networks to facilitate industrial-scale production and supply of green hydrogen.

Carbon taxes have a key role to play in realizing positive macroeconomic impacts. An industrial carbon tax increased in a phased manner over time is an essential policy lever to include within policy packages as an offset to declining government tax revenue from petroleum products (due to the reduction in overall fuel use) without increasing government debt. This is necessary to mitigate the negative impact on induced economic activity resulting from a significant reduction in government spending.

SECTION 1: INTRODUCTION

Background

The ongoing COVID-19 crisis has posed unprecedented social and economic challenges across the world. India is among the worst affected countries in terms of both human and economic tolls, and the gross domestic product (GDP) contracted by nearly 24 percent in the first quarter of fiscal year (FY) 2021 (Ghosh 2020). Despite a temporary reduction in greenhouse gas (GHG) emissions due to the COVID-induced recession, rebound emissions in 2021 are estimated to increase by about 1.4 percent over pre-pandemic levels as economic activity resumes (IEA 2021a). Furthermore, as India continues to expand and modernize its infrastructure, the country is expected to increase its energy consumption in order to meet its developmental goals. As of 2018, India's Human Development Index (HDI) was 0.64. According to the Economic Survey of 2019, the per capita energy consumption in India needs to quadruple if the country is to achieve an HDI level of 0.8. Up to this level, HDI is strongly correlated to per capita energy consumption (Gol 2019; Steinberger 2016). At the same time, India's rapid urbanization patterns are expected to contribute significantly to an increase in energy, land, and water use, with corresponding increases in GHG emissions.

While the path towards economic recovery is still uncertain, there is an opportunity to realign the country's growth and consumption patterns to be more efficient, affordable, resilient, and sustainable. For instance, falling costs and increasing efficiencies of fossil-free energy technologies globally are already demonstrating the economic feasibility of decarbonizing electricity supply, which constitutes nearly 40 percent of India's GHG emissions inventory (GoI 2021a).

India is also one of the few countries on track to achieve—and perhaps overshoot—its Nationally Determined Contribution (NDC) targets under the Paris Agreement. Thus, there is potential for revision of emissions reductions targets, given that absolute emissions are projected to continue growing. Further, there is a recognized need to streamline sectoral priorities with holistic global development goals, such as the 2030 Agenda for Sustainable Development and the NDCs, and to communicate long-term low-carbon development strategies under the Paris Agreement¹ (NITI Aayog 2019).

Motivation for the Study

Among key modelling studies that have looked at long-term low carbon development pathways for India recently, Shukla et al. (2015) and Gupta et al. (2019) adopted the approach of combining a bottom-up cost optimization model on the energy supply side, with a top-down economy-wide model on the demand side to analyze different 2°C compatible macroeconomic scenarios for India up to 2050. Parikh et al. (2018) explored three technology policy scenarios in the context of a 1.5°C carbon budget for India, using a hybrid, economy-wide optimization model. The International Energy Agency (IEA), in its *India Energy Outlook 2021*, presented four energy policy scenarios up to 2040, taking into account economic and technological impacts, using its World Energy Model (WEM) simulation model (IEA 2021b).

In the context of India's current NDC targets, the Center for Study of Science Technology and Policy (CSTEP) (Kaundinya et al. 2018) looked at the effect of proposed technologies and policies on energy intensity of GDP using its IMRT5 model—a bottom-up, cost-optimization model for the power sector—while Chaturvedi et al. (2018) conducted an uncertainty assessment of the cost of power generation technologies and behavior of energy demand in end-use sectors on India's NDC target scenarios, using the GCAM-IIM integrated assessment model. The approaches adopted by each study are summarized in Appendix A.

A general limitation with the variety of approaches outlined above is their inability to capture certain outcomes that may arise from market failures, non-optimizing behavior by economic actors, or non-linear feedback effects of policies across sectors. Consequently, we adopted a scenario-based approach for evaluating low carbon pathways using a *system dynamics* framework that can potentially better account for the inherent complexity in energy systems with social, economic, and environmental dimensions by capturing such effects,² and thereby help policymakers find more complete answers to challenging questions: How can policies be designed to achieve simultaneous goals of reducing emissions and meeting growing energy demand? What are the synergies and trade-offs between climate policies and sustainable development goals? What are the most cost-effective opportunities for enhancing India's NDC commitments? What are the implications of a clean energy transition on employment generation and resource use?

Study Methodology and Limitations

This analysis uses the Energy Policy Simulator (EPS), an open-source, system dynamics model. It was developed by Energy Innovation LLC and adapted for India in collaboration with World Resources Institute India.³

Our approach is to construct what-if scenarios aimed at evaluating the impact of alternate policy actions. Scenario or “what-if” thinking enables users to visualize the plausible outcomes to alternate courses of actions, thereby helping to identify and prioritize important policy interventions. This is a forward-simulating approach that evaluates the impacts of various policy actions, rather than providing a set of optimal policy actions to meet a predetermined target for emissions reductions. Hence, the results vary depending on each unique set of policy actions chosen by a user: there are many possible combinations of actions that can reach a potential emissions reductions outcome, each with their own implications on other outputs such as costs, social benefits, and economic impacts.

The EPS is designed to be simulated at aggregate geographical (national) and time (annual) scales. While aggregation allows for more comprehensive coverage of policies, it also results in certain limitations in modelling. This includes any simplistic assumptions made to represent granular data at aggregate scales.⁴ Further, data gaps in some input variables require making broad assumptions (such as fuel elasticities) and preclude the consideration of certain effects, like the rebound effect of efficiency policies. This introduces some uncertainty in the results that cannot be quantified in the model. Finally, while the model estimates the co-benefits of energy policies at an aggregate national level, it is outside its scope to capture distributional impacts of those co-benefits across states and population groups (socioeconomic, gender, or age).

Despite the above limitations, a scenario-based approach can be useful for comparing the outcomes of a wide variety of policy actions. This is because the limitations would uniformly apply across different policy combinations, and hence would not have an impact in comparing scenario results in relative terms. The process of scenario creation can enable decision-makers to compare the impacts of alternate policies in terms of their associated costs and benefits. It is participatory by design and can facilitate consensus building through a shared iterative modelling process conducted with multiple stakeholders with potentially conflicting interests.

SECTION 2: SCENARIO DESCRIPTION AND RESULTS

In our analysis, we consider two scenarios for modelling low carbon pathways for India’s medium- and long-term future.⁵ The impacts of a scenario capturing the cross-sectoral effects of the combination of policy choices can be assessed relative to the business-as-usual (BAU) scenario via key output parameters of emissions, costs, economic impacts, and social benefits. The BAU assumptions and results are available in the updated technical note for the India EPS (Swamy et al. 2021).

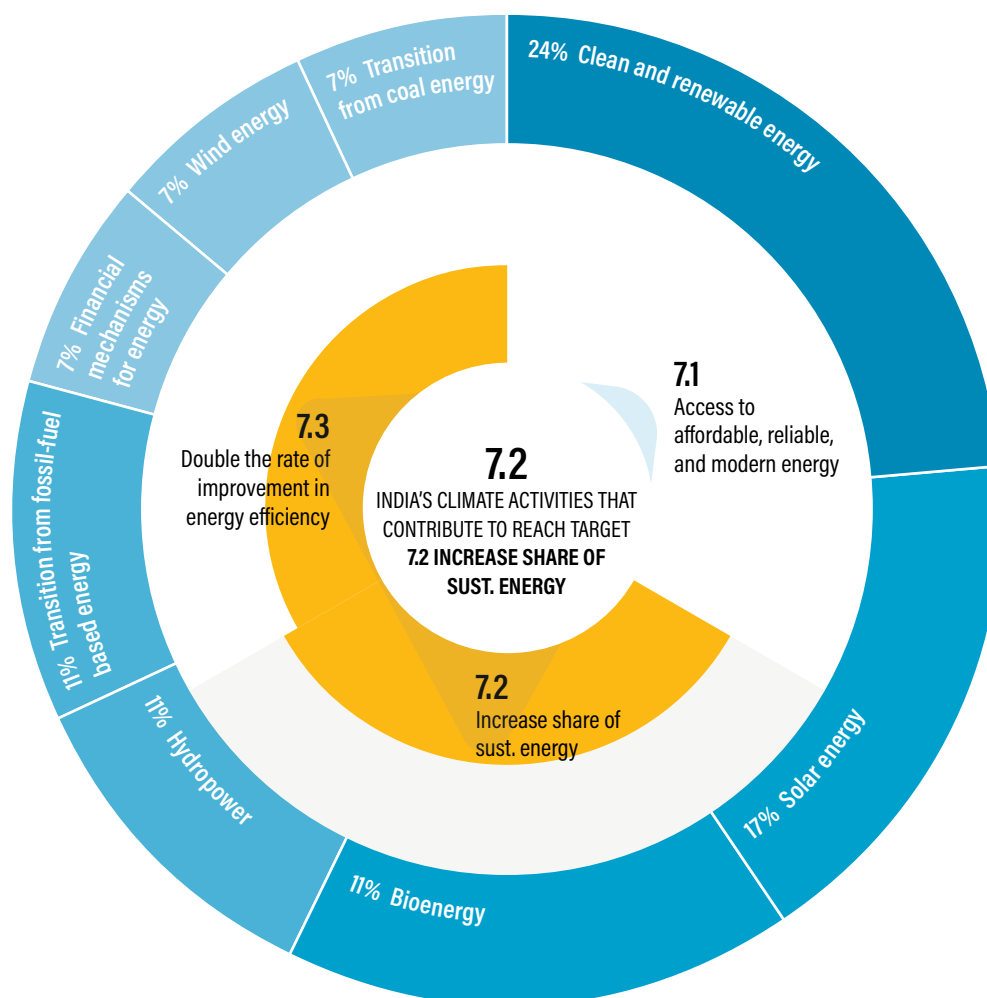
The level of ambition for the policy settings in each scenario is decided based on a combination of factors, including the existing level of achievement in the BAU case, review of literature to identify the technical potential achievable for the technologies modelled within the policies, and preliminary consultations with sectoral experts (listed in Appendix A) on policy feasibility given on-the-ground implementation challenges in India.

NDC-SDG Linkages Scenario

Scenario Set-Up: Description and Approach for Selection of Policies

In this scenario, we test policies that leverage the interconnections between India’s climate actions towards the Paris Agreement and the socioeconomic development goals under the 2030 Agenda for Sustainable Development.

To create the NDC-SDG Linkages scenario, we first identified synergies between India’s climate actions towards its NDC and the 169 targets within the 17 Sustainable Development Goals (SDGs) using the Stockholm Environment Institute’s NDC-SDG Connections tool, which quantifies the points of connection between a country’s NDC actions and SDGs to identify opportunities for more effective implementation of both agendas (SEI 2021). For instance, the outer ring in Figure 1 ranks India’s NDC actions according to their importance for SDG 7 to “ensure access to affordable, reliable, sustainable and modern energy for all” (UNGA 2017). The highest priority among India’s concrete NDC actions towards SDG 7 is promotion of clean and renewable energy, which accounts for 24 percent of India’s climate actions aligned with SDG 7 (Figure 1). Within the sub-targets under SDG 7, the inner ring shows that Target 7.2 (by 2030, increase substantially the share of renewable energy in the global energy mix) is the most prioritized in India.⁶

Figure 1 | **Alignment of SDG 7 with India's Climate Actions**

Source: Stockholm Environment Institute, NDC-SDG Connections tool (SEI 2021).

To choose the combination of policies within our scenario that align with the existing linkages between India's NDCs and the SDGs, we further map the respective climate actions linked to each SDG to the set of sectoral decarbonization policies that are modelled within the India EPS. For instance, to leverage the most significant synergy identified in Figure 1—between Target 7.2 and India's NDC climate actions to promote clean and renewable power—we implement the carbon-free electricity standard in the EPS in the NDC-SDG scenario. The results of this mapping exercise are presented in Appendix B.

For each of the mapped EPS policies, we assume policy settings that are to be reached by 2030. Most policies are implemented linearly, beginning with partial achievement of the 2030 levels in the initial years and reaching full strength of implementation by 2030. Beyond 2030, the settings are constant, and the model behavior is additionally determined by the cost optimization logic in the electricity supply and transport sectors, as well as BAU input trajectory assumptions such as technology costs and fuel price projections. The settings for the policies modelled in the NDC-SDG Linkages scenario, with the accompanying rationale, are summarized in Appendix C.⁷

Long-Term Decarbonization Scenario

Scenario Set-Up: Description and Approach for Selection of Policies

In this scenario, we focus on policies that show a high potential for GHG emissions abatement and implement them to high levels of ambition by 2050, guided by international best practice. Taking a long-term view, this scenario also considers post-2030 implementation of technologies that are currently nascent. These policies include substitution of fossil fuels in industrial applications with a mix of hydrogen and electricity,⁸ production of green hydrogen through electrolysis using carbon-free electricity sources, carbon capture and storage (CCS) in industry and electricity sectors, and deployment of electric and hydrogen vehicles in the transport sector.

To create the Long-Term Decarbonization (LTD) scenario, we tested all sectoral policies in the India EPS by enabling each policy separately to shortlist individual policies that demonstrate the highest reductions in GHG emissions by 2050 relative to the BAU scenario. We then

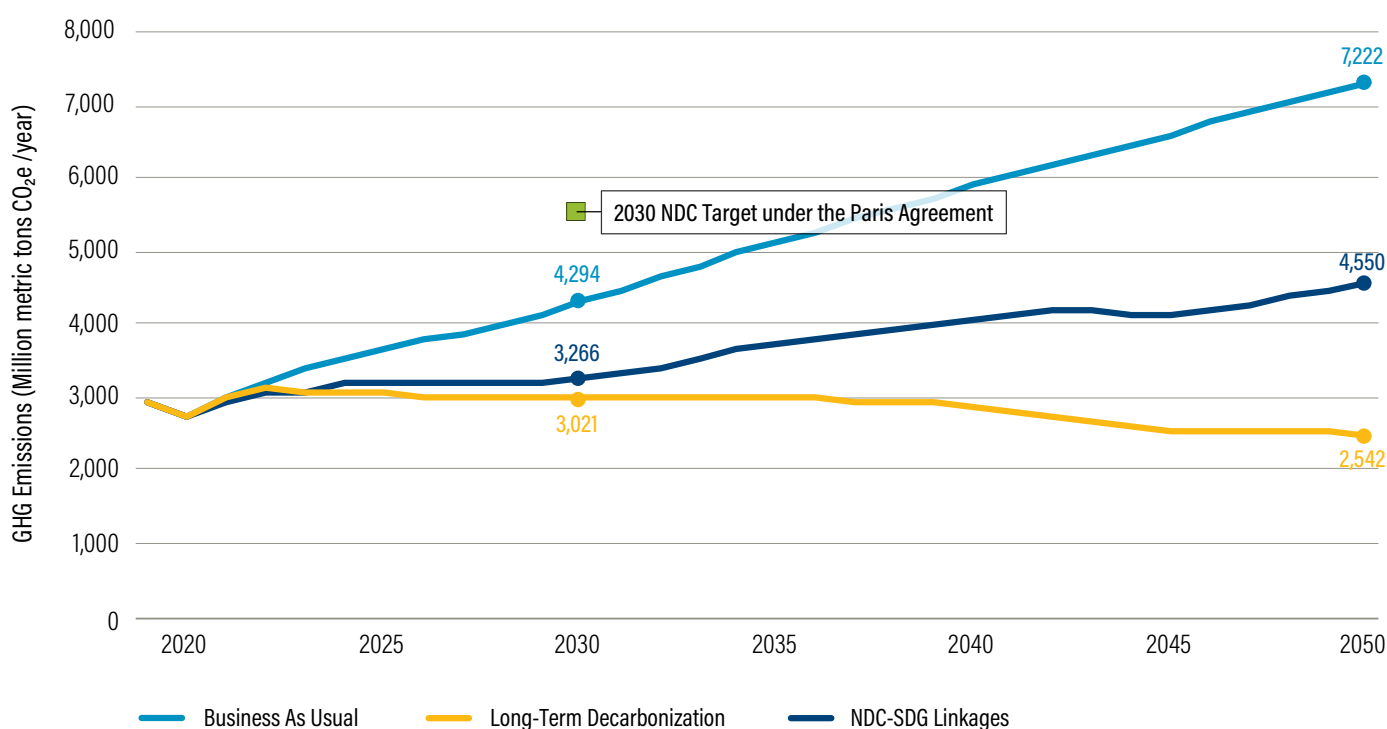
implemented the shortlisted policies (again, linearly for most policies) to attain 2050 policy settings to high levels of ambition. The settings for the important policies modelled in the LTD scenario, with the accompanying rationale, are summarized in Appendix C.⁹

Scenario Results

Emissions Abatement and Emissions Intensity of GDP

Total GHG emissions in the BAU scenario are projected to rise to 4,294 million metric tons (Mt) of carbon dioxide equivalent (CO₂e) in 2030 and 7,222 MtCO₂e in 2050.¹⁰ The NDC-SDG and LTD scenarios, respectively, achieve emission cuts of 24 percent and 30 percent relative to BAU emissions in 2030. The NDC-SDG scenario shows a continued rising trend in emissions until 2050. Emissions peak in 2022 in the LTD scenario and show a gradual decline thereafter, more so after 2040. In 2050, BAU emissions are reduced in the NDC-SDG and LTD scenarios by 37 percent and 65 percent, respectively (see Figure 2 and Table 1).

Figure 2 | GHG Emissions (Including Land-Use) in BAU, NDC-SDG, and LTD Scenarios



Source: Authors, using India EPS 2021.

Table 1 | Reductions in CO₂e Emissions, CO₂ Emissions, and Emissions Intensity of GDP

	CO ₂ e EMISSIONS IN 2030 (Mt)	REDUCTION FROM BAU LEVEL (%)	CO ₂ e EMISSIONS IN 2050 (Mt)	REDUCTION FROM BAU LEVEL (%)
BAU	4,294	n/a	7,222	n/a
NDC-SDG	3,266	24%	4,550	37%
LTD	3,021	30%	2,542	65%
	CO ₂ EMISSIONS IN 2030 (Mt)	REDUCTION FROM BAU LEVEL (%)	CO ₂ EMISSIONS IN 2050 (Mt)	REDUCTION FROM BAU LEVEL (%)
BAU	3,305	n/a	5,814	n/a
NDC-SDG	2,500	24%	3,513	40%
LTD	2,226	33%	1,379	76%
Base level (2005) ^a	18.49 gCO ₂ e/2018 INR ^b			
	EMISSIONS INTENSITY OF GDP IN 2030 (gCO ₂ e/2018 INR)	REDUCTION FROM 2005 LEVEL (%)	EMISSIONS INTENSITY OF GDP IN 2050 (gCO ₂ e/2018 INR)	REDUCTION FROM 2005 LEVEL (%)
BAU	9.49	49%	7.04	62%
NDC-SDG	7.22	61%	4.52	76%
LTD	6.61	64%	2.44	87%

Notes:

^a In its NDC, India committed to reducing the emissions intensity of its GDP by 33 to 35 percent by 2030, as compared to 2005 levels. In the absence of detailed source-wise GHG emissions inventory data for 2005, we interpolate between official GHG inventory data published for 2000 and 2007. F-gases are not included in the 2007 inventory so are separately factored in from independent published country level estimates for India. India's Biennial Update Reports have not included agricultural GHG emissions when estimating the reduction in emission intensity of GDP. However, India's NDC does not specify that agriculture is excluded from the target and is included for estimating the target here. India's official estimates use global warming potentials (GWP) from IPCC AR2, whereas the EPS uses newer GWP values from IPCC AR5. Historical GDP value for 2005 is based on World Bank's real GDP series for India (constant 2010–11 prices).

^b Grams of carbon dioxide equivalent per 2018 Indian rupee.

Source: Authors.

Significant reductions are also observed in the long term in CO₂ emissions and the emissions intensity of GDP. India's unconditional NDC target of reducing emissions intensity of GDP by 33 to 35 percent over 2005 levels by

2030 is surpassed in the BAU scenario itself. However, further reductions are seen in both the NDC-SDG and LTD scenarios (Table 1).

Policy Contributions to GHG Emissions Abatement

NDC-SDG Scenario

For the NDC-SDG scenario, the contributions of the various policies through 2050 can be visualized in Figure 3.

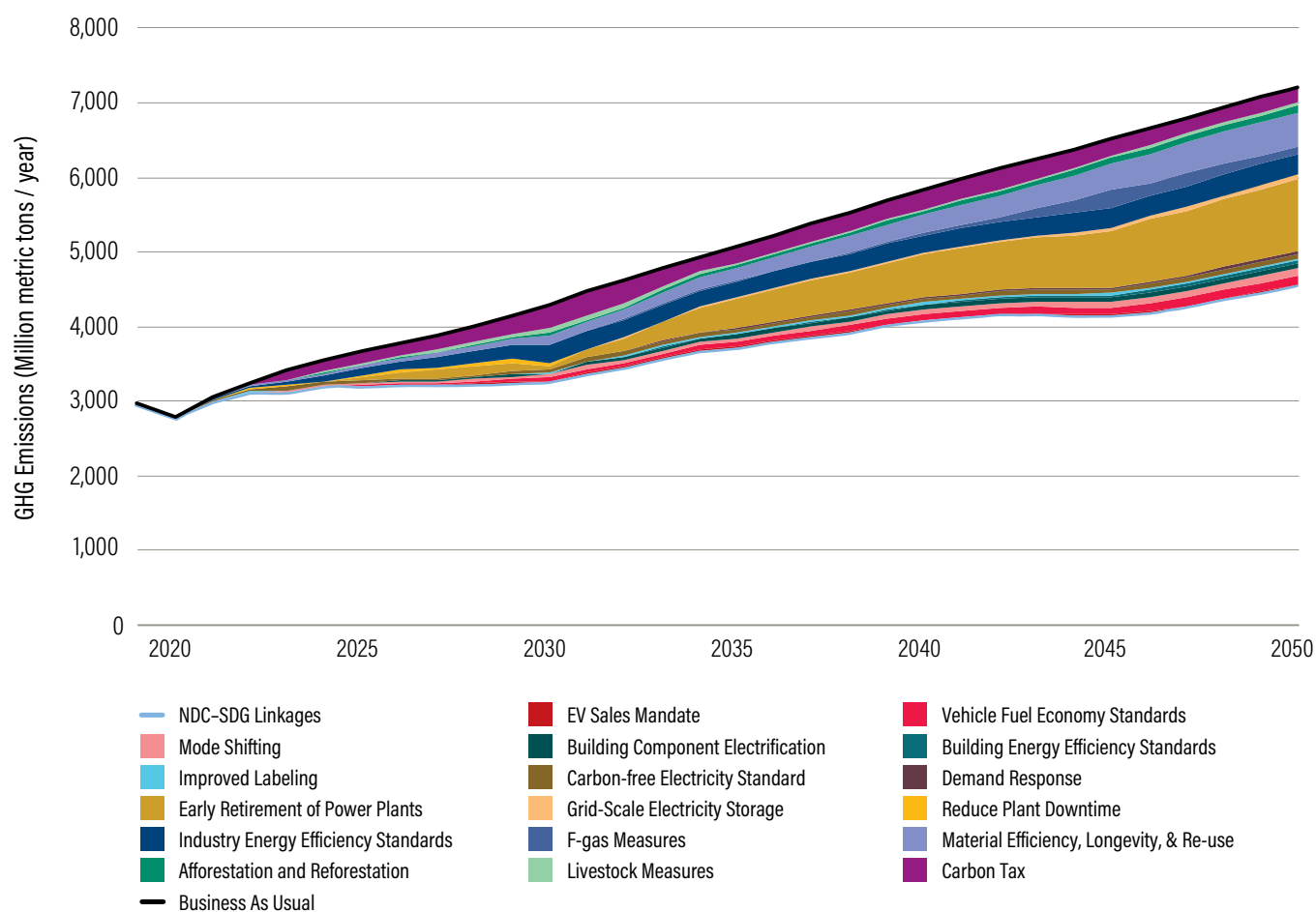
By 2030, 67 percent of total GHG emissions reductions of approximately 690 MtCO₂e can be achieved through just three policies: an industrial carbon tax (with 30 percent contribution); industrial energy efficiency standards (25 percent); and reduction of demand for cement, iron and steel, and wastewater treatment through material efficiency, longevity, and re-use (12 percent). In the long run, of the total GHG emissions abated in 2050, nearly 65 percent contribution (about 1,710 MtCO₂e) comes

from the early retirement of otherwise non-retiring coal power plants (36 percent), along with material efficiency (17 percent) and implementation of industrial energy efficiency standards (11 percent).

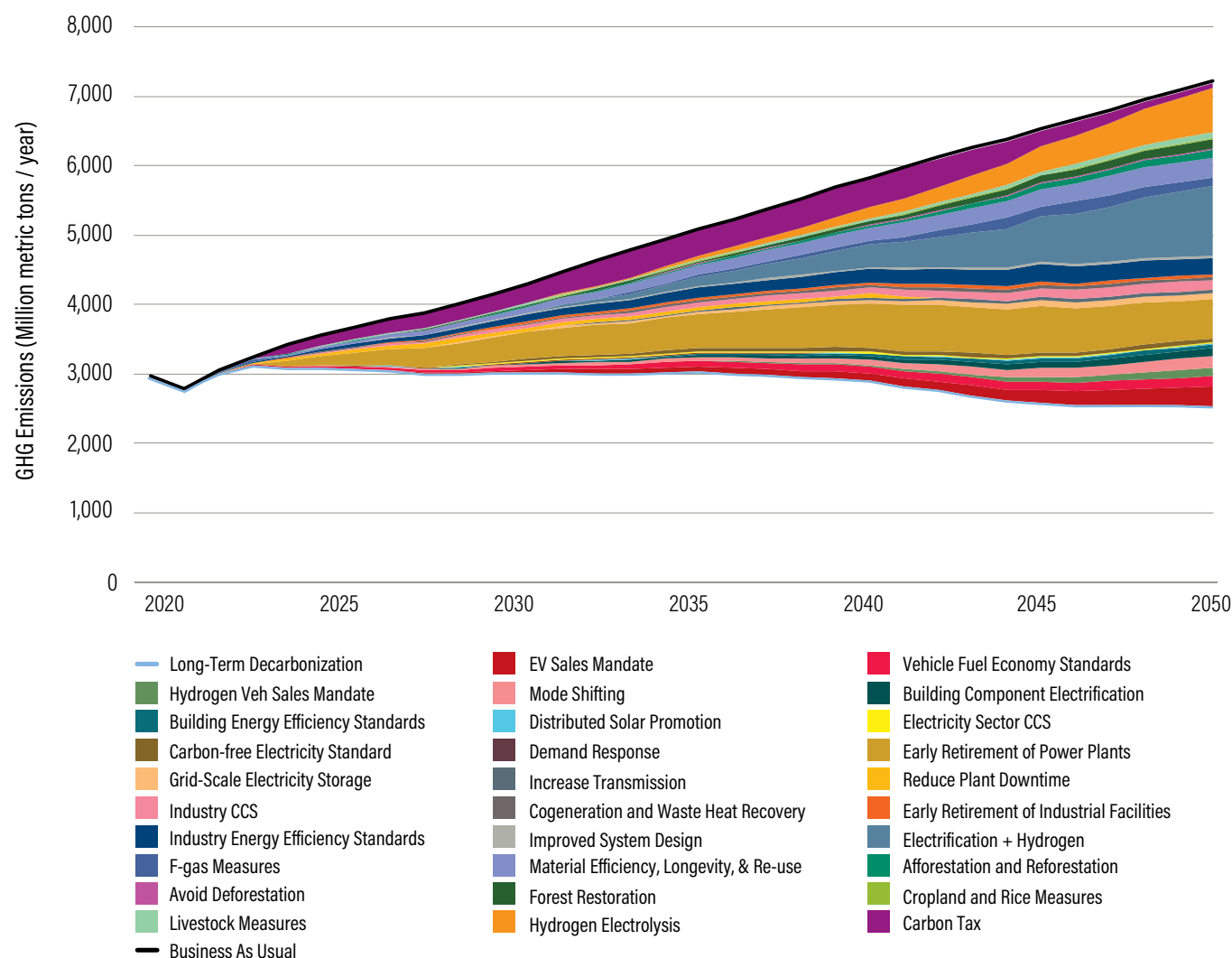
LTD Scenario

In the LTD scenario, 47 percent of the total GHG emissions reductions in 2050 (approximately 2,200 MtCO₂e) can be achieved through three policies implemented at ambitious levels. These include switching fossil fuel used in industrial facilities to a mixture of electricity and hydrogen (22 percent), production of hydrogen through electrolysis supported by carbon-free electricity generation (14 percent), and early retirement of otherwise non-retiring coal plants (12 percent) (Figure 4).

Figure 3 | Policy Contributions to Annual GHG Emissions (CO₂e) Abatement in the NDC-SDG Scenario



Source: Authors, using EPS India Model.

Figure 4 | Policy Contributions to Annual GHG Emissions (CO₂e) Abatement in the LTD Scenario

Source: Authors, using EPS India Model.

Shifting hydrogen production to electrolysis for meeting hydrogen demand is important for this deep decarbonization scenario because producing hydrogen via the default pathway using natural gas has an emissions intensity of 8 to 12 kilograms (kg) of CO₂ per kilogram of hydrogen produced (Blank and Molly 2020). Also, for ensuring emissions reductions from hydrogen electrolysis, it is critical to simultaneously implement clean electricity generation policies. Otherwise, the electricity demand for hydrogen electrolysis could be met through coal-based generation, which could ultimately increase emissions relative to BAU.

The early coal retirement policy could also be particularly impactful in the shorter term if implemented immediately from 2021, retiring all pre-existing coal capacity by 2032. The model would continue to build some new coal power plants to meet the electricity needs of the demand sectors based on the cost optimization logic in the electricity supply sector and planned retirements as per the National Electricity Plan (CEA 2018). However, we see coal capacity eventually phased out by 2042, due to the increasing cost competitiveness of variable renewable energy (VRE) technologies as well as the carbon-free electricity standard (CES) policy enacted in the LTD scenario. Policies with significant contribution to emissions abatement in 2030 and 2050 in both scenarios are tabulated in Appendix E.

The above results capture the economy-wide impacts of the scenarios. Table 2 shows the GHG emissions reductions by sector, relative to BAU in both scenarios.

In each sector, a handful of effective policies contribute to most of the emissions reductions in the 2030 and

2050 target years. The sector-wise policies that are most effective in reducing GHG emissions for the energy consuming sectors in both scenarios are listed in Table 3 below.

Table 2 | **GHG Emissions Reductions by Sector**

SECTOR	GHG EMISSIONS REDUCTIONS RELATIVE TO BAU (MtCO ₂ e AND % REDUCTIONS)							
	NDC-SDG				LTD			
	IN 2030	REDUCTIONS	IN 2050	REDUCTIONS	IN 2030	REDUCTIONS	IN 2050	REDUCTIONS
Agriculture	67	9%	63	6%	39	5%	129	12%
Buildings	34	18%	74	40%	19	10%	109	58%
Transport	80	15%	206	18%	109	21%	641	57%
Electricity	358	34%	1,031	83%	564	53%	1,124	91%
Industry	459	25%	1,157	32%	508	27%	2,430	67%
Land	17	6%	83	28%	22	7%	188	63%

Source: Authors.

Table 3 | **Policies Contributing to Most Sectoral Emissions Abatement in 2030 and 2050^a**

SECTOR	EFFECTIVE MID-TERM POLICIES CONTRIBUTING TO AT LEAST 75% SECTORAL EMISSIONS REDUCTIONS IN NDC-SDG SCENARIO (2030)	EFFECTIVE LONG-TERM POLICIES CONTRIBUTING TO AT LEAST 75% SECTORAL EMISSIONS REDUCTIONS IN LTD SCENARIO (2050)
Agriculture	<ul style="list-style-type: none"> ▪ Livestock Measures ▪ Industry Energy Efficiency Standards^b 	<ul style="list-style-type: none"> ▪ Livestock Measures ▪ Electrification
Buildings	<ul style="list-style-type: none"> ▪ Building Component Electrification ▪ Improved Labeling 	<ul style="list-style-type: none"> ▪ Building Component Electrification
Electricity	<ul style="list-style-type: none"> ▪ Carbon-free Electricity Standard ▪ Early Retirement of Power Plants (Coal) ▪ Reduce Plant Downtime 	<ul style="list-style-type: none"> ▪ Early Retirement of Power Plants (Coal) ▪ Grid-Scale Electricity Storage ▪ Demand Response
Industry	<ul style="list-style-type: none"> ▪ Carbon Tax ▪ Industry Energy Efficiency Standards ▪ Material Efficiency Longevity and Re-use 	<ul style="list-style-type: none"> ▪ Electrification and Hydrogen ▪ Industry Energy Efficiency Standards ▪ Material Efficiency Longevity and Re-use
Transport	<ul style="list-style-type: none"> ▪ Vehicle Fuel Economy Standards ▪ Mode Shifting 	<ul style="list-style-type: none"> ▪ Electric Vehicle (EV) Sales Mandates ▪ Mode Shifting ▪ Hydrogen Vehicle Sales Mandate ▪ Vehicle Fuel Economy Standards

Notes: ^a The sectoral policies listed here are more effective in relative terms. In some cases, the absolute emissions abated from some of these policies need not be significant. For instance, the emissions abated from the improved labeling policy, which reduces the energy use of specific appliances based on the improvements between consecutive efficiency bands of Bureau of Energy Efficiency's (BEE) Standards & Labeling (S&L) program, is about 10 MtCO₂e in 2030, which is less than 1 percent of the total abatement from the NDC-SDG scenario in that year. This is because the emissions cuts are relative to BAU, which has a lot of new wind and solar. Therefore, a lot of the new electricity demand from the buildings sector is being met by zero-carbon resources. Reducing that electricity demand through the efficiency policy is displacing some coal generation—but it is also displacing clean electricity generation, which has no emissions impact. For that reason, there is less of an emissions impact from buildings efficiency policies as the power sector increases its share of clean generation. However, efficiency measures are cost effective. They lead to significant savings over time from avoided fuel expenditures and a reduced need for new electricity capacity.

^b The industrial efficiency standard applies to end-use energy consumption in the agriculture sector mainly from use of electricity, diesel, and liquefied petroleum gas (LPG). The policy reduces fuel consumption by the agriculture sector by increasing the efficiency of industrial equipment (such as agricultural pumpsets) through stronger standards.

Source: Authors.

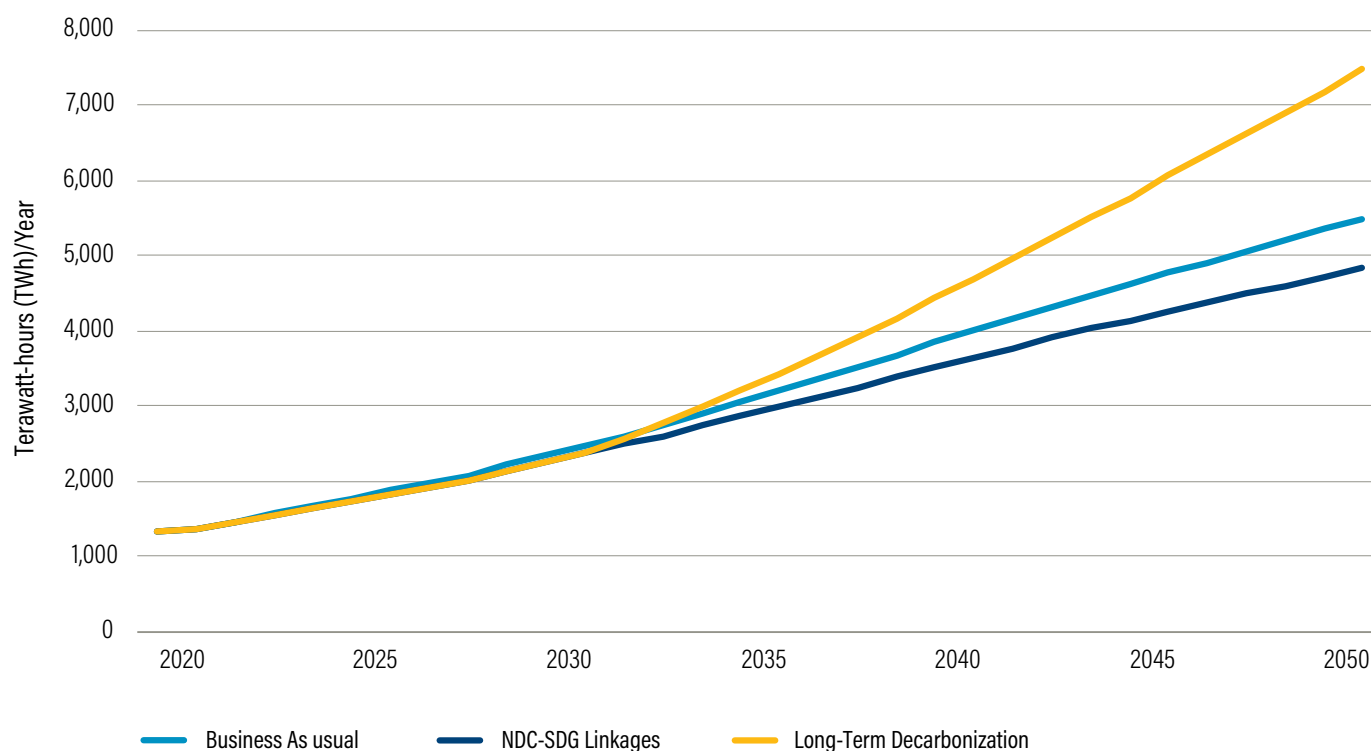
Electricity Consumption, Capacity, Generation, and Costs

By 2030, net electricity consumption in the economy is projected to marginally reduce relative to BAU in both NDC-SDG and LTD scenarios due to electricity savings from the implementation of demand-side efficiency measures that outweigh increased electricity demand from gradual implementation of end-use electrification policies.¹¹ This trend continues through 2050 in the NDC-SDG scenario as energy efficiency policies continue to be implemented in the industry and buildings sectors. In the LTD scenario, however, electricity consumption increases by 48 percent over BAU levels to reach about 7,461 terawatt-hours (TWh) in 2050 (Figure 5). This is largely driven by increased electricity demand for industrial applications and electric vehicles (EVs). Further, there is increased electricity demand for production of hydrogen through electrolysis, as hydrogen and electricity substitute fossil fuel use in the industry sector.

There is a significant share of VRE, such as wind and solar, in installed capacity deployed within the BAU case itself (45 percent in 2030, 68 percent in 2050), which increases in the NDC-SDG scenario to 51 percent

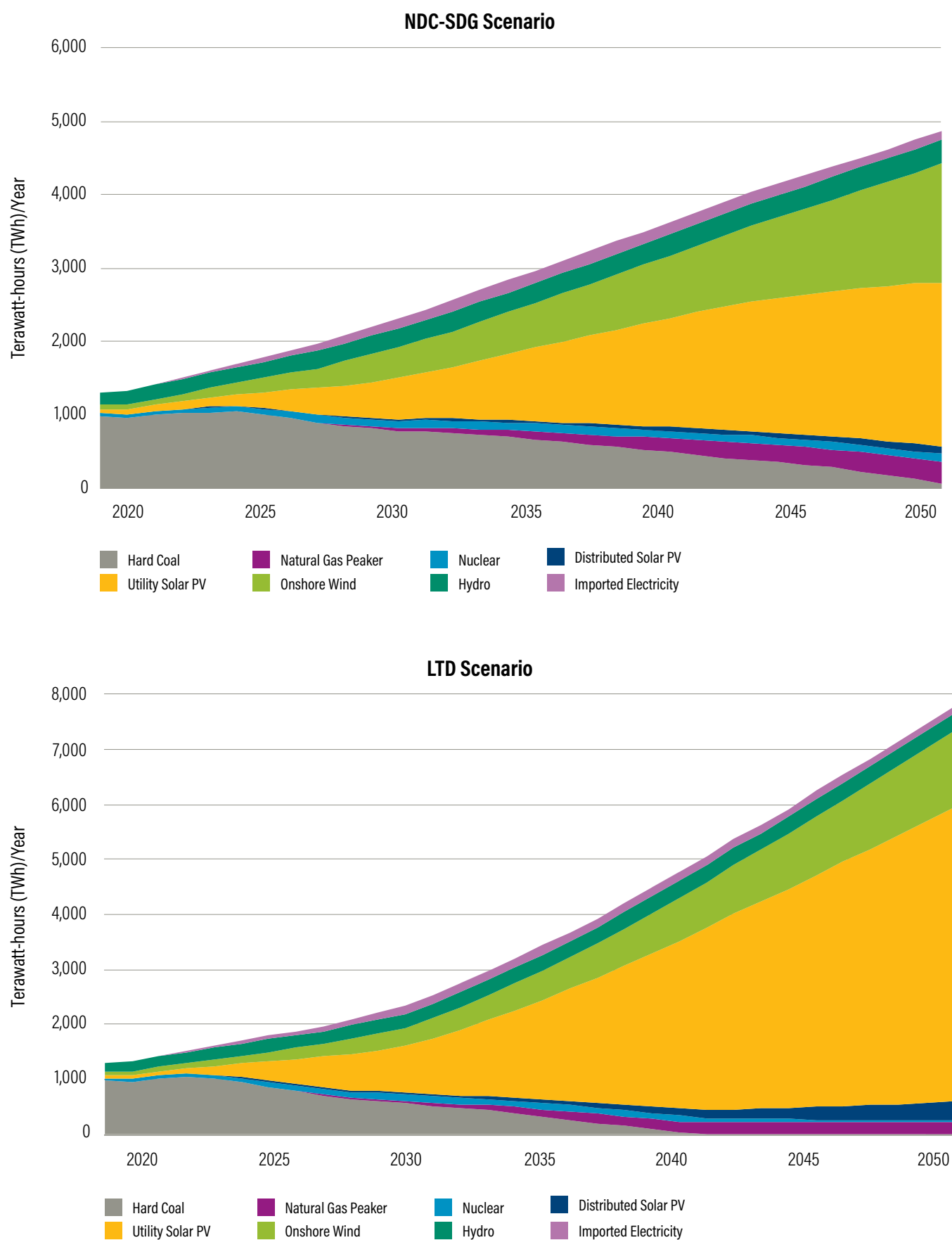
(2030) and 75 percent (2050), and in the LTD scenario to 61 percent (2030) and 85 percent (2050). In terms of electricity generation, in the NDC-SDG scenario, implementing the CES¹² ensures approximately 59 percent of the total electricity is generated from fossil-free sources by 2030, including wind, solar, hydro, nuclear, and municipal solid waste. Additionally, recent state-level announcements from Chhattisgarh and Gujarat have indicated plans to halt the addition of new coal capacity (Climate Trends 2019). In the NDC-SDG scenario, extending this intervention and considering the increasing cost competitiveness of wind and solar generation technologies, otherwise non-retiring coal capacity is gradually retired by 7,000 megawatts (MW) per year starting in 2030 and continuing at the same rate through 2050. With other supporting policies that encourage technological improvements in VRE technologies to reduce plant downtime, increase in demand response capacity, augmentation of grid-scale electricity storage, and reduction in transmission and distribution (T&D) losses, the share of fossil-free sources in domestic generation reaches 89 percent by 2050 (Figure 6).¹³

Figure 5 | Electricity Consumption over Time in BAU, NDC-SDG, and LTD Scenarios



Source: Authors, using EPS India Model.

Figure 6 | Electricity Generation over Time in NDC-SDG and LTD Scenarios



Source: Authors, using EPS India Model.

In the LTD scenario, the retirement of coal capacity by 7,000 MW per year begins from 2021. Coupled with a high CES target of 75 percent by 2050 and higher levels of ambition in supporting policies for VRE deployment discussed above, the share of fossil-free sources in domestic generation increases to 92 percent in 2050, and new coal capacity is completely phased out by 2042 (Figure 6). The sources of installed capacity and generation in 2030 and 2050 for each scenario are listed in Appendix D.

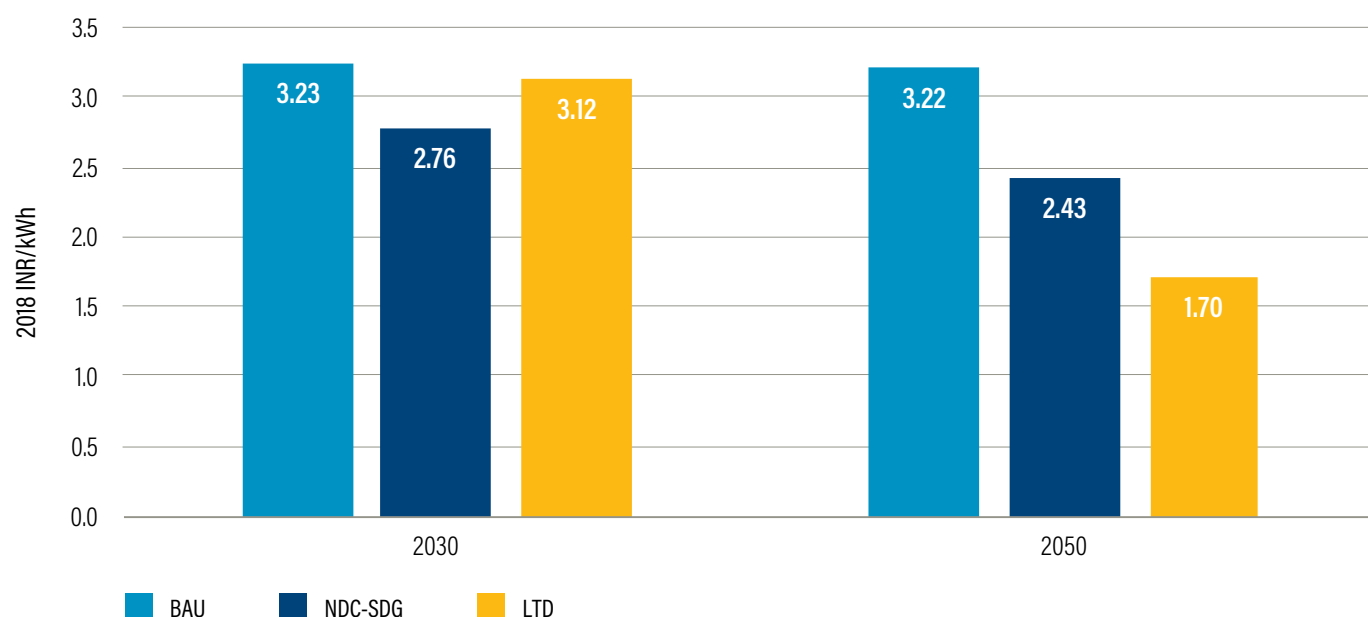
Over the model run, the levelized costs of electricity (LCOE) from VRE sources decrease with falling technology costs and supporting subsidies, while the LCOE of fossil-based sources (coal and natural gas)

increase due to rising fuel costs, partly driven by an increasing carbon tax rate over time. As a result, we see an overall decline in the generation-weighted average LCOE as the share of VRE generation increases in both scenarios, relative to BAU (Figure 7).¹⁴ The sources of LCOE for all scenarios are listed in Appendix D.

Primary Energy Consumption by Fuel, Energy-related CO₂ Emissions, Energy Intensity of GDP

Both the NDC-SDG and LTD scenarios show a decreasing reliance on primary energy from fossil fuels and increasing use of renewable energy sources due to clean energy and energy efficiency policies (Figure 8).

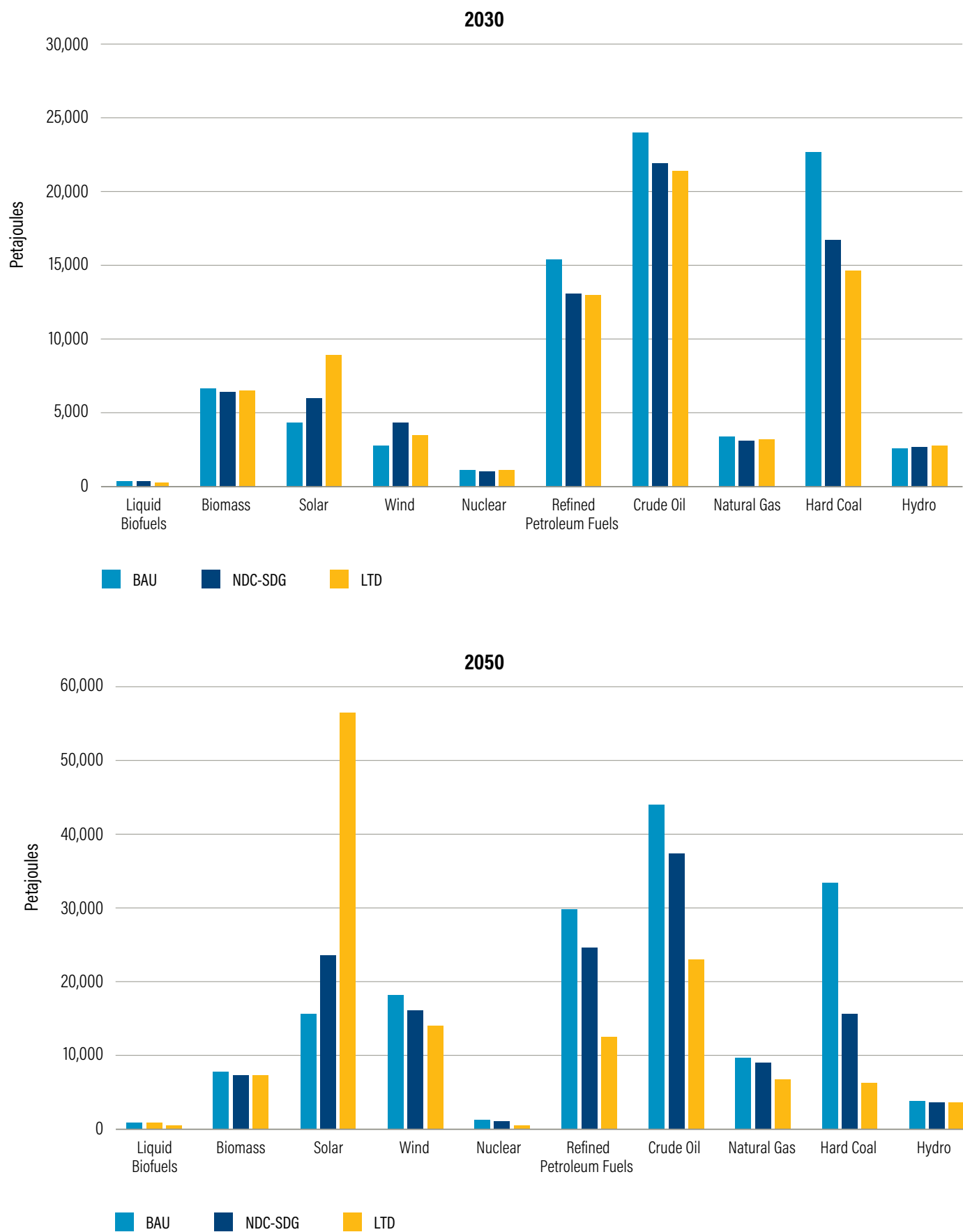
Figure 7 | **Generation-Weighted LCOE in BAU, NDC-SDG, and LTD Scenarios**



Note: LCOE is expressed as 2018 INR per kilowatt-hour, or 2018 INR/kWh. 68.42 INR = 1 USD (in 2018).

Source: Authors.

Figure 8 | **Primary Energy Consumption by Fuel Type**

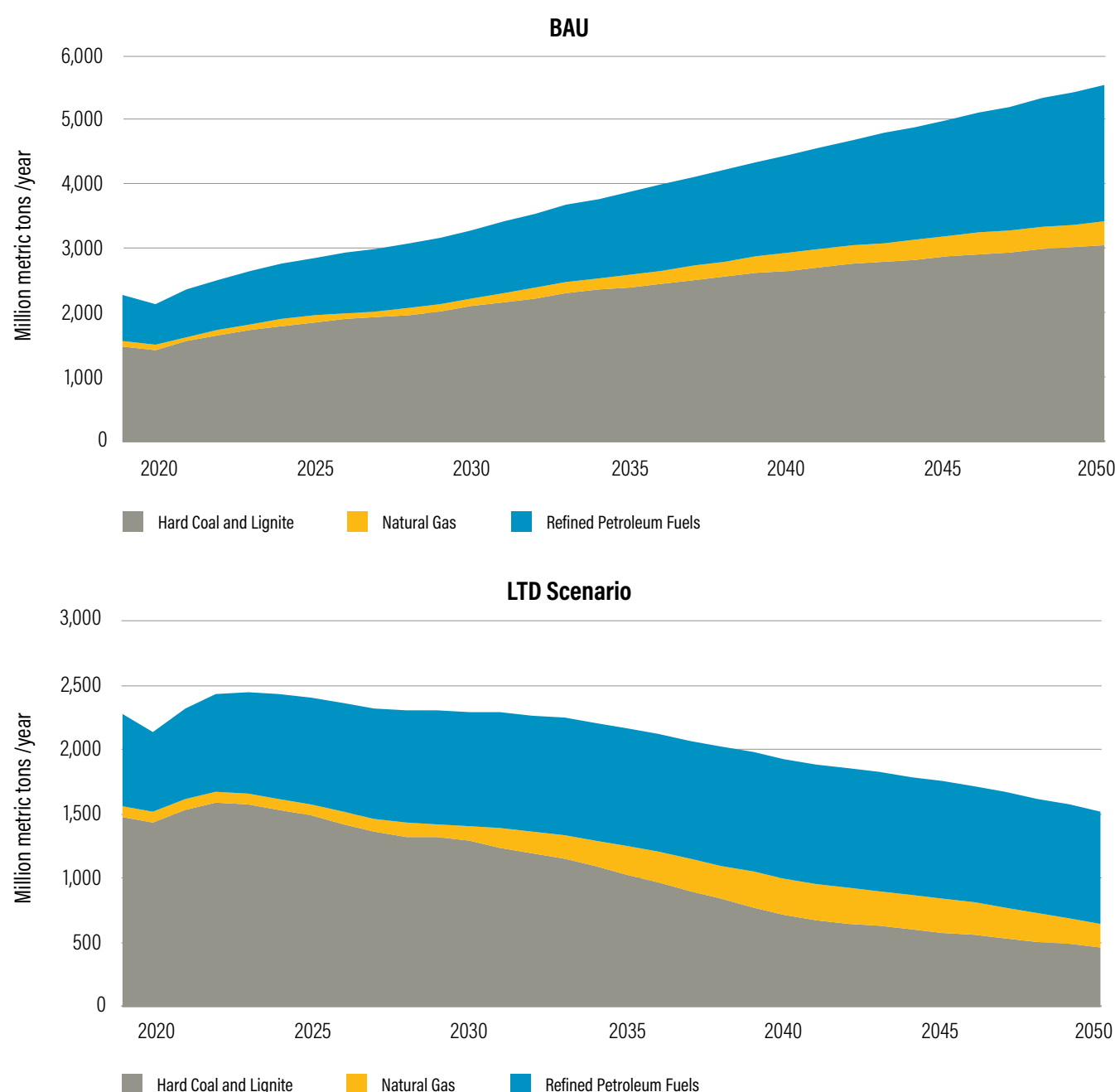


Source: Authors.

Relative to BAU, primary energy consumption from fossil-free sources—predominantly from utility scale solar photovoltaic (PV), followed by contributions from wind, large hydro, and nuclear—increases by 14 percent and 93 percent in 2050 in the NDC-SDG and LTD scenarios, respectively. In the LTD scenario, this increase is largely driven by a significant increase in solar-based electricity generation. Primary energy consumption from fossil fuels (refined petroleum products, crude oil, natural gas, and coal) decreases from BAU by 26 percent and 59 percent in 2050 in the NDC-SDG and LTD scenarios, respectively.

The transition away from fossil fuels towards renewable energy (RE) sources results in significant decline in CO₂ emissions, especially in the long run. In the LTD scenario, energy-related CO₂ emissions peak at 2,439 Mt in 2023 and decline by 38 percent from the peaking value in 2050. Relative to BAU, in which we do not see CO₂ emissions peaking within the model timeframe, the LTD scenario results in a 73 percent cut in energy-related CO₂ emissions in 2050 (Figure 9).

Figure 9 | **Energy-Related CO₂ Emissions by Fuel Type**

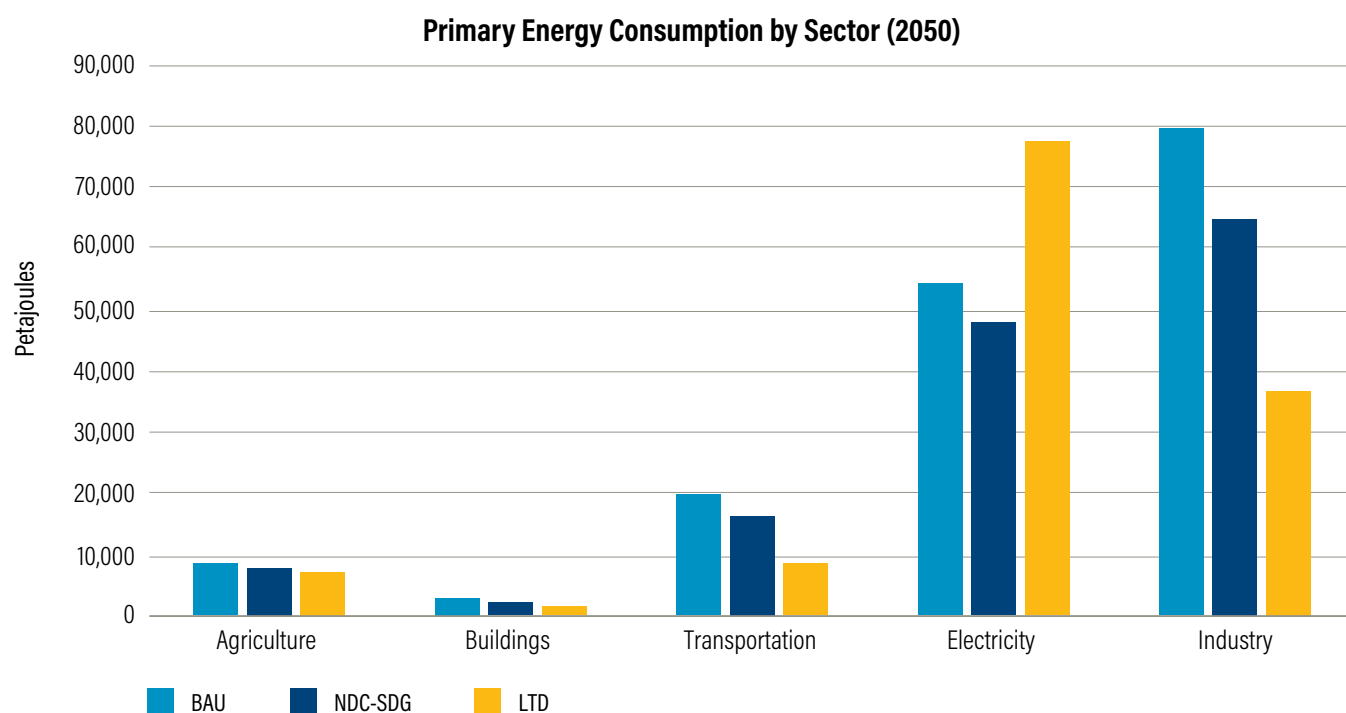


Source: Authors, using EPS India Model.

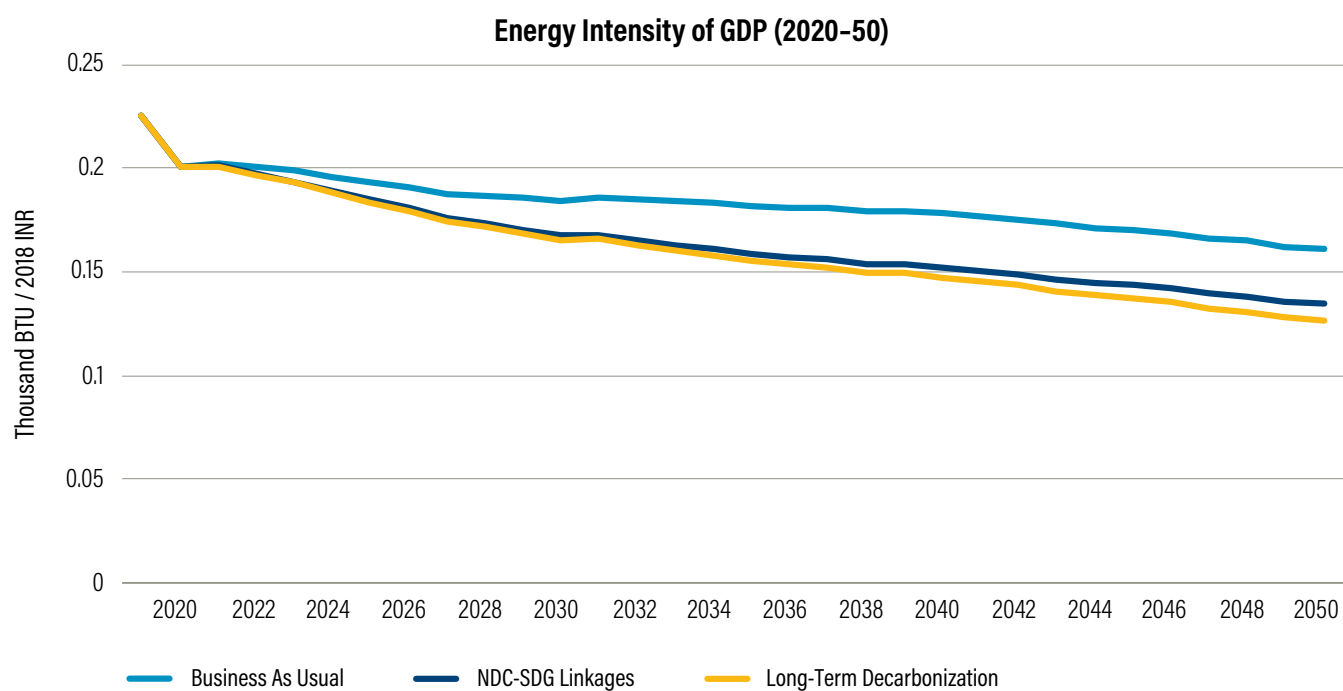
Due to energy and material efficiency policies, overall primary energy consumption in the economy decreases in 2050 (relative to BAU) by 15 percent and 20 percent in the NDC-SDG and LTD scenarios, respectively, largely driven by reduction in industrial and transport

sector energy consumption (Figure 10). This leads to an improvement in the energy intensity of GDP in the economy in the LTD scenario, especially beyond 2030 (Figure 10).

Figure 10 | **Energy Consumption and Energy Intensity of GDP for BAU, NDC-SDG, and LTD Scenarios**



Source: Authors.



Note: 68.42 INR = 1 USD (in 2018).

Source: Authors, using EPS India Model.

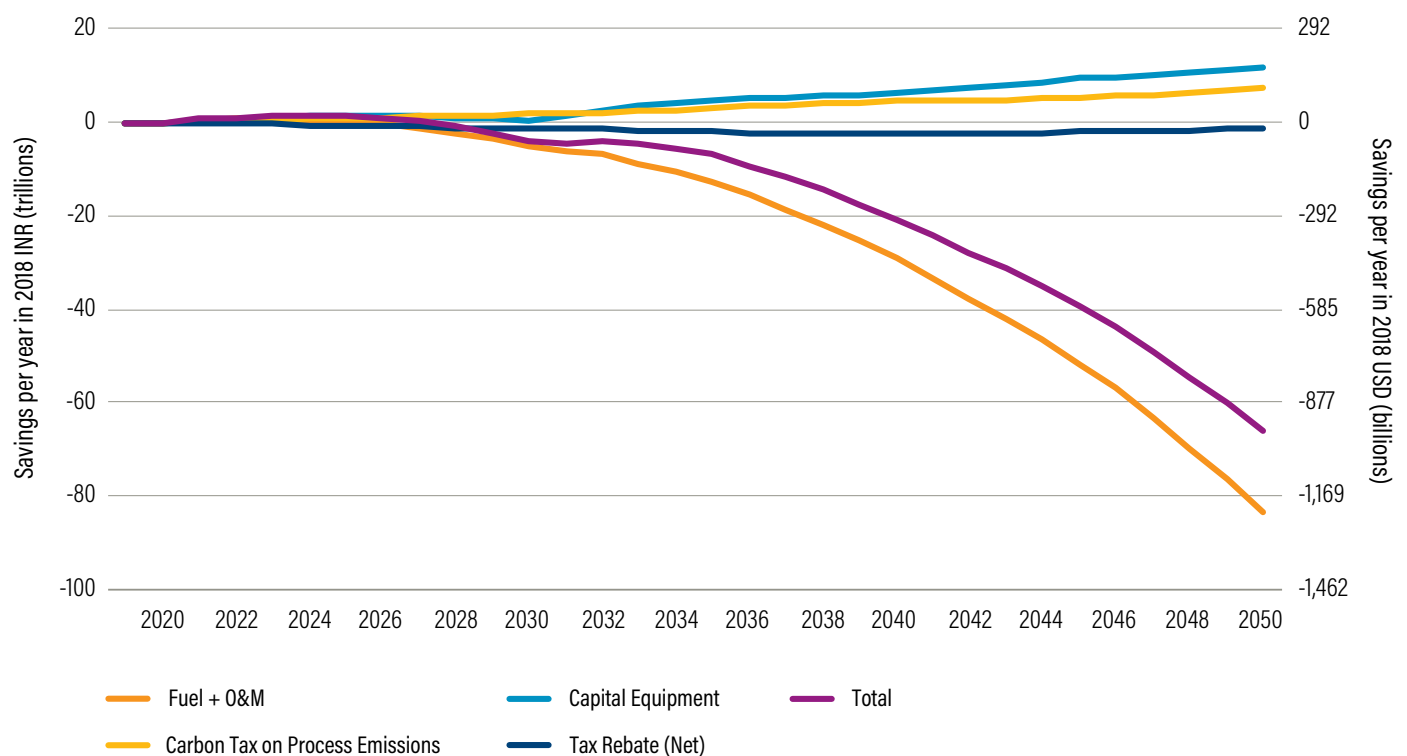
Scenario Costs and Policy Cost Effectiveness

The EPS represents various cost metrics for any scenario. In this analysis, we consider two important cost metrics: the total costs of a scenario and the relative cost-effectiveness of individual policies.

The total net costs (or savings) of a scenario can be represented by the overall change in capital and operational expenditures, relative to BAU, from implementing the combination of policies in the scenario.¹⁵ As most decarbonization policies are phased in linearly in our scenarios, expenditures on capital equipment increase at a gradual pace over time. At the

same time, more and more fossil fuel is displaced as there is more cumulative instalment of clean energy technologies and energy efficiency standards are strengthened. This results in an increasing rate of savings from avoided coal expenditures in power plants and avoided petrol and diesel expenditures in vehicles. These savings outweigh the increased spending on capital equipment (such power plants and vehicles) and carbon taxes¹⁶ over time, resulting in overall savings relative to BAU in the medium to long term.

Figure 11 | **LTD Scenario Change in Capital Expenditures and Operating Expenses Relative to BAU**



Source: Authors, using EPS India Model.

On comparing the total costs of the NDC-SDG and LTD scenarios, we find that both scenarios lead to increasing net savings over time relative to BAU (Figure 12).

The NDC-SDG scenario shows net savings as early as 2024. Short-term expenditures are higher in the LTD scenario due to higher capital expenses from the deployment of clean technologies. Additionally, compared to the NDC-SDG scenario, fuel savings accrue more slowly in the LTD scenario in the initial years as decarbonization and efficiency policy settings are phased in more gradually over a longer timeframe (until 2050). However, the LTD scenario begins to show net savings in 2028 and results in higher long-term savings compared to the NDC-SDG scenario from 2038 onward. Total savings in each scenario relative to BAU are summarized in Table 4.

Table 4 | Total Savings in Capital Expenditures and Operating Expenses, Relative to BAU (Trillion INR)

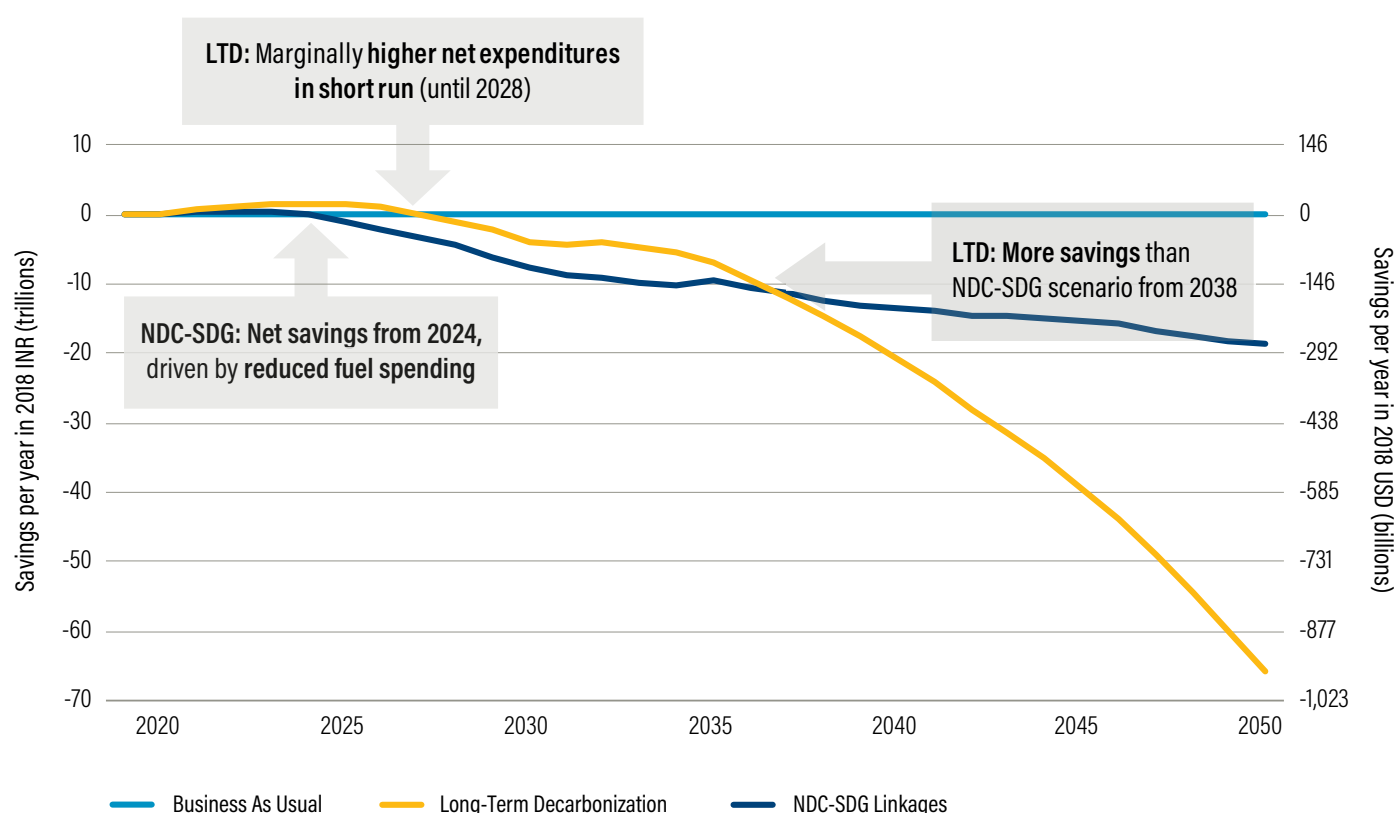
	IN 2030	IN 2050
NDC-SDG Scenario	7.8	18.7
LTD Scenario	4.0	66.0

Note: Estimates provided according to the 2018 rate of the Indian rupee.
68.42 INR = 1 USD (in 2018).

Source: Authors.

Additionally, the cost-effectiveness of individual policies can be a valuable indicator for policymakers to prioritize decisions on targeting investments and resources for planning policy and implementation timelines.

Figure 12 | LTD and NDC-SDG Scenario Change in Total Capital Expenditures and Operating Expenses Relative to BAU



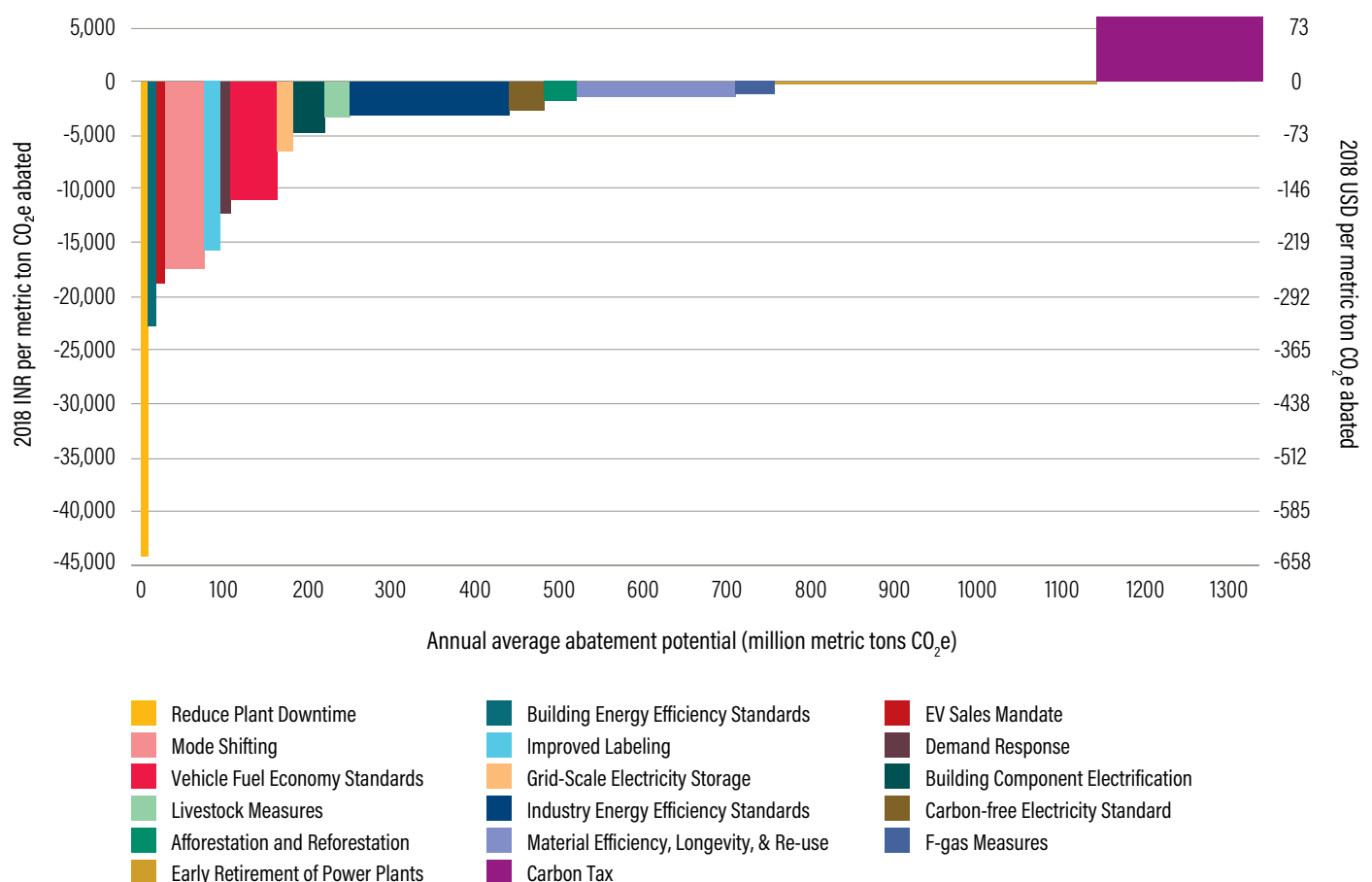
Source: Authors, using EPS India Model.

The EPS estimates the cost-effectiveness of each policy in a scenario in terms of the annual average cost per metric ton of CO₂e abated (Figure 13).¹⁷

Figure 13 shows the CO₂e abatement cost curve for policies in the NDC-SDG scenario through 2030. The least-cost policy with net savings (costs below y-axis) is the policy to reduce T&D losses. If we consider the annual average abatement potential as well, one of the most cost-effective policies—bringing with it significant annual CO₂e abatement—is the mode shifting policy in the transport sector, with an approximate savings of INR 32,000 per metric ton of CO₂e abated. In this policy, significant fuel and vehicle cost savings are achieved by 2030 by shifting 15 percent of the passenger car travel demand to buses and 10 percent of road-

based freight travel demand to more efficient freight rail corridors. The industrial carbon tax is most effective in reducing CO₂e emissions, with an annual average abatement potential of 129 MtCO₂e. In the NDC-SDG scenario, we see significant abatement if a carbon tax is applied to the industry sector and phased in to approximately INR 1,300 per metric ton of CO₂e (tCO₂e) by 2030, a factor of about five times higher than the current equivalent carbon tax rate from the goods and services tax (GST) compensation cess of INR 400 levied per metric ton of coal¹⁸ (IISD n.d.). Some of the other cost-effective policies in the NDC-SDG scenario are vehicle fuel economy standards, improved labeling of building appliances, reduced plant downtime, industrial energy efficiency standards, and material efficiency, longevity, and re-use.

Figure 13 | CO₂e Abatement Cost Curve for Policies in the NDC-SDG Scenario (Net Present Value through 2030)



Source: Authors, using EPS India Model.

In the LTD scenario, the mode shifting policy in the transport sector emerges to be the least cost policy per metric ton of CO₂e abated (net present value through 2050), with net savings of about INR 16,000/tCO₂e abated (Figure 14). The maximum reduction in emissions comes from the early retirement policy for coal plants, with an annual average abatement potential of 425 MtCO₂e. Other cost-effective policies in the LTD scenario include building energy efficiency standards, vehicle fuel economy standards, EV sales mandates, reduced plant downtime, industrial energy efficiency standards, and material efficiency, longevity, and re-use.

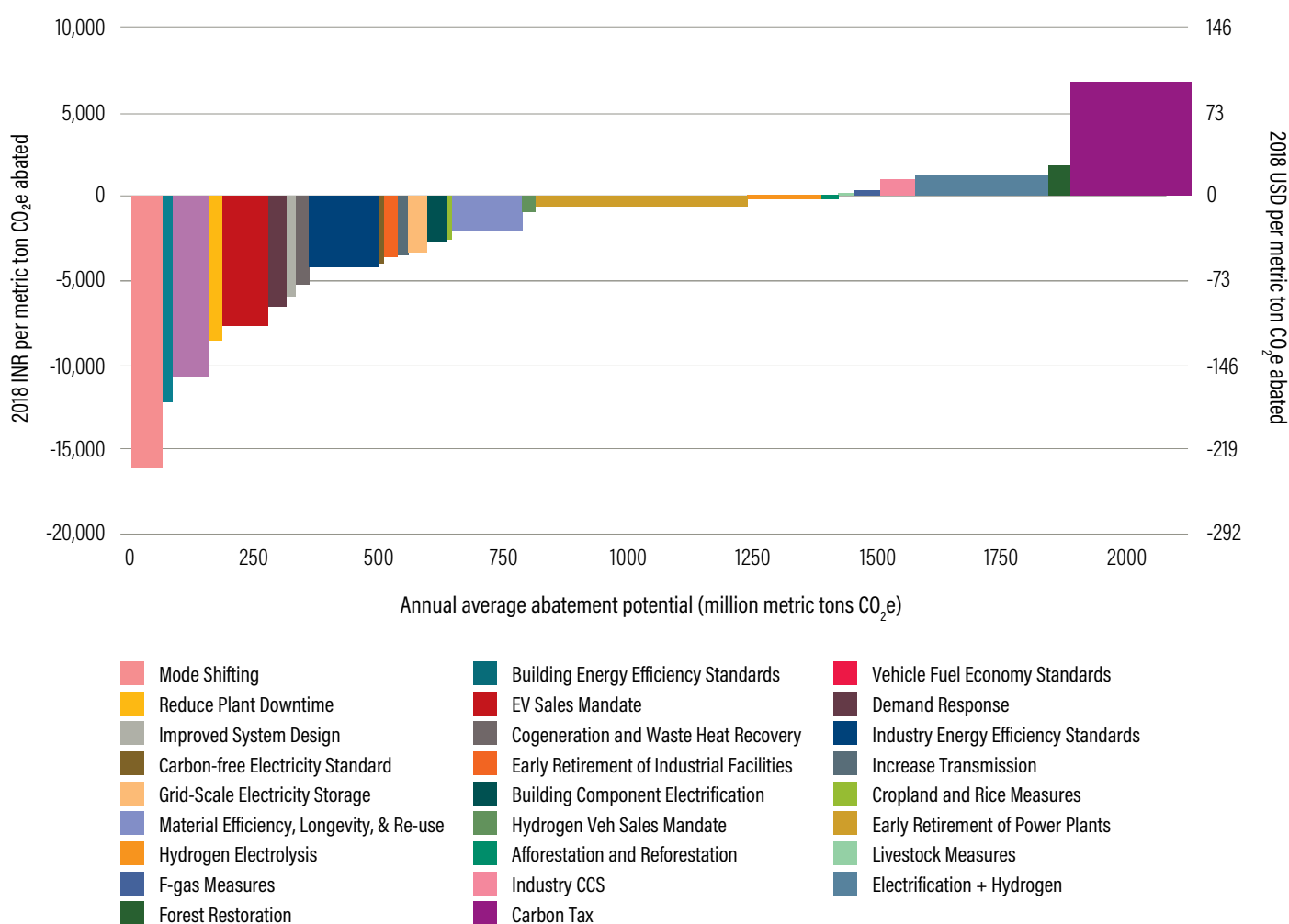
In general, the lowest cost policies are those with the most fuel savings (like efficiency policies). Their cost effectiveness increases in the longer term as fuel savings build up. Some of the more expensive policies in both

scenarios are concentrated in the electricity sector.¹⁹ Policies that focus on newer technologies, like hydrogen, that are still early in the commercialization pipeline, are also more expensive. Research and development (R&D) investments and government support for these technologies can help further bring down costs.

Impacts on Jobs and GDP

The EPS estimates the impacts of a scenario on jobs and GDP based on direct, indirect, and induced impacts on economic activity.²⁰ Direct economic impacts are within an affected industry because of a policy. For instance, if a policy causes the electricity supply industry to grow, then the industry would hire more workers as a direct consequence. Indirect economic impacts are those within the suppliers of the directly affected industry,

Figure 14 | CO₂e Abatement Cost Curve for Policies in the LTD Scenario (Net Present Value through 2050)

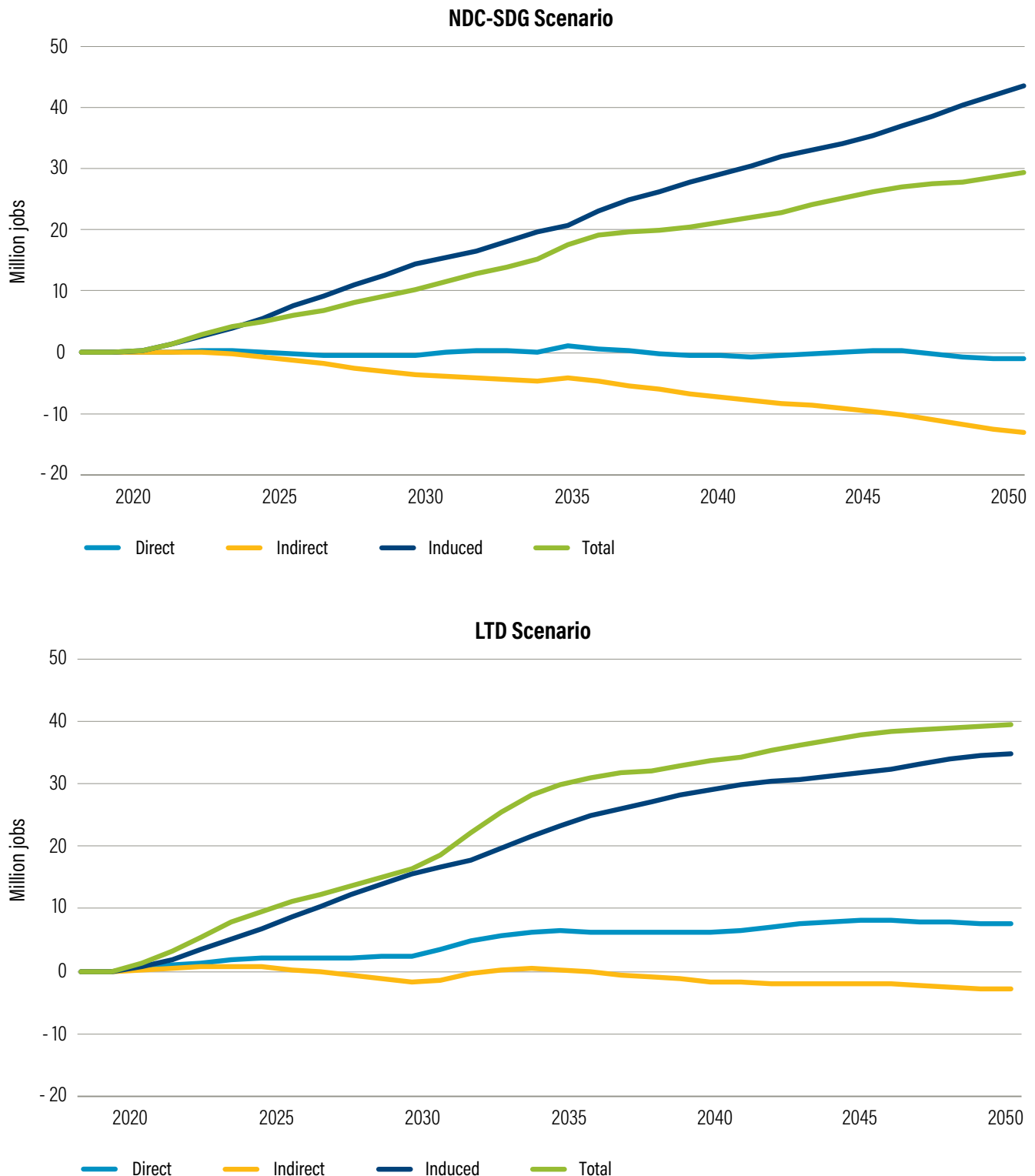


Source: Authors, using EPS India Model.

while the induced impacts are due to re-spending of money paid to workers or government because of the growth of the affected industry. In both the NDC-SDG and LTD scenarios, there is a significant net increase in

jobs relative to BAU. The net increase is predominantly driven by job creation due to induced economic activity in both the cases (Figure 15). There is also an increase in the total GDP of the economy (Table 5).

Figure 15 | **Change in Direct, Indirect, and Induced Jobs Relative to BAU**



Source: Authors, using EPS India Model.

Table 5 | **Additional Jobs and GDP in NDC-SDG and LTD Scenarios Relative to BAU**

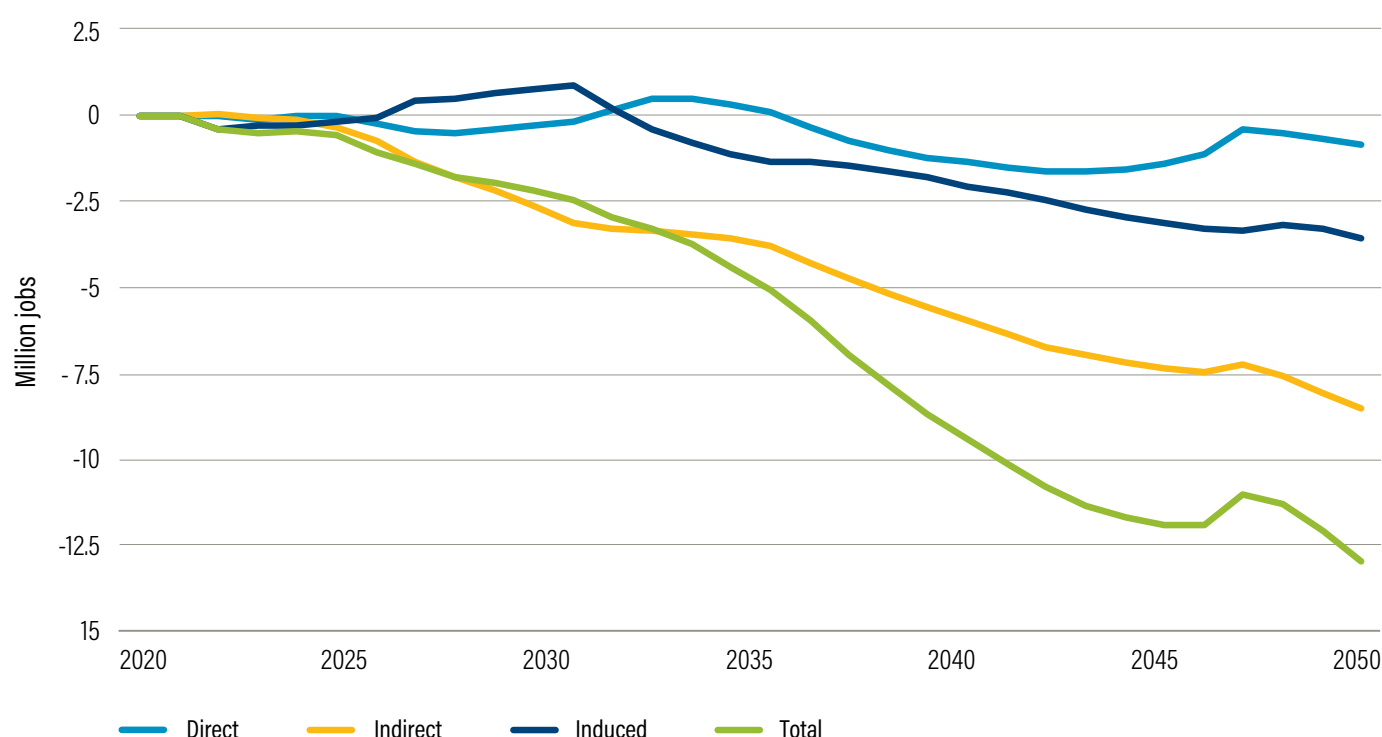
SCENARIO	INCREASE IN TOTAL JOBS OVER BAU (IN MILLIONS)		INCREASE IN GDP			
			2018 INR (TRILLIONS)		PERCENT INCREASE	
	2030	2050	2030	2050	2030	2050
NDC-SDG	10	29	0.1	11.2	0.03%	1%
LTD	16	39	4.4	15.6	0.96%	1.5%

Note: 68.42 INR = 1 USD (in 2018).

Source: Authors.

We now take the case of the NDC-SDG scenario below to explore some of the associated trade-offs. The NDC-SDG scenario referred to so far in this section includes an industrial carbon tax. However, if we consider the set of clean energy and energy efficiency policies in the scenario without the industrial carbon tax, there

is a net decline of jobs in the economy relative to BAU (Figure 16), primarily in indirect and induced jobs. This is also on account of some of the default mechanisms by which government revenue is re-spent, discussed later in this section.

Figure 16 | **Impact on Direct, Indirect, and Induced Jobs in the NDC-SDG Scenario, without the Carbon Tax**


Source: Authors, using EPS India Model.

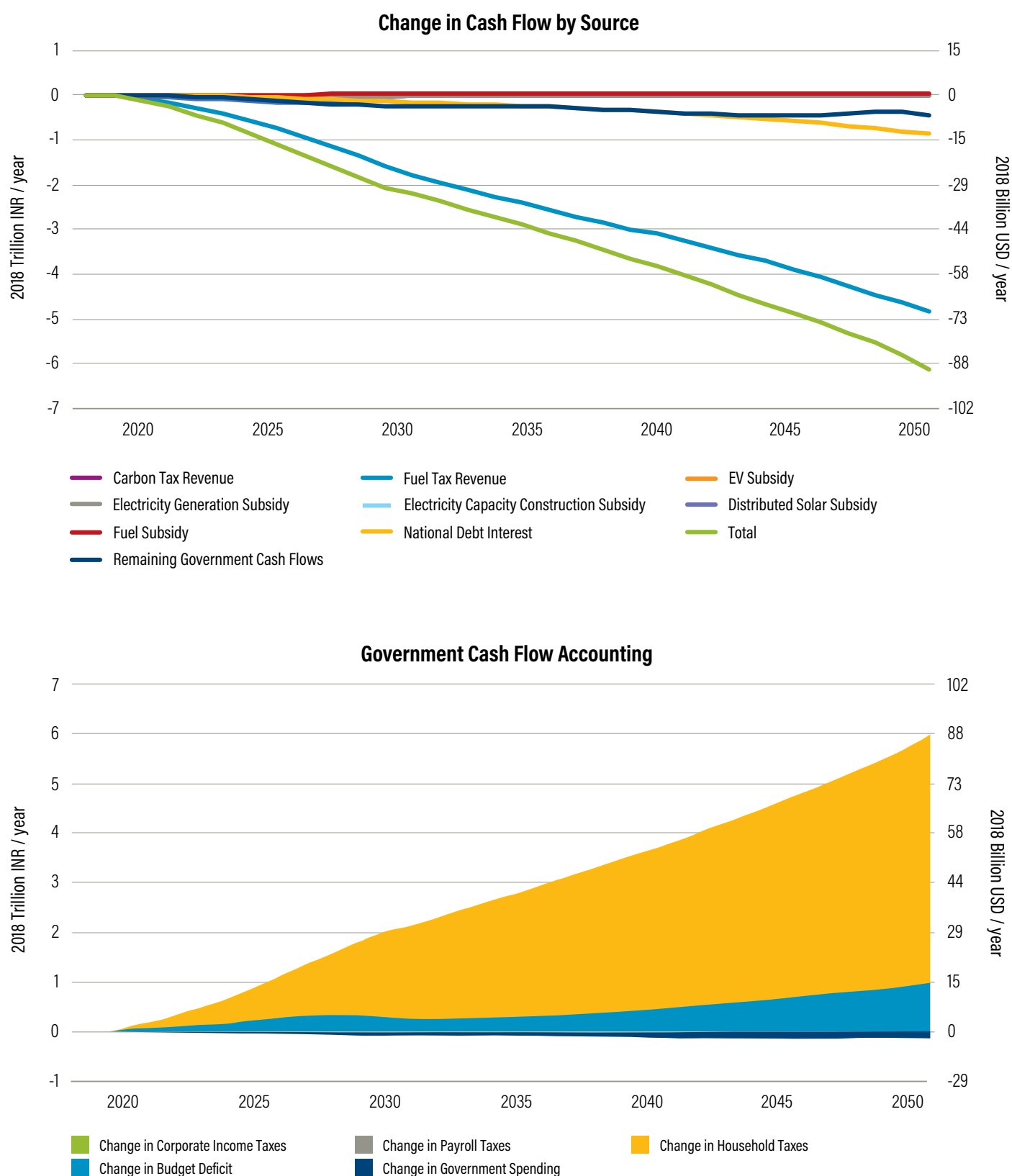
In the impacts shown in Figure 16, there are some gains in direct jobs in the agriculture sector between 2030 and 2035, and in the construction industry after 2045. However, these gains are more than offset by direct job losses in the electricity, manufacturing, and mining sectors after 2030, leading to net direct job losses in the scenario. Indirect job losses occur predominantly due to a drop in jobs in wholesale and retail trade, transportation/storage industry, and repair of motor vehicles. However, the largest decline in jobs comes from induced effects in the agriculture sector. The induced effects are mostly driven by the rise in household taxes to make up for lost fuel tax revenue, which means consumers have less money to re-spend in the economy relative to the BAU scenario. Relatively small changes in the cash flow of consumers, who spend a large fraction of their income on agricultural products, can impact the demand for agricultural products, and the resulting impact on agricultural jobs is quite high given how labor-intensive the sector is.

Most savings in the scenario come from avoided fossil fuel expenditures. This, however, results in significant loss of tax revenues to the government (Figure 17).²¹ Independent estimates indicate that the share of fossil fuel production and consumption in India's government revenues were as high as 18 percent in 2017 (Garg and Geddes 2019). By default, the government revenue accounting mechanism makes up for this loss by increasing household taxes (Figure 17). Together, this leads to a significant reduction in induced jobs in the economy. Another option for the

government is to rely on a combination of increasing the national debt and corporate taxes to make up for the shortfall in fuel tax revenues, instead of increasing household taxes. However, relying on deficit spending significantly increases the cumulative national debt (and corresponding interest payments) in the long run.

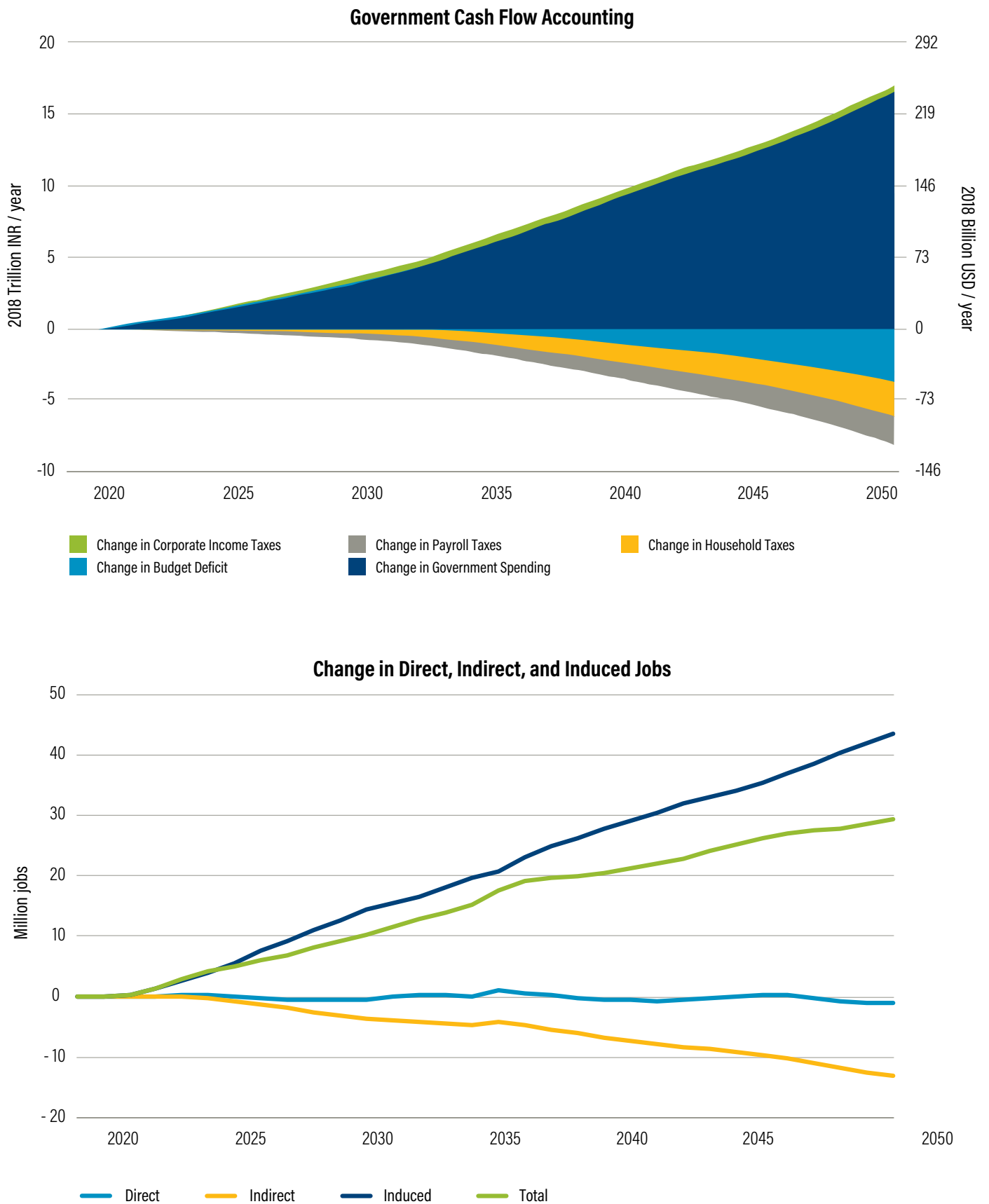
The above negative impacts can be mitigated by introducing policy mechanisms to augment government revenue; such mechanisms have been included in the final scenarios of this analysis. One of those policy options is to phase in a gradual carbon tax in the industry sector to reach 2018 INR 4000/tCO₂e by 2050. Our analysis then redirects the largest share of the carbon tax revenues to government spending, which we find most effective to induce economic activity. The remaining revenue is used to make up for government budget deficit and passed as tax benefits to workers, and households. By applying these measures, we find that overall government spending in the NDC-SDG scenario increases, accompanied by a reduction in household taxes and long-term reduction in budget deficit after a minor increase in the short run. As a result, there are gains in indirect and induced jobs, thus resulting in an overall boost to employment in the economy from implementing the decarbonization policies (Figure 18). Similar impacts are observed in the LTD scenario.

Figure 17 | **Government Cash Flow in the NDC-SDG Scenario without Carbon Tax**



Source: Authors, using EPS India Model..

Figure 18 | Government Cash Flow and Change in Jobs in the NDC-SDG Scenario (with Carbon Tax)



Source: Authors, using EPS India Model.

The role of a carbon tax is pivotal to balancing the trade-offs from the loss of induced economic activity, the result of reduced government spending due to declining fossil tax revenues. As fossil fuels are gradually phased out over the long run, a high carbon tax is particularly effective in augmenting government revenue if implemented in the medium term. This is because there is still a sizeable carbon tax base in the end use sectors when the transition to clean energy is underway. For instance, in the LTD scenario, increasing the target carbon tax rate by 1.5 times—from 5,000 to 7500 2018 INR/tCO₂e—and accelerating the pace to reach 100 percent of the target by 2030 (instead of 2050) can lead to nearly 4 times as many jobs in 2030 and 1.6 times as many jobs in 2050. However, it is to be noted that the carbon tax is applied on top of already existing fossil fuel taxes in the BAU scenario. The government can thus first explore alternate mechanisms—such as the optimal utilization of various cesses collected across sectors—to reduce the high reliance on fossil fuel tax revenues in the BAU scenario. Subsequently, government income can be further augmented through an additional carbon tax to induce economic activity and create additional jobs.

Co-benefits Achieved in the NDC-SDG and LTD Scenarios

Pollutants, Avoided Premature Deaths, and Water Use by Power Plants

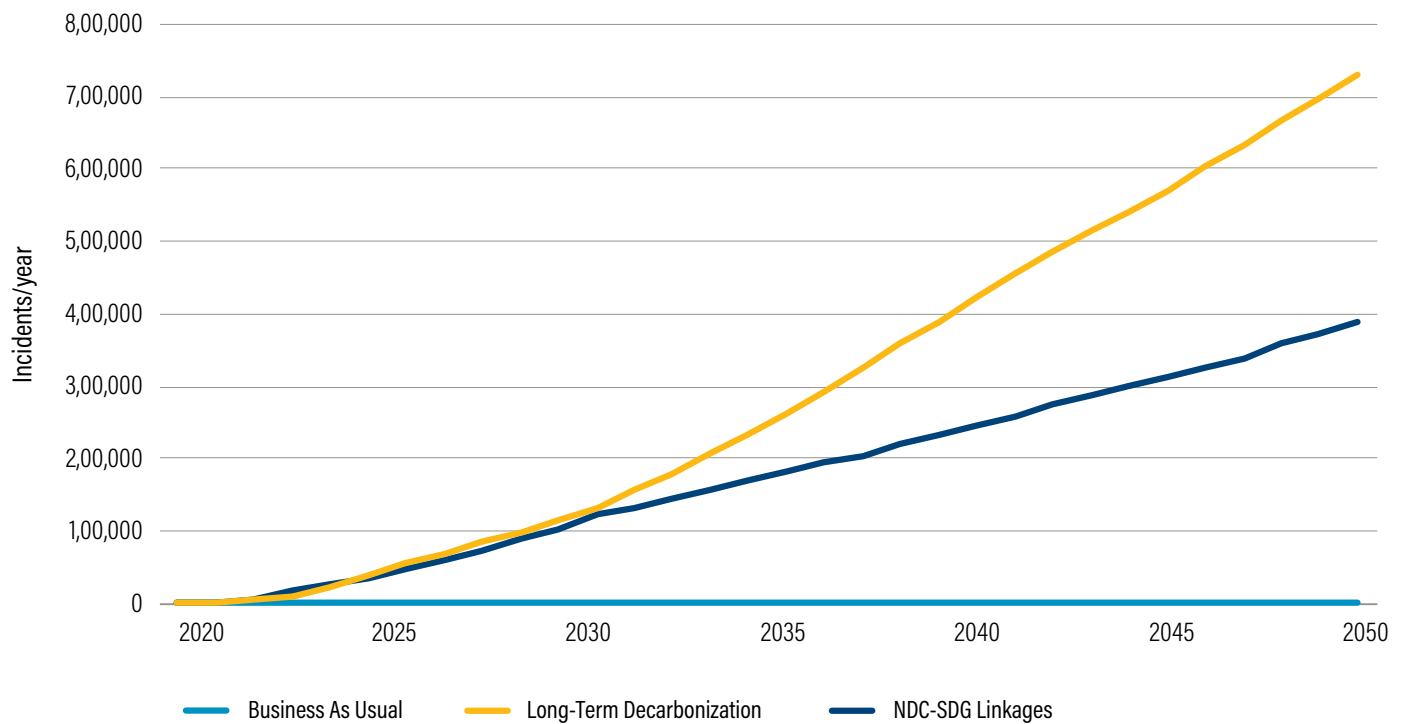
Most policies implemented in our decarbonization scenarios that reduce GHG emissions also deliver reductions in other pollutants that have negative impacts on human health, such as particulate matter (PM_{2.5}), oxides of sulfur (SO_x), and oxides of nitrogen (NO_x). The EPS estimates the premature mortality and other health-related incidents, such as respiratory symptoms, that are avoided per metric ton reduction of these three pollutants.²²

Both the NDC-SDG and LTD scenarios result in significant reductions in harmful health pollutants over the 2030 and 2050 timeframe (Table 6). Maximum impacts are seen on SO_x emissions, with a 75 percent reduction in 2050 in the LTD scenario. This is predominantly driven by reduced coal usage in the electricity and industry sectors through the implementation of the early retirement of coal power plants and electrification and hydrogen substitution in industry, respectively.

Table 6 | **Reduction in Harmful Health Pollutants**

	PERCENT REDUCTION FROM BAU			
	NDC-SDG SCENARIO		LTD SCENARIO	
	2030	2050	2030	2050
PM _{2.5}	14%	26%	14%	48%
NO _x	14%	19%	19%	57%
SO _x	23%	46%	31%	75%

Source: Authors.

Figure 19 | Premature Deaths Avoided in the NDC-SDG and LTD Scenarios

Source: Authors, using EPS India Model.

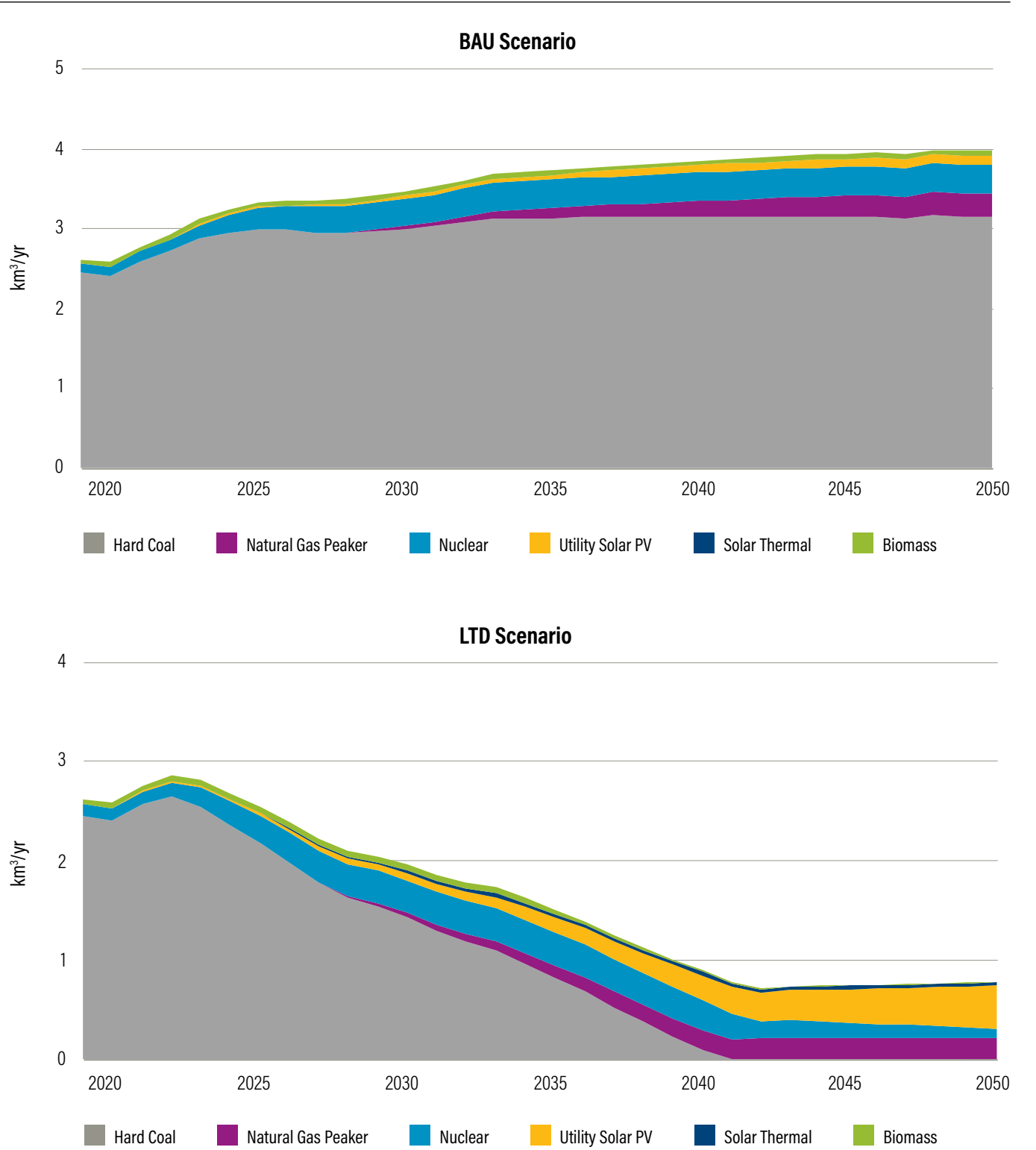
The pollutant emission cuts result in direct benefits of avoided premature mortality, with much higher benefits from the LTD scenario in the long run (Figure 19). Mortality from air pollution is a serious concern for India, resulting in approximately 1.1 million deaths in 2015, projected to rise to 1.7 million deaths in 2030 and 3.6 million deaths in 2050 if no additional measures are taken (Health Effects Institute 2018). In the NDC-SDG scenario, about 1,20,000 premature deaths are avoided in 2030. Policies that contribute the most towards this

positive impact include industrial energy efficiency standards; material efficiency, longevity, and re-use; building component electrification; and conventional pollutant standards in the transport sector. In the LTD scenario, additional long-term policies such as electrification and hydrogen substitution in industrial units and early retirement of coal power plants play a significant role in 2050, resulting in about 7,30,000 avoided premature deaths.

The early retirement of coal power plants also significantly reduces the water withdrawals and consumption in the power sector. Figure 20 shows the water consumption by the various power plant types in the BAU and LTD scenarios, measured as

cubic kilometers per year (km³/yr), while Table 7 summarizes the reductions achieved in water use in terms of withdrawal and consumption²³ in the NDC-SDG and LTD scenarios in 2030 and 2050.

Figure 20 | Water Consumption by Power Plants



Source: Authors, using EPS India Model.

Table 7 | **Water Use by Power Plants**

	WATER WITHDRAWAL				WATER CONSUMPTION			
	2030		2050		2030		2050	
	Total (km ³ /yr)	% Reduction from BAU	Total (km ³ /yr)	% Reduction from BAU	Total (km ³ /yr)	% Reduction from BAU	Total (km ³ /yr)	% Reduction from BAU
BAU	32.16	n/a	34.22	n/a	3.42	n/a	3.98	n/a
NDC-SDG	23.67	26%	11.24	67%	2.45	28%	1.03	74%
LTD	20.50	36%	3.77	89%	1.97	42%	0.78	80%

Source: Authors.

Monetized Avoided Premature Deaths and Climate Benefits

The monetary values for avoided climate damages and the avoided premature deaths are computed by multiplying the reduced CO₂e emissions with a Social Cost of Carbon (SCC) in a particular year and by

multiplying the avoided mortality with the value of a statistical life (VoaSL), respectively.²⁴ Factoring these monetized social benefits into the NDC-SDG and LTD total scenario costs results in an increase in the savings achieved, equivalent to 4 percent and 11 percent of the GDP in 2050, respectively (Table 8).

Table 8 | **Net Savings, Including Monetized Social Benefits, Relative to BAU**

	2030		2050	
	Total (2018 INR, trillions)	Percent of GDP	Total (2018 INR, trillions)	Percent of GDP
NDC-SDG	14.6	3%	44.4	4%
LTD	11.6	3%	113.3	11%

Note: 68.42 INR = 1 USD (in 2018).

Source: Authors.

Policy Delay Analysis

Impact of Delaying Key Abatement Policies in the LTD Scenario

Here we consider the impact of delaying the implementation of the top five policies that contribute 60 percent of the total emissions reduction achieved in the LTD scenario relative to BAU in 2050, on key output variables.

The approach for this analysis was to delay the start year in the implementation schedule of each policy by five years, keeping the rate of policy implementation the same as in the original scenario.²⁵ This is done individually for each policy in turn, while holding all other policies the same as the original LTD scenario. Key results of the analysis are discussed in this section. The implementation schedule of the five policies in the original scenario is provided in Appendix C and the full results of the analysis in Appendix E.

Emissions

As compared to the original LTD scenario, emissions in 2050 increase in the range of 1.3 to 6.5 percent²⁶ in the delayed policy implementation scenarios, while cumulative emissions between 2020 and 2050 show an increase of 1 to 2.8 percent. The largest increase in emissions—6.5 percent in 2050 and 2.8 percent from 2020 to 2050—is seen from delaying the implementation of the “Electrification and Hydrogen”

policy, which highlights the importance of shifting away from fossil fuel use in the industrial sector, given the expected growth in the sector through 2050. Emissions in a scenario where all five policies are delayed together are significantly larger (Table 9).

GDP and Jobs

Delaying the implementation of the “Electrification and Hydrogen” policy in the LTD scenario shows a significant decline in the increase of GDP and jobs relative to BAU in 2050, as compared to the original LTD scenario (Figure 21). This clear impact highlights the potential boost to the economy from high-investment hydrogen production. The opposite is seen in the case of the “Material Efficiency, Longevity, and Re-Use” policy, highlighting that policies that target emissions through demand-side interventions can involve trade-offs in terms of GDP and jobs impacts by depressing industrial output.

Policy Package Cost or Savings

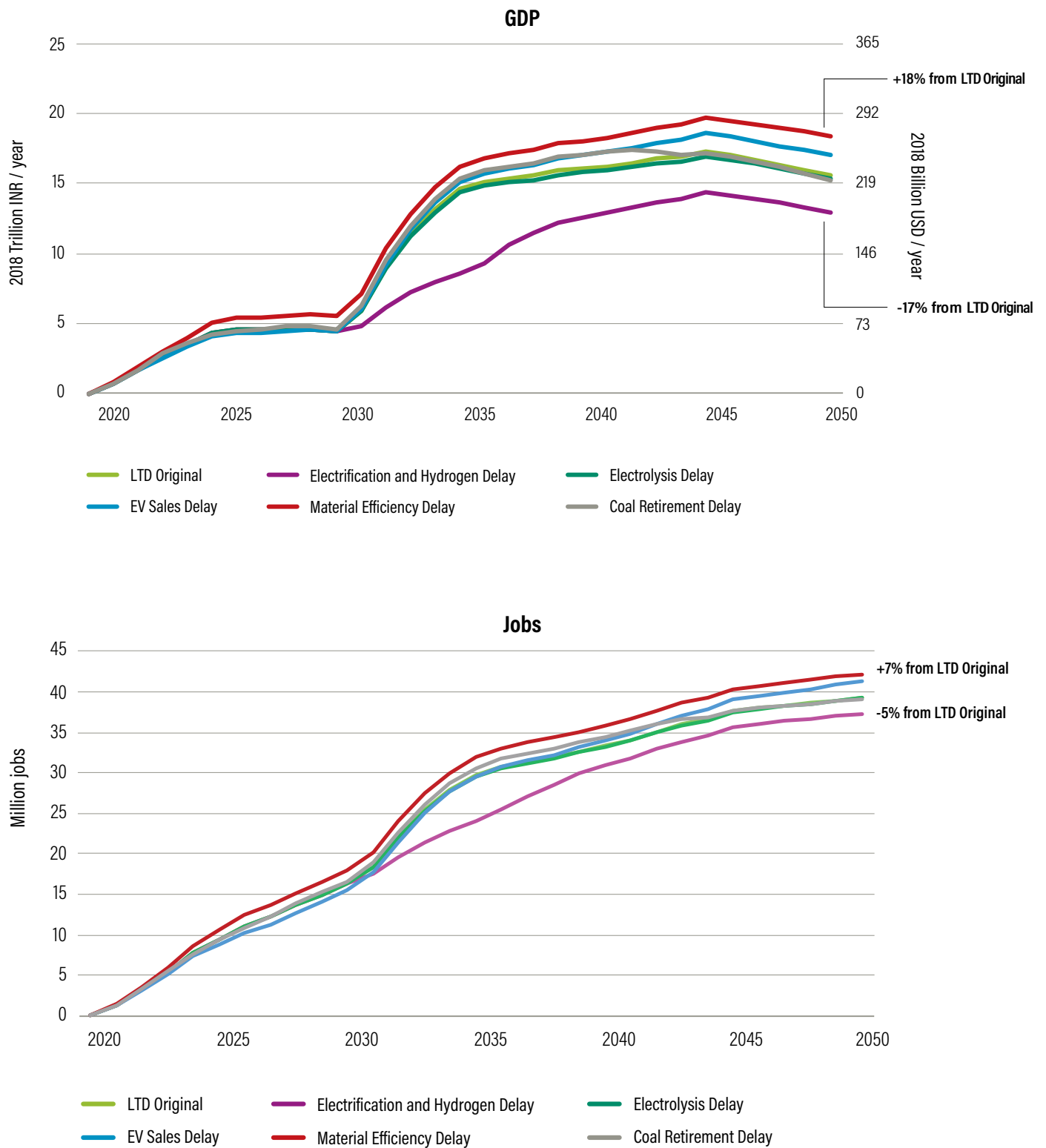
The total (negative) costs or savings from implementing the policy package in 2050, as compared to the original LTD scenario, show a significant decline in the case of delaying the “EV Sales Mandate” policy (Figure 22). This is primarily owing to rising fuel price projections over time, thereby highlighting the cost-effectiveness of shifting away from fossil fuels in the transport sector.

Table 9 | Effect on Emissions of Delayed Implementation of All Five Policies

	2050		2020–2050	
	Emissions (MtCO ₂ e)	Increase relative to LTD Scenario (%)	Emissions (MtCO ₂ e)	Increase relative to LTD Scenario (%)
LTD	2,542	n/a	89,381	n/a
All Policy Delay	2,875	13.1%	97,450	9.0%

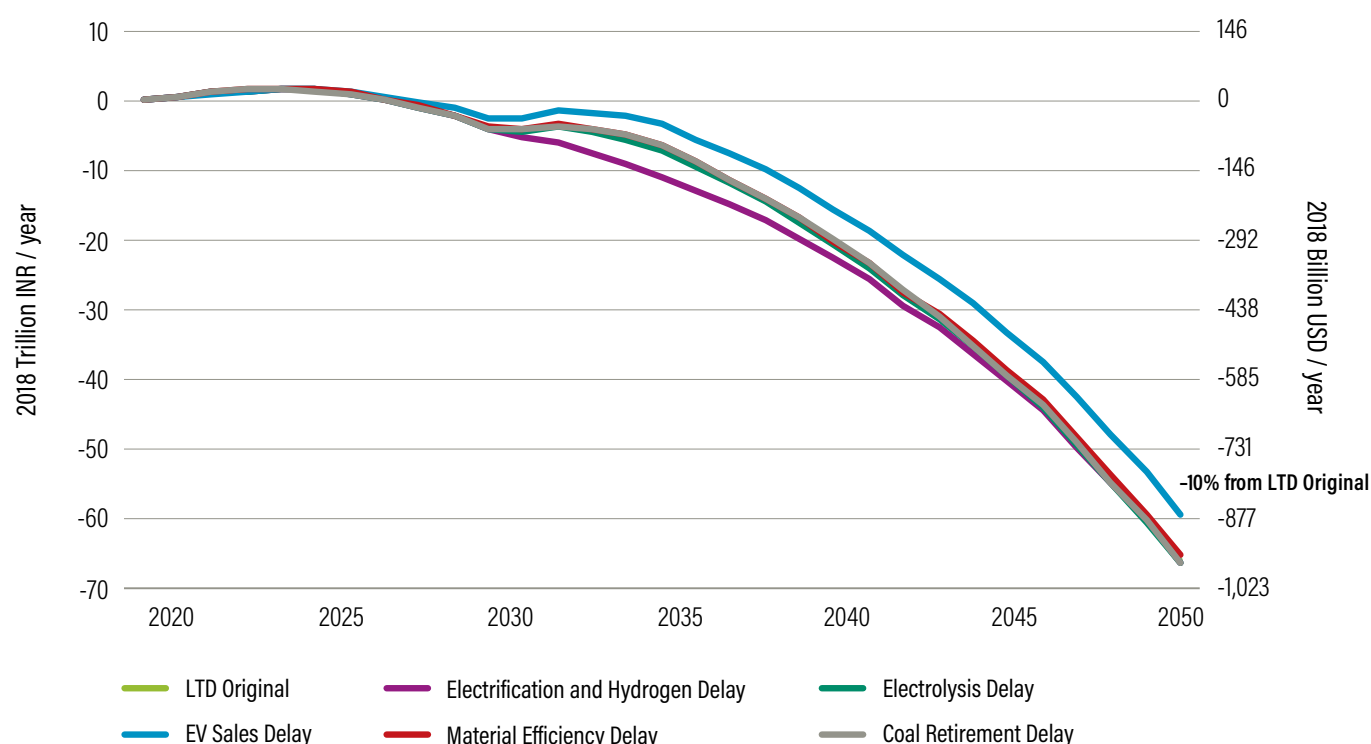
Source: Authors.

Figure 21 | Effect of Delayed Policy Implementation in the LTD Scenario



Source: Authors.

Figure 22 | Effect of Delayed Policy Implementation on Policy Package Cost in the LTD Scenario



Source: Authors.

Impact of Grid Support Policies on RE Curtailment

In the electricity sector, VRE generation sources such as wind and solar are intermittent in nature, requiring flexibility in the grid to absorb their diurnal and seasonal variation.²⁷ The important sources for grid flexibility include the grid support functions

of grid battery storage, demand response capacity, and transmission capacity. We examined the effect of strengthening the grid support policies for the CES standard of attaining a minimum of 60 percent electricity generation from renewable sources in the NDC-SDG scenario. The corresponding policy settings are listed in Table 10.

Table 10 | Strengthened Grid Support Policy Settings in the NDC-SDG Scenario

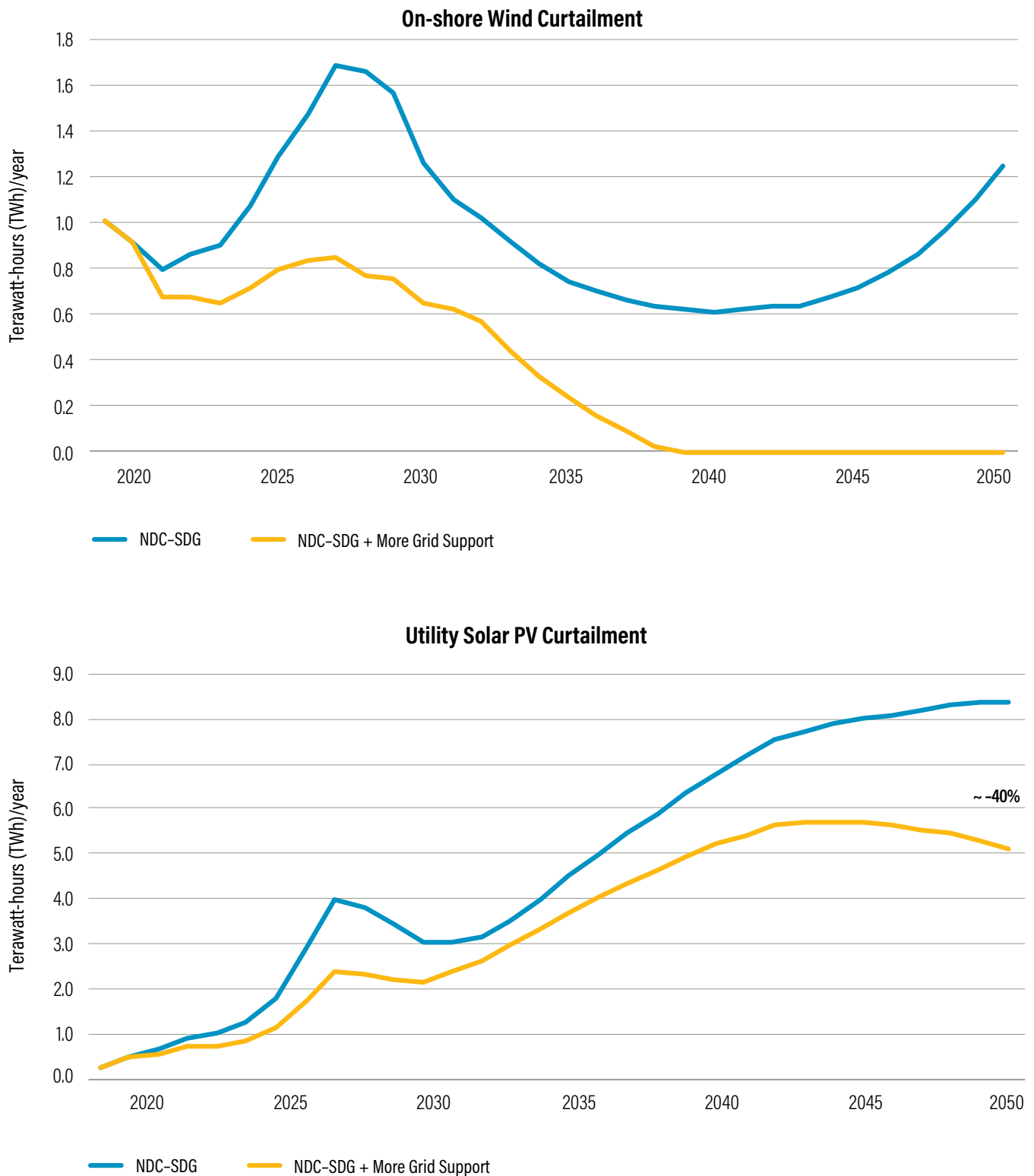
GRID SUPPORT POLICY	NDC-SDG	NDC-SDG + MORE GRID SUPPORT
Grid scale electricity storage	50% of total potential, or 223 gigawatts (GW) achieved in 2050	75% of total potential (335 GW achieved in 2050)
Increase transmission	No additional capacity built over BAU capacity growth	75% increase in transmission capacity over BAU by 2050
Demand response	50% of additional DR potential achieved (an additional 106 GW of DR capacity in 2050 over the BAU capacity of 4 GW)	100% of additional DR potential achieved (an additional 212 GW of DR capacity in 2050 over the BAU capacity of 4 GW)

Source: Authors.

Strengthening the supporting grid infrastructure results in near zero curtailment of onshore wind energy from 2038 onwards. Curtailed energy from solar PV

generators also decreases significantly by about 40 percent in 2050 (Figure 23).

Figure 23 | **Impact of Strengthening Grid Support on VRE Curtailment in NDC-SDG Scenario**

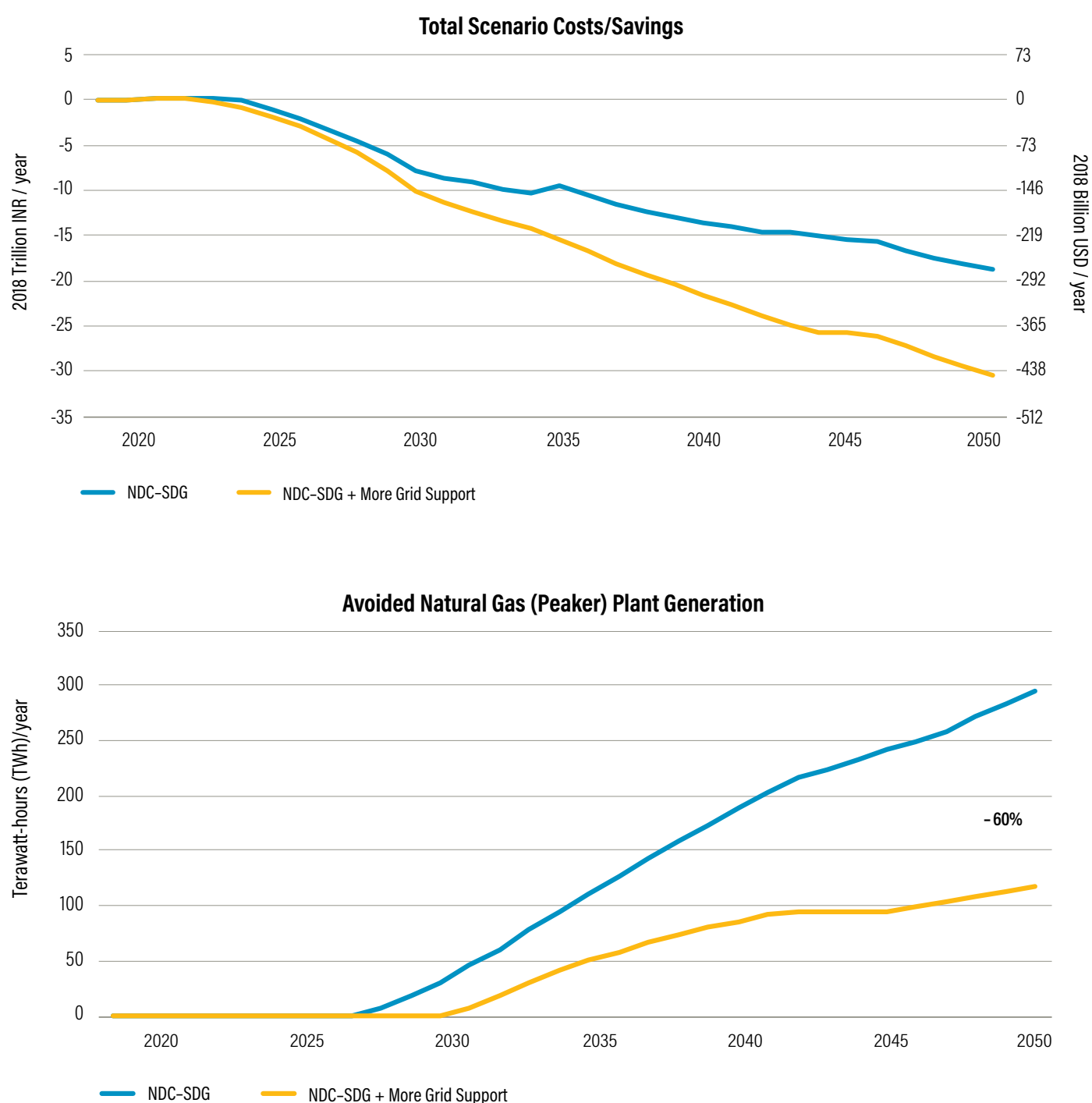


Source: Authors, using EPS India Model.

Augmenting grid support infrastructure incurs no overall additional net costs to the NDC-SDG scenario. In fact, savings increase by a significant 63 percent, compared to the NDC-SDG scenario in 2050 (Figure 24). The biggest cost benefits are due to the avoided need to build natural gas peaker plants to contribute

to grid flexibility, as nearly 60 percent of peaker gas generation can be avoided by strengthening the grid (Figure 24). Further, there is a reduction in the need for solar and wind capacity, which operate at higher capacity factors due to the additional grid support.

Figure 24 | **Impact of Strengthening Grid Support on Total Scenario Costs and Peaker Gas Generation in NDC-SDG Scenario**



Source: Authors, using EPS India Model.

SECTION 3: POLICY IMPLICATIONS

We find ambitious long-term policies for 2050 in the LTD scenario are more effective for reducing BAU emissions in both the medium term (2030) and long term (2050), compared to strategies focused on medium-term ambition by 2030 in the NDC-SDG scenario. While short-term costs of the implementation of policies in the LTD scenario are higher, they are made up over the long-term with increased savings, notably in fossil fuel expenditures, compared to the NDC-SDG scenario, from 2037 onward.

Aggressive early retirements of coal power plants to phase out coal completely by 2043, coupled with a high share of electricity and hydrogen in industrial units (50 percent by 2050) results in substantially larger health benefits in the LTD scenario compared to the NDC-SDG scenario. The shift away from coal is also the primary driver of the co-benefits of reduced air pollution, mortality, and water use in the electricity sector. Hence, it is important to focus on strengthening standards for source-based emissions reductions through measures such as early coal retirement and fuel switching in industrial units.

Most deep decarbonization policies tend to displace fossil fuel use with carbon-free alternatives. Given the resulting loss in fossil fuel tax revenues and its associated implications, it is crucial to explore alternate mechanisms for government revenue generation. An ambitious carbon tax in the industry and electricity sectors—implemented while the transition from fossil fuels to clean energy is still underway—can be particularly helpful to augment government revenues and mitigate potential trade-offs in the economy.

It is also important that policy interventions consider complementarity between policies and are implemented in a timely manner. For example, decarbonization of the electricity grid is critical for achieving the mitigation potential of several key policies in the long term that rely on the availability of green electricity, such as electrification in the industry, production of hydrogen via electrolysis, and EV sales mandates. Similarly, alternate policies to increase grid flexibility can lead to significant reductions in curtailed electricity from VRE sources and avoid the cost of building peaker gas capacity needed for managing their variability. We also find that delaying implementation of these key abatement policies has clear negative implications in terms of higher emissions and associated health costs.

Long-term strategies aimed at a mid-century vision for ambitious levels of decarbonization need to be translated into actionable climate mitigation policies and milestones in the short to medium term. To achieve the deep emission cuts in the LTD scenario, the below policies with proven technologies need to be phased in with immediate effect.

■ **Early retirement of coal power plants**

A much higher proportion—around 93 gigawatts (GW)—of existing coal capacity falls in the category of coal plants with variable costs higher than the present levelized cost of solar, indicating a significantly higher scope for early retirement in purely economic terms in the short run, as compared to Central Electricity Authority (CEA) projections of 43 GW of coal retirement by 2027 (Shrimali 2020). Furthermore, recent independent reviews of India's thermal power sector identify several non-performing plants that are financially insolvent. Increasing accumulation of unfunded interest expenses by financially unviable thermal plants can also have a detrimental effect on the clean energy transition by limiting the banking sector's ability to invest in renewable energy projects (Buckley et al. 2019).

■ **Material efficiency, longevity, and re-use**

To realize the targeted reduction in end-use demand for emissions-intensive industrial products (such as cement and steel), there is a need for guidelines for material efficiency for the construction sector, certification and creation of formal markets for sustainable building materials, and financial incentives for the use of such materials, such as a lower goods and services tax.

■ **Industrial energy efficiency standards**

A roadmap to achieve the energy efficiency potential of targeted schemes, such as the Perform-Achieve-Trade mechanism (PAT), in the medium to long term is needed, as cost-effective opportunities for efficiency improvements in current technology are exhausted, and investments in new technology are required. The roadmap should address issues such as strengthening and widening the coverage of existing schemes like PAT, creating incentives for investment in new energy efficient technologies, and deregulating prices for energy intensive products, such as fertilizers, which will provide clear market price signals for improving energy efficiency (BEE et al. 2018).

■ Industrial carbon tax

The assumed carbon tax rate for the industry in the short term closely reflects the trend of the rising cess on coal (IISD n.d.). Although there is uncertainty regarding the tax rate assumed over the long term, the Indian government has recently signaled its intention to expand and strengthen carbon pricing policies by constituting the Apex Committee for the Implementation of the Paris Agreement (AIPA), a high-level inter-ministerial committee that includes the task of formulating guidelines on carbon pricing in the country among its key functions (GoI 2020).

Among more nascent technologies, the use of hydrogen as a fuel emerges as key to emissions reduction in the long term and is particularly important for decarbonizing hard-to-abate parts of the industry and freight transport sectors. Implementation of key policies—like switching the production of hydrogen via electrolysis and industrial fuel to a combination hydrogen and electricity starting between 2025 and 2030—would entail a significant need for the development of supporting infrastructure and policies under the National Hydrogen Mission announced in the Union Budget 2021 (GoI 2021b). The key priority issues for policy planning are creating incentives for technology investments for fuel-switching in the private sector, the development of hydrogen distribution infrastructure, and grid improvements to increase transmission and storage capacity required for industrial-scale production of green hydrogen.

Expedited focus on long-term policy strategies can create policy certainty and an enabling environment for technology innovation to gain from early action. Further, it can avoid potential lock-in of investments into energy-intensive infrastructure with long gestation periods and high decommissioning costs. Finally, it can help situate long-term climate actions in the context of India's developmental needs by identifying synergies and gaps between multiple goals. However, there is greater uncertainty involved in translating long-term policies into action, arising from associated technology assumptions, implementation constraints, and questions of political feasibility.

Scenario analysis of this kind is a first step in identifying high impact opportunities for emissions abatement and associated co-benefits. Translating the identified opportunities into action requires more detailed sectoral and technology-specific analysis through further research and stakeholder consultations to inform the feasibility of these interventions in the Indian context in terms of practical constraints, implementation challenges, and financing needs. This, in turn, can inform the creation of targeted investment plans and time-bound implementation roadmaps to enable deep decarbonization in the long term for India.

APPENDIX A. MODELING APPROACHES FOR INDIA IN RECENT STUDIES AND EXPERTS CONSULTED FOR THIS STUDY

Table A1 | **Overview of Modeling Approaches Adopted by Recent Studies for India**

STUDY	APPROACH
IEA (2021b)	Looks at four economic and policy scenarios up to 2040 for India using IEA's World Energy Model (WEM), a simulation model covering energy supply, energy transformation, and energy demand, and relying on IEA's databases for macroeconomic data and on IEA's Energy Technology Perspectives (ETP) model for technical and economic parameters of energy technologies.
Gupta et al. (2019)	Explored different 2°C compatible macroeconomic scenarios for India until 2050, by combining the bottom-up Asia-Pacific Integrated (AIM)/End-use cost optimization model for energy supply with the top-down IMAClim-IND model to produce sectoral end-use demand, via iterative exchange of model outputs.
Chaturvedi et al. (2018)	Conducted an uncertainty assessment of the cost of power generation technologies and the behavior of energy demand in end-use sectors in the context of India's NDC targets. Used the GCAM-IIM, an integrated assessment model, with a detailed representation of the electricity, building, and transportation sectors and an aggregate representation of the industrial sector.
Kaundinya et al. (2018)	Studied the effect of proposed technologies and policies on energy intensity of GDP in the context of India's NDC targets using CSTEP's IMRT5 model, a bottom-up cost optimization model for the power sector, soft-linked to a spreadsheet-based accounting framework representing end-use energy demand.
Parikh et al. (2018)	Explored three technology-policy scenarios and their implications for a 1.5°C carbon budget for India by 2050. Used the IRADe-Neg50, a hybrid optimization model, which covers the whole economy, with specific technological options in both supply and demand.
NITI Aayog (2015)	An Excel-based energy accounting calculator that constructs different scenarios of energy security and policy effort for India, presenting the energy sector up to 2047, with energy demand, supply, costs, land requirement, and CO ₂ as outputs in an interactive web tool.
Shukla et al. (2015)	Analyzed two development scenarios for India until 2050, consistent with the globally agreed 2°C stabilization target, using the Soft-Linked Integrated Model System (SLIM) that combines a Global Computable General Equilibrium (CGE) model along with a bottom-up energy system model.

Table A2 | **Sectoral Experts Consulted for Feedback on Scenario Policy Settings and Assumptions**

ELECTRICITY		
Serial No.	Name	Organization
1	Anoop Singh	Indian Institute of Technology, Kanpur
2	Raghav Pachouri	The Energy and Resources Institute (TERI)
3	Rahul Tongia	Centre for Social and Economic Progress
4	Ramya Natarajan	Center for Study of Science, Technology & Policy (CSTEP)
5	Rangan Banerjee	Indian Institute of Technology, Bombay
6	Rasika Athawale	Regulatory Assistance Project
7	Thomas Spencer	TERI
8	Usha Ramachandra	Administrative Staff College of India
BUILDINGS		
Serial No.	Name	Organization
1	Aditya Chuneekar	Prayas Energy Group
2	Megha Behal	TERI
3	Mohini Singh	International Finance Corporation
4	Ramya Natarajan	CSTEP
5	Sangeeta Mathew	Alliance for an Energy Efficient Economy
6	Smita Chandiwalla	Energe-se
7	Sumedha Malaviya	World Resources Institute, India (WRI-India)
INDUSTRY		
Serial No.	Name	Organization
1	Kaveri Ashok	CSTEP
2	Shruti Dayal	TERI
3	Suresh Krishna	ACC Limited
4	Tirtha Biswas	Council on Energy, Environment, and Water
5	Will Hall	TERI
TRANSPORT		
Serial No.	Name	Organization
1	Alekhya Datta	TERI
2	Madhav Pai	WRI-India
3	Shruti Dayal	TERI
4	Shweta Srinivasan	CSTEP

Notes: Stakeholders' organization or affiliation is as of November 2020, when the consultation discussions were held. The Input Output Model was integrated into the India EPS subsequently, and had not been reviewed through stakeholder consultations at the time of this writing.

APPENDIX B. MAPPING NDC-SDG LINKAGES TO EPS POLICIES

Table B1 | Mapping NDC-SDG Linkages to EPS Policies

SDGS AND TARGETS	INDIA NDC CLIMATE ACTIONS	EPS POLICIES USED IN NDC-SDG LINKAGES SCENARIO (BY SECTOR)
SDG 2: No Hunger 2.4 Ensure sustainable agricultural systems for climate change	<ul style="list-style-type: none"> Climate-smart and sustainable agriculture 	Agriculture: Cropland and rice measures, livestock measures
SDG 3: Good Health and Well-being 3.3 End epidemics and diseases 3.9 Reduce illness and deaths from chemicals and pollution	<ul style="list-style-type: none"> Climate-induced health risks prevention 	Transport: Conventional pollutant standards All other mitigation measures with impacts on reduction in pollutants, such as: Electricity: Carbon-free electricity standard Industry: Energy efficiency measures
SDG 6: Clean Water and Sanitation 6.3 Improve water quality and reduce pollution 6.4 Increase water-use efficiency across all sectors	<ul style="list-style-type: none"> Water quality improvement Water treatment Efficient use of water 	Water & Waste: Industry energy efficiency standards; methane capture and destruction; material efficiency, longevity, and re-use Electricity: Carbon-free electricity standard, early retirement of power plants (coal)
SDG 7: Affordable and Clean Energy 7.1 Access to affordable, reliable, and modern energy 7.2 Increase share of sustainable energy 7.3 Double the rate of improvement in energy efficiency	<ul style="list-style-type: none"> Power plants construction Clean and renewable energy targets Transition from coal and other fossil fuel-based energy Off-grid systems Financial mechanisms for energy Codes, labeling, and standards establishment Efficient appliances and lighting 	Electricity: Carbon-free electricity standard, early retirement of power plants (coal), subsidy for electricity production, supporting policies for high RE Buildings: Building energy efficiency standards, appliance labeling, promotion of distributed solar, building component electrification
SDG 8: Decent Work and Economic Growth 8.1 Sustain economic growth 8.2 Promote resource efficiency	<ul style="list-style-type: none"> Low-carbon economy Resource efficiency 	Economy-wide low-carbon measures Industry: Material efficiency, longevity, and re-use.
SDG 9: Industry, Innovation, and Infrastructure 9.2 Sustainable industrialization and raise employment and GDP 9.4 Upgrade infrastructure, resource efficiency, and new technology 9.5 Strengthen research and development	<ul style="list-style-type: none"> Green industry Resource efficiency Building codes and standards Research and development 	Industry & Buildings: Efficiency measures; material efficiency, longevity, and re-use
SDG 11: Sustainable Cities and Communities 11.2 Accessible and sustainable transport systems	<ul style="list-style-type: none"> Clean fuel and fuel efficiency Use of electric vehicles (EVs) 	Transport: Fuel economy standards, EV mandates, mode shifting

Table B1 | Mapping NDC-SDG Linkages to EPS Policies (cont.)

SDGS AND TARGETS	INDIA NDC CLIMATE ACTIONS	EPS POLICIES USED IN NDC-SDG LINKAGES SCENARIO (BY SECTOR)
SDG 12: Responsible Consumption and Production 12.2 Efficient use of natural resources 12.4 Reduce release of waste and chemicals 12.5 Reduce waste by recycling 12.6 Encourage private sector for sustainable practices	<ul style="list-style-type: none"> Waste management Waste-to-energy development Recycling and re-use Solid waste management Composting of organic waste Wastewater treatment 	Industry (Water & Waste): Industry energy efficiency standards; methane capture and destruction; material efficiency, longevity, and re-use Electricity: Carbon-free electricity standard, including municipal solid waste (MSW)
SDG 15: Life on Land 15.1 Conserve and restore inland ecosystems 15.2 Promote sustainable forests and halt deforestation 15.3 Restore degraded land and combat desertification	<ul style="list-style-type: none"> Forest management Afforestation Conservation, restoration, and rehabilitation of ecosystems Biodiversity protection REDD+ implementation Carbon sequestration 	Land: Afforestation and reforestation, avoid deforestation, forest restoration, improved forest management

Note: Relevant SDGs and Targets summarized by authors. All SDGs and Targets available from UNGA 2017.

APPENDIX C. SCENARIO POLICY SETTINGS

Table C1 | Policy Settings in NDC-SDG Linkages Scenario

SECTOR	POLICY	2030 POLICY SETTING ^a	REFERENCE/ASSUMPTION FOR POLICY SETTING
Cross-Sector	Carbon Tax	INR 1,333 (2018)/metric ton CO ₂ e in the industry sector (energy-related and process emissions)	<u>Parry et al.</u> estimate that increasing carbon tax gradually to reach INR 2,310 /ton CO ₂ by 2030 can reduce emissions intensity by 22% against BAU levels. The setting is linearly phased in to reach INR 4,000 by 2050 to augment government revenue from fuel tax revenue losses.
Industry	Energy Efficiency Standards	<p>Cement: 10% reduction in energy use from coal, petroleum, and LPG; 15% reduction in energy use from natural gas</p> <p>Natural gas and petroleum: 15% reduction in energy use from natural gas</p> <p>Iron and steel: 15% reduction in energy use from coal, petroleum, LPG, and natural gas</p> <p>Chemicals and other industries: 10% reduction in energy use from coal, petroleum, LPG, and natural gas</p> <p>Coal mining: 33% reduction in energy use from LPG</p> <p>Water and wastewater: 33% reduction in energy use from coal</p> <p>Agriculture: 25% reduction in energy use from petroleum and LPG</p>	<p>Cement: Estimated savings by 2030 under the Perform-Achieve-Trade (PAT) mechanism by the <u>Bureau of Energy Efficiency (BEE)</u></p> <p>Natural gas and petroleum: Based on estimated short-term savings under PAT Cycle II by <u>BEE</u></p> <p>Iron and steel, chemicals, and other industries: In "<u>Energy Efficiency Potential in India</u>" (2018), The Energy and Resources Institute (TERI) estimates potential energy savings of 19% by 2041 in the iron and steel sector, 14% in the fertilizer sector, and 12% in the other industries (including bricks, aluminum, paper, and pulp).</p> <p>Coal mining: In "<u>Benchmarking Energy Efficiency of Opencast Mining in India</u>" Sahoo et al. estimate potential energy savings of 26–56%, by comparing the specific energy consumption of a best practice coal mine among seven opencast mines in India. According to the study, opencast mines account for about 70% of total Indian coal production.</p> <p>Water and waste: In "<u>Towards a better water-energy-carbon nexus in cities</u>," Dhakal et al. estimate potential energy savings of 35% by implementing decentralized sewage treatment plants for a case study of wastewater management in New Delhi, India.</p> <p>Agriculture: A joint <u>study</u> by Copenhagen Centre on Energy Efficiency, EESL, Indian Institute of Management, Ahmedabad, and the UN Environment Programme identifies usage of energy efficient electric pump-sets in the agriculture sector as a high impact opportunity, with an estimated 25% improvement in Specific Energy Consumption (SEC) by 2030.</p>
		Material Efficiency, Longevity, and Re-Use	<p>A reduction in demand for cement (3.3%), iron and steel (8.3%), and water and waste management services (6.7%) by 2030, linearly phased in from 2020 to reach 2050 targets</p> <p>Mid-level settings for 2030 are based on the following 2050 potential demand reduction estimates:</p> <p>Cement: In "<u>Pathways to Deep Decarbonization in India</u>," Shukla et al. estimate that with compact urbanization patterns, use of low-energy and local materials, mixing of fly ash in cement, and recycling and re-use of industrial and construction waste, cement demand for construction could be reduced by up to 30% by 2050.</p> <p>Iron and steel: In "<u>Towards a Low Carbon Steel Sector</u>," TERI estimates that active adoption of resource efficiency measures can reduce steel demand by 25% relative to baseline growth by 2050.</p> <p>Water and waste: India's <u>National Water Mission</u> aims to ensure integrated water resource management and improve water use efficiency by 20% through regulatory mechanisms.</p>

Table C1 | Policy Settings in NDC-SDG Linkages Scenario (cont.)

SECTOR	POLICY	2030 POLICY SETTING ^a	REFERENCE/ASSUMPTION FOR POLICY SETTING
Electricity	Early Retirement of Power Plants	Linearly phased in from 2020 to retire 7,000 MW/yr of otherwise non-retiring coal capacity each year from 2030	There are recent state-level announcements to phase out coal. This setting, coupled with carbon-free electricity standards, results in about 50 GW of existing coal capacity to be phased out by 2030, and the remaining capacity to be gradually phased out by 2050.
	Carbon-free Electricity Standard	60% of total electricity generation is from carbon-free sources, including solar, wind, hydro, nuclear, and municipal solid waste (MSW)	Based on " Renewable Power Pathways: Modelling the Integration of Wind and Solar in India by 2030 " (TERI 2020), the Ministry of Power announced a potential achievement of 60% power capacity from renewable energy by 2030. The policy setting results in nearly 60% of installed capacity from utility-scale wind, solar, hydro, nuclear, and MSW by 2030.
	Reduce Plant Downtime	A 15% reduction in downtime for new (constructed during the model run) solar PV and onshore wind plants	<p>Solar PV: Typical crystalline silicon cells today have efficiencies of 20–25%, while today's best multi-junction cells (used primarily in concentrator PV and aerospace applications) have efficiencies of 40–45%. If the typical cells installed in 2050 will have efficiencies similar to today's best multi-junction cells, this might be represented as a 26% setting of this policy lever. A conservative improvement of 15% by 2030 is assumed.</p> <p>Onshore wind: In India, the expected capacity factor (CF) for new onshore wind turbines in the BAU case rises from 24% to 31% over the course of the model run. In "Future of Wind," the International Renewable Energy Agency projects global-average onshore wind CFs ranging between 32% and 58% by 2050. The average CF of 45% in this range (a downtime of 55%) corresponds to a 21% reduction in the lever setting. A conservative reduction of 15% is assumed by 2030.</p>
Transportation	Vehicle Fuel Economy Standards	<p>An improvement in the fuel economy (km/liter) of passenger light-duty vehicles (LDVs) (30%), passenger heavy-duty vehicles (HDVs) (6%), freight HDVs (8%), 2-wheeled vehicles (30%), and 3-wheeled vehicles (30%)</p> <p>For passenger LDVs, 2-wheeled, and 3-wheeled vehicles, 50% of full policy implementation is assumed to occur linearly by 2022, and the remaining linearly between 2022 and 2030</p>	Based on 2030 targets in the New Policies scenario of the study: CSTEP, CEEW, IRADe, PNNL, and TERI (2019) " Comparison of Decarbonisation Strategies for India's Land Transport Sector: An Inter Model Assessment ".
	Mode Shifting	A reduction in demand for passenger LDVs (15%), passenger aircraft (5%), and freight HDVs (10%) by shifts to other travel modes	<p>Passenger LDVs: Based on the Sustainable Urban Mobility Scenario in "Transport Scenarios for India: Harmonising Development and Climate Benefits" (Dhar et al. 2015), 30% shift of private transport demand to public transport by 2050 relative to BAU.</p> <p>Passenger aircraft: Based on the BLUE Shifts scenario in "Transport, Energy, and CO₂: Moving toward Sustainability" (IEA 2009), 10% reduction in aircraft use in non-OECD countries by 2050 relative to BAU.</p> <p>Freight HDVs: Based on the High Rail scenario in "Future of Rail" (IEA 2019), freight rail activity in 2050 is 25% higher than BAU, mainly due to shift from freight HDVs.</p>

Table C1 | Policy Settings in NDC-SDG Linkages Scenario (cont.)

SECTOR	POLICY	2030 POLICY SETTING ^a	REFERENCE/ASSUMPTION FOR POLICY SETTING
	EV Sales mandate	Proportion of new fleet additions running on electricity: <ul style="list-style-type: none"> Passenger LDVs (20%) Passenger HDVs (12%) Passenger rail (100%) Freight rail (100%) 2-wheeled vehicles (30%) 3-wheeled vehicles (65%) 	Combination of the EV sales proportions in 2030 in the model BAU based on cost optimization in the transport sector, and estimates for EV penetration by KPMG based on analysis of key enablers.
Buildings and Appliances	Building Component Electrification	Replacement of newly sold non-electric components with electric variants: <ul style="list-style-type: none"> Urban residential appliances (35%) Rural residential lighting (100%) Rural residential appliances (30%) Commercial lighting (100%) Commercial appliances (50%) 	Moderately higher settings than electrification rates in BAU. BAU levels of electrification in 2030 are as follows: <ul style="list-style-type: none"> Urban residential appliances (26%) Rural residential lighting (100%) Rural residential appliances (20%) Commercial lighting (100%) Commercial appliances (40%)
	Improved Labeling	Reduced energy consumption in newly sold building components through improved labeling: cooling and ventilation (7%), envelope (9%), lighting (26%), and appliances (11%) The policy is fully implemented starting from 2021	The average percentage improvement is based on the efficiency improvement between two consecutive bands for each appliance under BEE's S&L program. Consecutive bands are selected based on a market research study that indicates that consumers are more likely to pay for incremental improvements of efficiency rather than, for instance, transition directly from a two-star to a five-star rated appliance.
Agriculture, Land Use and Forestry	Livestock Measures	60% of the emissions reduction potential from livestock measures to reduce formation of enteric methane is achieved, resulting in a reduction of 2.3% in agricultural process emissions	Potential reductions for non-CO ₂ gases in the agriculture sector is derived from the U.S. Environmental Protection Agency (EPA)'s estimates of global non-CO ₂ GHG projections and mitigation potential for all countries. ^b 60% of this potential is assumed to be achieved by 2030.
	Cropland and Rice Measures	60% of the emissions reduction potential from cropland management practices—such as crop rotation, reduced tillage, and improved fertilizer composition and application—is achieved, resulting in a reduction of 5.5% in agricultural process emissions	Potential reductions for non-CO ₂ gases in the agriculture sector is derived from the EPA's estimates of global non-CO ₂ GHG projections and mitigation potential for all countries; 60% of this potential is assumed to be achieved by 2030.
	Afforestation and Reforestation	60% of the carbon sequestration potential from afforestation and reforestation is achieved through an afforestation/reforestation rate of 0.84 million acres per year	Based on annual commitments for increasing forest cover and improving the quality of tree cover of forest/non-forest land within India's NDC under the Paris Agreement, there is potential for an afforestation and reforestation rate of approximately 1.4 million acres/year. ^c 60% of this potential is assumed to be achieved by 2030.

Table C1 | Policy Settings in NDC-SDG Linkages Scenario (cont.)

SECTOR	POLICY	2030 POLICY SETTING ^a	REFERENCE/ASSUMPTION FOR POLICY SETTING
Control Settings	COVID-19 Recession	<p>-7.7% shrinkage of GDP growth rate in 2020, relative to 2019</p> <p>Based on a V-shaped recovery assumption, the shrinkage is reduced by 50% each subsequent year to gradually return to counter-factual GDP growth rate projections by 2030</p>	As of January 2021, India's National Statistical Office (NSO) estimated a 7.7% contraction in GDP growth for the current financial year. This is the default BAU setting.
Government Revenue Accounting	Carbon Tax Revenue	<p>Revenues accrue to below government revenue components in the following ratios:</p> <ul style="list-style-type: none"> ▪ Regular government spending (62%) ▪ Budget deficit (15%) Household taxes (7.7%) ▪ Payroll taxes (7.7%) ▪ Corporate income taxes (7.7%) 	Settings chosen to minimize negative impacts on jobs and GDP due to scenario policies.
	Fuel Tax Revenue	Shortfalls are passed on to below government revenue components in budget deficit (50%) and corporate income taxes (50%)	Settings chosen to minimize negative impacts on jobs and GDP due to scenario policies.

Notes:

^a Unless noted specifically, the 2030 settings for the policies are assumed to be linearly phased in from 2020. Percentage changes in policy settings are relative to the BAU scenario.

^b See model variable indst/PERAC for more details.

^c See model variable land/PLANAbPiaSY for more details.

Table C2 | Policy Settings in Long-Term Decarbonization Scenario

SECTOR	POLICY	2050 POLICY SETTING ^a	REFERENCE/ASSUMPTION FOR POLICY SETTING
Cross-sector	Carbon Tax	<p>INR 5000 (2018)/metric ton CO₂e in industry, transport, electricity, and commercial buildings sectors.</p> <p>The tax applies to both energy-related and process emissions in industry.</p> <p>This policy is phased in linearly from 2022 to 2050.</p>	<p>Parry et al. estimate that increasing carbon tax gradually to reach INR 2,310/ton CO₂ by 2030 can reduce emissions intensity by 22% against BAU levels.</p> <p>For an ambitious setting, the tax rate is approximately doubled to reach INR 5,000/tCO₂e by 2050.</p>
	Electrification and Hydrogen	<p>50% of fuel use shifted from high carbon sources (coal, biomass, natural gas, petroleum, heavy or residual fuel oil, LPG) to a mixture of electricity (based on the industry's electrification potential) and hydrogen (for the remainder). Only fuel consumed for energy, not fuel used as a chemical feedstock, is affected by this policy.</p> <p>This policy is phased in linearly until 2050 starting from 2030.</p>	<p>Based on significant cost reductions anticipated for green hydrogen and growing demand for end-use of hydrogen in industry (TERI 2020). Ambitious setting applied to all sectors with significant consumption of fossil fuels.</p>
	Industry Carbon Capture and Storage (CCS)	<p>10% of energy and process-related CO₂ emissions are captured and stored in all industrial sectors; namely, cement, petroleum and natural gas, iron and steel, chemicals, and other industries.</p>	<p>There is significant long-term coal consumption by industry in the LTD scenario even with fuel-switching and energy efficiency policies. Very few CCS-equipped industrial facilities exist today, so a conservative setting of 10% is assumed.</p>
	F-Gas Measures	<p>A reduction in F-gas emissions through substitution (56%), destruction (3%), recovery (16%), and equipment maintenance and retrofits (7%).</p>	<p>Potential reductions for non-CO₂ gases in the agriculture sector is derived from the EPA's estimates of global non-CO₂ GHG projections and mitigation potential for all countries.^b Full potential is assumed to be achieved by 2030.</p>

Table C2 | **Policy Settings in Long-Term Decarbonization Scenario (cont.)**

SECTOR	POLICY	2050 POLICY SETTING ^a	REFERENCE/ASSUMPTION FOR POLICY SETTING
Energy Efficiency Standards		Cement: 20% reduction in energy use from coal, petroleum, and LPG.	Cement: 2050 settings are assumed to be double the estimated savings by 2030 under the PAT mechanism by Bureau of Energy Efficiency (BEE).
		Natural gas and petroleum: 30% reduction in energy use from natural gas.	Natural gas and petroleum: The ICF International report , "Study on Energy Efficiency and Energy Saving Potential in Industry from possible Policy Mechanisms," estimates energy savings of 25% in 2030 to be technically feasible for the petroleum refinery sector in the European Union. A higher savings of 30% is assumed for 2050.
		Iron and steel: 25% reduction in energy use from coal, petroleum, LPG, and natural gas.	Iron and steel, chemicals, and other industries: In " Energy Efficiency Potential in India " (2018), The Energy and Resources Institute (TERI) estimates potential energy savings of 19% by 2041 in the iron and steel sector, 14% in the fertilizer sector, and 12% in the other industries (including bricks, aluminum, paper, and pulp). Higher savings are assumed for 2050.
		Chemicals and other industries: 20% reduction in energy use from coal, petroleum, LPG, and natural gas.	
		Coal mining: 40% reduction in energy use from LPG.	Coal Mining: In " Benchmarking Energy Efficiency of Opencast Mining in India ," Sahoo et al. estimate potential energy savings of 26–56% by comparing the specific energy consumption of a best practice coal mine among seven opencast mines in India. A mid-range estimate of 40% is assumed for 2050.
		Water and waste: 35% reduction in energy use from coal.	Water and waste: In " Towards a better water-energy-carbon nexus in cities ," Dhakal et al. estimate potential energy savings of 35% by implementing decentralized sewage treatment plants for a case study of wastewater management in New Delhi, India.
Material Efficiency, Longevity, and Re-use		Agriculture: 30% reduction in energy use from petroleum and LPG.	Agriculture: A joint study by Copenhagen Centre on Energy Efficiency, EESL, Indian Institute of Management, Ahmedabad, and the UN Environment Programme identifies usage of energy efficient electric pumpsets in the agriculture sector as a high impact opportunity, with an estimated 25% improvement in Specific Energy Consumption (SEC) by 2030. A higher estimate of 30% is assumed by 2050.
		A reduction in demand for cement (15%), iron and steel (25%), and water and waste management services (20%)	Cement: In " Pathways to Deep Decarbonization in India ," Shukla et al. estimate that with compact urbanization patterns, use of low-energy and local materials, mixing of fly ash in cement, and recycling and re-use of industrial and construction waste, cement demand for construction could be reduced by up to 30% by 2050. A conservative setting is assumed as most of the infrastructure is yet to be built in India's current development trajectory.
			Iron and steel: In " Towards a Low Carbon Steel Sector ," TERI estimates that active adoption of resource efficiency measures can reduce steel demand by 25% relative to baseline growth by 2050.
Cogeneration and Waste Heat Recovery			Water and waste: India's National Water Mission aims to ensure integrated water resource management and improve water use efficiency by 20% through regulatory mechanisms.
		A reduction in emissions of 5.5% from the cement, iron and steel, and chemicals sectors, and 4% from all other industrial sectors due to reduced fuel consumption	Fuel saving potentials from cogeneration and waste heat recovery are based on estimates by IEA and WBCSD . ^c Full potential is assumed to be achieved by 2050.

Table C2 | Policy Settings in Long-Term Decarbonization Scenario (cont.)

SECTOR	POLICY	2050 POLICY SETTING ^a	REFERENCE/ASSUMPTION FOR POLICY SETTING
Electricity	Early Retirement of Power Plants	7,000 MW/yr of otherwise non-retiring coal capacity retired each year. This policy is fully implemented starting from 2021.	The model builds significant VRE capacity in the BAU scenario itself due to increasing cost competitiveness of wind and solar generation technologies. In the LTD scenario, we assume that grid balancing mechanisms like storage and transmission would enable higher shares of RE in the future mix and accelerate coal capacity retirements to phase out coal by 2045.
	Carbon-free Electricity Standard	75% of total electricity generation is from carbon-free sources that include solar, wind, hydro, nuclear, and MSW.	The model builds significant VRE capacity in the BAU scenario itself due to increasing cost competitiveness of wind and solar generation technologies. In the LTD scenario, we assume that grid balancing mechanisms like storage and transmission would enable higher shares of RE in the future mix.
	Grid-scale Electricity Storage	Grid-scale electricity storage capacity (from chemical batteries) of approximately 335 GW is achieved.	Potential for additional grid battery storage is based on IEA's <u>projections</u> for India in the case of cheaper battery costs; ^d 75% of this potential is assumed to be achieved by 2050.
	Demand Response	A demand response capacity of 216 GW is added to the electric grid. This policy is fully implemented starting from 2021.	Potential for additional demand response capacity is based on CPI's <u>estimates</u> for India in different end-uses; ^e 100% of this potential is assumed to be achieved by 2050.
	Reduce Plant Downtime	A reduction in downtime for new (constructed during the model run) solar PV (26%), onshore wind (25%), and offshore wind (20%) plants.	Solar PV: Typical crystalline silicon cells today have efficiencies of 20–25%, while today's best multi-junction cells (used primarily in concentrator PV and aerospace applications) have efficiencies of 40–45%. If the typical cells installed in 2050 will have efficiencies similar to today's best multi-junction cells, this might be represented as a 26% setting of this policy lever. Onshore wind: In India, the expected CF for new onshore wind turbines in the BAU case rises from 24% to 31% over the course of the model run. In "Future of Wind," the International Renewable Energy Agency projects global-average onshore wind CFs ranging between 32% and 58% by 2050. The average CF of 45% in this range (a downtime of 55%) corresponds to a 21% reduction in the lever setting.
Hydrogen	Shift Hydrogen Production to Electrolysis	100% of merchant hydrogen (i.e., hydrogen produced for sale, not hydrogen produced and consumed on-site within a facility) is produced via electrolysis rather than via other production pathways. This policy is phased in linearly through 2050 starting from 2025.	Based on significant cost reductions anticipated for green hydrogen and growing demand for end-use of hydrogen in industry (<u>TERI, 2020</u>); all hydrogen is assumed to be produced via electrolysis by 2050.

Table C2 | **Policy Settings in Long-Term Decarbonization Scenario (cont.)**

SECTOR	POLICY	2050 POLICY SETTING ^a	REFERENCE/ASSUMPTION FOR POLICY SETTING
Transportation	Hydrogen Vehicles Sales Mandate	<p>Proportion of new fleet additions running on hydrogen: freight HDVs (25%), passenger and freight aircraft (25%), and passenger and freight ships (25%).</p> <p>This policy is phased in linearly through 2050 starting from 2025.</p>	Based on discussion with sectoral experts, it was assumed that the ICE passenger fleet would transition predominantly to EVs in the mid-term. Hydrogen vehicle technologies are still in the research and development phase, and moderate targets are assumed to apply for the heavy-duty freight, aircraft, and shipping segments.
	EV Sales Mandate	<p>Proportion of new fleet additions running on electricity: passenger LDVs (40%), passenger HDVs (50%), freight LDVs and HDVs (30%), passenger and freight rail (100%), 2-wheeled vehicles (80%), and 3-wheeled vehicles (100%).</p> <p>For 2-wheeled vehicles, 62.5% of full policy implementation is assumed to occur linearly by 2030 and the remaining linearly between 2030 and 2050.</p>	Raised level of ambitions from the settings estimated from BAU levels and independent assessments in the NDC-SDG scenario.
	Vehicle Fuel Economy Standards	<p>An improvement in the fuel economy (km/liter) of passenger LDVs (40%), passenger HDVs (11%), freight LDVs (50%), freight HDVs (13%), passenger and freight rail (10%), passenger ships (15%), and 2-wheeled vehicle and 3-wheeled vehicles (40%).</p> <p>For passenger LDVs, 2-wheeled and 3-wheeled vehicles, 50% of full policy implementation is assumed to occur linearly by 2022, and the remaining linearly between 2022 and 2030. Full implementation continues from 2030 through 2050.</p> <p>For passenger and freight HDVs and rail, the policy is linearly phased into full implementation by 2030. Full implementation continues from 2030 through 2050.</p>	Based on 2030 targets in the High Ambitions scenario of the study: CSTEP, CEEW, IRADe, PNNL, and TERI (2019), " Comparison of Decarbonisation Strategies for India's Land Transport Sector: An Inter Model Assessment. "

Table C2 | Policy Settings in Long-Term Decarbonization Scenario (cont.)

SECTOR	POLICY	2050 POLICY SETTING ^a	REFERENCE/ASSUMPTION FOR POLICY SETTING
	Mode Shifting	A reduction in demand for passenger LDVs (30%), passenger aircraft (10%), and freight HDVs (25%) by shifts to other travel modes.	<p>Passenger LDVs: Based on the Sustainable Urban Mobility Scenario in "Transport Scenarios for India: Harmonizing Development and Climate Benefits" (Dhar et al. 2015), 30% shift of private transport demand to public transport by 2050 relative to BAU.</p> <p>Passenger aircraft: Based on the BLUE Shifts scenario in "Transport, Energy, and CO₂: Moving toward Sustainability" (IEA 2009), 10% reduction in aircraft use in non-OECD countries by 2050 relative to a BAU case.</p> <p>Freight HDVs: Based on the High Rail scenario in "Future of Rail" (IEA 2019), freight rail activity in 2050 is 25% higher than BAU, mainly due to shift from freight HDVs.</p>
Buildings and Appliances	Building Component Electrification	<p>Replacement of newly sold non-electric components with electric variants: urban residential appliances (80%), rural residential lighting (100%), rural residential appliances (50%), commercial lighting (100%), and commercial appliances (80%).</p> <p>For commercial lighting, the policy is linearly phased into full implementation by 2022. Full implementation continues from 2022 through 2050.</p>	Significantly higher levels of electrification (near 100%) than BAU rates
	Building Energy Efficiency Standards	<p>Reduction in energy-use in newly sold building components:</p> <p>Urban Residential: Cooling and ventilation (40%), envelope (30%), lighting (50%), appliances (40%), and other components (44%).</p> <p>Commercial: Cooling and ventilation (40%), envelope (50%), lighting (50%), appliances (50%), and other components (50%).</p>	<p>2050 settings are based on ambitious levels of below estimates for potential energy savings:</p> <p>Urban residential and commercial cooling and ventilation: The India Cooling Action Plan estimates that through improvements in cooling equipment efficiency and better servicing practices, building cooling energy consumption can be reduced by 30% by 2038.</p> <p>Urban residential envelope: As per BEE, successful implementation of ECBC-R Phase I for building envelope is expected to achieve a minimum of 20% energy saving, as compared to a typical building, by 2030.</p> <p>Urban residential lighting and appliances: In "Residential Buildings in India: Energy Use Projections and Savings Potentials," the Global Buildings Performance Network estimates a 50% reduction in residential lighting energy use and 40% reduction in residential appliance energy use by 2050 (relative to BAU) in the aggressive case.</p> <p>Other components: In "Residential Buildings in India: Energy Use Projections and Savings Potentials," the Global Buildings Performance Network estimates a 44% reduction in total residential energy use (aggressive case) relative to BAU by 2050.</p> <p>Commercial envelope, lighting, appliances, and other components: India launched the revised Energy Conservation Building Code (ECBC) in 2017. The updated code sets energy performance standards for new commercial buildings to reduce energy consumption, and adoption of ECBC 2017 for new commercial buildings across India is estimated to achieve a 50% reduction in energy use by 2030.</p>

Table C2 | Policy Settings in Long-Term Decarbonization Scenario (cont.)

SECTOR	POLICY	2050 POLICY SETTING ^a	REFERENCE/ASSUMPTION FOR POLICY SETTING
Agriculture, Land Use and Forestry	Livestock Measures	A 3% reduction in agricultural process emissions from livestock measures to reduce formation of enteric methane.	Potential reductions for non-CO ₂ gases in the agriculture sector is derived from the EPA's <u>estimates</u> of global non-CO ₂ GHG projections and mitigation potential for all countries; ^f 100% of this potential is assumed to be achieved by 2050.
	Afforestation and Reforestation	An afforestation and reforestation rate of 1.4 million acres (roughly equal to 0.17% of the total land area of India) per year is achieved.	Based on annual commitments for increasing forest cover and improving the quality of tree cover of forest/non-forest land within India's NDC under the Paris Agreement, there is potential for an afforestation and reforestation rate of approximately 1.4 million acres/year; ^g 100% of this potential is assumed to be achieved by 2050.
	Forest Restoration	3.5 million acres of degraded forests are restored per year.	Based on India's annual commitments for forest restoration under the Bonn Challenge, there is potential for a restoration rate of approximately 3.5 million acres/year; ^h 100% of this potential is assumed to be achieved by 2050.
Control Settings	COVID-19 Recession	-7.7% shrinkage of GDP growth rate in 2020, relative to 2019. Based on a V-shaped recovery assumption, the shrinkage is reduced by 50% each subsequent year to gradually return to counter-factual GDP growth rate projections by 2030.	As of January 2021, India's National Statistical Office (NSO) estimated a 7.7% contraction in GDP growth for the current financial year. This is the default BAU setting.
Government Revenue Accounting	Carbon Tax Revenue	Revenues accrue to below government revenue components in the following ratios: <ul style="list-style-type: none"> ▪ Regular government spending (55%) ▪ Budget deficit (18%) ▪ Household taxes (9%) ▪ Payroll taxes (9%) ▪ Corporate income taxes (9%) 	Settings chosen to minimize negative impacts on jobs and GDP due to scenario policies.
	Fuel Tax Revenue	Shortfalls are passed on to below government revenue components in the following ratios: <ul style="list-style-type: none"> ▪ Regular government spending (32%) ▪ Budget deficit (23%) ▪ Household taxes (15%) ▪ Payroll taxes (15%) ▪ Corporate income taxes (15%) 	Settings chosen to minimize negative impacts on jobs and GDP due to scenario policies.

Notes:

^a Unless otherwise noted, the 2050 settings for the policies are assumed to be linearly phased in from 2020. Percentage changes in policy settings are specified relative to the BAU scenario.

^b See model variable indst/PERAC for more details.

^c See model variable indst/PPRiFuCaWHR for more details.

^d See model variable elec/BGrBSC for more details.

^e See model variable elec/DRC for more details.

^f See model variable indst/PERAC for more details.

^g See model variable land/PLANAbPiaSY for more details.

^h See model variable land/PLANAbPiaSY for more details.

APPENDIX D. ADDITIONAL SCENARIO RESULTS FOR THE ELECTRICITY SECTOR

Table D1 | Break-Up of Installed Capacity and Generation in 2030 and 2050 in Each Scenario, by Source

SOURCE	INSTALLED CAPACITY (GW)						GENERATION (TWh)					
	BAU		NDC-SDG		LTD		BAU		NDC-SDG		LTD	
	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050
Pumped Hydro	7.2	19.4	6.6	18.8	7.4	15.3	14.3	38.5	13.2	37.5	14.7	30.5
Biomass	11.5	11.5	11.5	3.5	11.5	0.4	30.2	30.2	30.2	9.2	30.2	1.0
Solar Thermal	0.0	0.0	4.8	4.8	3.3	3.3	0.0	0.0	18.3	19.5	12.4	13.2
Distributed Solar PV	8.1	45.3	11.5	49.8	18.4	166.8	14.4	93.2	20.7	102.6	33.1	345.2
Utility Solar PV	207.7	713.6	191.9	732.1	329.0	1,406.5	415.4	1,476.3	561.1	2,237.5	845.2	5,326.3
Onshore Wind	126.8	695.6	142.7	463.9	127.8	348.4	282.1	1,825.2	425.3	1,612.2	336.5	1,390.3
Offshore Wind	0.1	0.3	3.0	3.0	3.0	3.1	0.3	1.0	9.4	10.3	10.4	14.1
Hydro	68.6	93.7	72.1	90.8	74.2	93.3	239.9	330.3	252.5	319.8	259.7	328.7
Nuclear	17.8	18.3	16.3	16.3	17.3	15.8	113.1	119.0	102.9	104.9	109.7	33.8
Distributed Non-solar	26.9	0.0	26.9	0.0	26.9	0.0	23.6	0.0	23.6	0.0	23.6	0.0
Municipal Solid Waste	0.1	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Petroleum	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Natural Gas Peaker	33.8	284.1	29.9	260.9	34.8	213.2	35.0	294.1	31.0	294.0	36.8	220.4
Natural Gas Nonpeaker	24.8	24.8	24.6	24.6	22.2	13.9	0.1	0.1	0.1	5.0	1.2	0.0
Lignite	0.3	0.3	0.0	0.0	0.0	0.0	0.9	1.0	0.0	0.0	0.0	0.0
Hard Coal	221.4	221.4	148.9	9.0	106.5	0.0	1,203.9	1264.6	785.4	69.5	577.2	0.0
Imported Electricity	n/a	n/a	n/a	n/a	n/a	n/a	141.7	118.2	141.7	118.2	141.7	118.2

Table D2 | LCOE in 2030 and 2050 in Each Scenario, by Source

SOURCE	LCOE (2018 INR/MWH)					
	BAU		NDC-SDG		LTD	
	2030	2050	2030	2050	2030	2050
Pumped Hydro	3,322	3,322	3,322	3,322	3,322	3,322
Biomass	5,841	5,841	5,125	5,841	5,164	5,960
Solar Thermal	6,904	6,357	1,694	6,357	1,694	6,357
Utility Solar PV	2,437	2,090	1,630	1,405	1,834	1,084
Onshore Wind	2,706	1,828	1,894	1,410	2,186	1,235
Offshore Wind	4,593	3,197	2,649	3,151	2,662	2,399
Hydro	3,873	3,466	3,873	3,466	3,873	3,466
Nuclear	2,993	3,192	2,993	3,192	2,993	3,192
Municipal Solid Waste	11,876	10,922	11,876	10,922	11,916	11,040
Petroleum	21,789	25,847	21,789	25,847	22,999	29,479
Natural Gas Peaker	12,566	13,305	12,566	13,305	13,419	15,864
Natural Gas Non-peaker	8,300	9,062	8,300	9,062	9,047	11,302
Lignite	3,661	4,778	3,661	4,778	5,548	10,439
Hard Coal	3,176	4,058	3,176	4,058	4,470	7,938

APPENDIX E. POLICY CONTRIBUTION TO ABATEMENT AND DELAY ANALYSIS

Table E1 | Key Policies for Emissions Abatement in the NDC-SDG Scenario

POLICY	SECTOR	EMISSIONS REDUCTION RELATIVE TO BAU (MtCO ₂ e)		RELATIVE CONTRIBUTION TO TOTAL EMISSION REDUCTION (%)	
		2030	2050	2030	2050
Carbon Tax	Industry	308	191	30%	7%
Industry Energy Efficiency Standards	Industry	255	283	25%	11%
Material Efficiency, Longevity, and Re-use	Buildings/Transportation/Industry	124	458	12%	17%
Livestock Measures	Agriculture	69	43	7%	2%
Vehicle Fuel Economy Standards	Transportation	47	118	5%	4%
Early Retirement of Coal Power Plants	Electricity Supply	26	967	2%	36%
Sum		829	2,060	81%	77%

Note: Arranged in descending order of contribution to emissions abatement in 2030.

Table E2 | Key Policies for Emissions Abatement in the LTD Scenario

POLICY	SECTOR	EMISSIONS REDUCTION RELATIVE TO BAU (MtCO ₂ e)		RELATIVE CONTRIBUTION TO TOTAL EMISSION REDUCTION (%)	
		2030	2050	2030	2050
Electrification and Hydrogen	Industry	0	1008	0%	22%
Hydrogen Production via Electrolysis	Hydrogen	0	632	0%	14%
Early Retirement of Coal Power Plants	Electricity Supply	384	559	30%	12%
Material Efficiency, Longevity, and Re-use	Buildings/Transportation/Industry	92	290	7%	6%
EV Sales Mandate	Transportation	36	282	3%	6%
Industry Energy Efficiency Standards	Industry	99	230	8%	5%
Carbon Tax	Industry	259	65	20%	1%
Sum		870	3,066	68%	66%

Note: Arranged in descending order of contribution to emissions abatement in 2050.

Table E3 | **Effect of Delaying Policy Implementation by Five Years in the LTD Scenario**

OUTPUT VARIABLE	VALUE (2050)												
	LTD-Original	Elec + Hyd Delay	% Change	Electrolysis Delay	% Change	EV Sales Delay	% Change	Mat. Efficiency Delay	% Change	Coal Retirement Delay	% Change	All Delay	% Change
Total Emissions (MtCO ₂ e)	2542	2707	6.49%	2629	3.42%	2614	2.83%	2576	1.34%	2,530	-0.47%	2875	13.10%
Policy Package Cost/Savings (relative to BAU, in million 2018 INR)	6,59,89,200	-6,61,69,300	0.27%	-6,63,15,700	0.49%	-5,92,91,300	-10.15%	-6,51,65,700	-1.25%	-6,62,79,100	0.44%	-5,93,13,700	-10.12%
Change in Jobs (relative to BAU)	3,92,32,200	3,73,55,300	-4.78%	3,92,23,600	-0.02%	4,12,39,000	5.12%	4,21,31,800	7.39%	3,90,33,400	-0.51%	4,20,17,000	7.10%
Change in GDP (relative to BAU, in million 2018 INR)	1,55,90,900	1,29,61,300	-16.87%	1,53,34,300	-1.65%	1,70,11,900	9.11%	1,83,51,200	17.70%	1,52,37,100	-2.27%	1,64,74,900	5.67%
Avoided Premature Deaths	7,29,456	6,85,982	-5.96%	7,28,760	-0.10%	7,24,022	-0.74%	7,24,754	-0.64%	7,29,563	0.01%	6,74,091	-7.59%
Water Consumption by Power Plants (km ³ /yr)	0.79	0.7	-11.39%	0.78	-1.27%	0.78	-1.27%	0.79	0.00%	0.74	-6.33%	0.66	-16.46%

ENDNOTES

1. In accordance with Article 4, paragraph 19, of the Paris Agreement, all Parties should strive to formulate and communicate long-term low GHG emission development strategies, mindful of Article 2 taking into account their common but differentiated responsibilities and respective capabilities, in the light of different national circumstances.
2. A term coined in the mid 1950's by Jay Forrester of the Massachusetts Institute of Technology, "system dynamics" can be defined as a theoretical framework that represents the non-linear behavior of a complex system over time. The system is typically modelled using stocks, flows, and feedback loops. This approach considers energy use and economic processes as a constantly changing system that is not in equilibrium.
3. The EPS provides an interactive interface for testing a comprehensive list of policy options in the buildings, electricity, fuels, industry, transport, and land-use sectors. It also includes a fully integrated input-output model that enables an assessment of the macroeconomic effects of policy options, including on GDP and employment. More information on the India EPS can be found at <https://india.energypolicy.solutions/docs/>.
4. For instance, in the electricity sector, the use of capacity factors of renewable energy plants at an annual scale approximates variable generation from renewable sources that may change at even 15-minute timescales. This approximation impacts the accuracy of estimates of fast-ramping sources of generation such as natural gas peaker plants that are needed to balance the intermittency from variable renewable sources.
5. Close to 70 decarbonization policies can be modelled across all sectors. To explore the policies in further detail, please visit <https://india.energypolicy.solutions/scenarios/home>.
6. More details on the methodology adopted in the NDC-SDG Connections tool can be found at <https://mediamanager.sei.org/documents/Publications/SEI-PB-2017-NDC-SDG-Connections.pdf>.
7. These policies contribute to nearly 95 percent of the total GHG emissions abated between 2020 and 2030, relative to the BAU scenario.
8. This policy results in replacement of fossil fuel end-use in industry sectors with a mix of hydrogen and electricity. The proportion of the electricity to hydrogen mix varies depending on the applicability in the industrial sub-sector.
9. These policies contribute to nearly 95 percent of the total GHG emissions abated between 2020 and 2050, relative to the BAU scenario.
10. This accounts for GHG emission sinks from the land-use sector.
11. The model does not estimate rebound specifically for electrifying end-uses. However, it includes an elasticity of demand for fuel based on fuel prices, as well as an elasticity to represent that consumers tend to buy more efficient equipment when fuel prices are higher.
12. The CES policy in the EPS is similar to India's Renewable Purchase Obligation (RPO), which specifies a fraction of electricity generation that must come from wind, solar, and biomass sources. However, in the decarbonization scenarios, we include large hydro, nuclear, and MSW, in addition to wind and solar, as it is relevant to meeting recent ambitious RE targets of 450 GW by 2030. Biomass is excluded because it is not truly carbon-neutral and has other issues such as negative impacts on local air quality, competing land use, and feedstock availability challenges. Nuclear is included because it provides base load for the medium term until variable VRE intermittency can be managed with storage. Hydro is included due to India's recent policy proposal to include large hydro as an RPO qualifying source.
13. Fossil free sources include utility scale on-shore and offshore wind, solar PV, large hydro, nuclear, and MSW plants.
14. The model includes separate levers for adding transmission, demand response, and battery storage, all of which are added in the policy scenarios covered here (and have their costs tracked separately and added into the total). Without these additional technologies, the power sector is not able to support high penetration of renewables. But the costs for these separately tracked technologies are not included in the LCOE estimates.
15. An important note is that this framing excludes costs associated with subsidies and loss of tax revenue. This is a sum of the change in capital expenditures (CapEx); fuel and operational expenditures, including labor (OpEx); and additional carbon tax on process emissions. For example, Figure 11 represents the total change in CapEx and OpEx of the LTD scenario.
16. The model uses macroeconomic feedback loops to account for indirect and induced impacts in energy service demand for the industrial, buildings, and transportation sectors (for more detail, see model documentation here). For example, labor and consumers will re-spend fuel savings proportionally to how households currently spend across the economy, which raises demand for things like agricultural or food products. The industry sector will increase production (and therefore energy consumption and related process emissions) to meet this demand. Furthermore, industries can "pass through" savings on to consumers. In other words, lower fuel spending due to industrial efficiency means industries lower the costs of goods, which increases demand for products (and resulting energy consumption). If consumers have savings due to lower product prices, they can also re-spend that money in the economy, which would also lead to higher demand for some goods and services.
17. This is done by starting with the total scenario cost/savings and noting the difference by disabling each policy in turn. The result of this assessment is an abatement cost curve (Figure 13) where each policy is represented as a box. The width of the box indicates its corresponding average annual CO₂e abatement, while the height of the box indicates its average cost in 2018 INR/ton of CO₂e abated. Positive values of the y-axis indicate costs and negative values indicate savings; the cost effectiveness can be assessed for both the medium- and long-term timeframes in terms of a Net Present Value (NPV) through 2030 and 2050, respectively.
18. India's current Goods and Services Tax (GST) compensation cess of INR 400 levied per tonne of coal (IISD n.d.) works out to around INR 253/tCO₂, based on the specific emissions for coal used in Indian thermal plants. This is not factored as an explicit carbon tax in our BAU, as the cess is primarily intended to compensate states for any shortfalls in revenues from GST collections.
19. Subsidies, such as electricity capacity construction and production subsidies, are expensive because renewables are already cheap. Substantial wind and solar gets deployed in the BAU case and hence the government is subsidizing a lot of capacity that would have been built anyway. However, subsidies are still beneficial because they help accelerate the transition and bring down the costs in later years. Subsidy policies don't appear in the graph as they contribute to less than 3 percent of total emissions abatement in the scenario.

20. More detail on the working of the macroeconomic input-output model is available at <https://us.energypolicy.solutions/docs/io-model.html>.
21. The spike in 2030 is due to the implementation schedule of the electricity sector subsidies, which are set to be phased out beginning in 2030.
22. Estimates for India are computed by scaling United States (U.S.) estimates from the U.S. Environmental Protection Agency (EPA)'s reduced form tools for calculating benefits from reducing pollutants across sectors. A "population exposure multiplier" is applied to U.S. data to reflect differences in population exposure between the two regions. More details on the methodology is available in the input data variable add-outputs/HOI0TP.
23. Water withdrawal accounts for water that is diverted from the source for use in power plants and is discharged after use. Water consumption accounts for the water withdrawn that is not returned to source.
24. Estimates of societal costs for India as well as globally have little consensus in literature, and it is important to note the above results in the context of underlying assumptions. The estimates for India's SCoC vary widely across global studies, ranging from INR 100/tCO₂ (Nordhaus 2017) to INR 6,300/tCO₂ (Ricke et al. 2018). The India EPS uses a median SCoC from India-specific estimates across a range of global studies summarized in Nordhaus (2017). This is about INR 560/tCO₂, projected to reach INR 2,730/tCO₂ in 2050 (at 2018 cost). The growth in this value is as per the baseline scenario in Nordhaus (2017) that includes existing climate policies at a 5 percent discount rate. Similarly, the monetized benefits of avoided deaths are based on the VoasL using Majumder and Madheswaran (2018) that estimates the value in India using a hedonic wage approach that accounts for recent changes in the Indian labor market since the 90s, and the change in patterns in job risk, fatal industrial incidents, and job risk preferences of workers. The value is comparable to the OECD (2014) estimate for India, which uses a willingness-to-pay approach for assessing individual's valuation of their willingness to pay to reduce the risk of death.
25. For example, the "Hydrogen Production via Electrolysis" policy has a linear implementation schedule starting from 0 percent in 2025 and reaching 100 percent of the set policy level in 2050 (implying a uniform policy implementation rate of 4 percent per annum) in the original scenario. A delayed implementation of this policy implies that policy implementation will start from 0 percent in 2030 at the same annual rate of implementation to reach 80 percent of the set policy level in 2050.
26. One exception is the case of delay in early retirement of coal plants, which marginally reduces emissions in 2050 by 0.25 percent. The delay in coal retirement results in less natural gas peaker capacity added in the earlier years, which is required to compensate for coal retirement in the LTD scenario. Once built, peaker gas plants continue to generate, resulting in marginally higher emissions in 2050 in the original scenario. However, in terms of cumulative emissions between 2020 and 2050, the delay in coal retirement results in an increase in emissions by 2.13 percent as compared to the LTD scenario.
27. The EPS, which considers annual time-steps, uses a synthetic unit called a "flexibility point," defined as the flexibility on the grid needed to support one MW of VRE generation, to account for grid flexibility. The availability of flexibility points is based on exogenous input representing the power sector at a more granular time scale. If the amount of VRE in the system exceeds the available flexibility points, then the expected capacity factors of wind and solar fall, representing curtailment of VRE.

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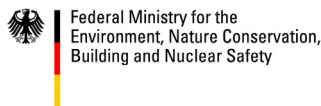
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SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.



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