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TECHNICAL NOTE

A TOOL FOR DESIGNING POLICY PACKAGES TO ACHIEVE INDIA'S CLIMATE TARGETS

Methods, Data, and Reference Scenario of the India Energy Policy Simulator

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ABSTRACT

India is currently the world's third largest emitter of greenhouse gases (GHGs) after China and the United States (WRI 2019), and is set to experience continued growth in its population, economy, and energy consumption. Exploring low-carbon development pathways for India is therefore crucial for achieving the goal of global decarbonization. India has pledged to reduce the emission intensity of its gross domestic product (GDP) by 33–35 percent relative to 2005 levels by 2030 through its Nationally Determined Contribution (NDC), among other related targets for the renewable energy and forestry sectors (GoI 2016). Further, countries, including India, are expected to respond to the invitation of the Conference of the Parties (COP) to the Paris Agreement to communicate new or updated NDCs with enhanced ambition and long-term low-GHG development strategies for 2050.

To design effective policy packages to support the planning and achievement of such climate targets, policymakers need to identify policies that can reduce GHG emissions in a timely and cost-effective manner, while meeting development-related and other national objectives. The India Energy Policy Simulator (India EPS), an open-source system dynamics (SD) model, can enable an integrated quantitative assessment of different cross-sectoral climate policy packages for India through 2050 and their implications for key variables of interest such as emissions, GDP, and jobs.

The tool was developed by Energy Innovation LLC and adapted for India in partnership with World Resources Institute. It is available for open access through a Web interface as well as a downloadable application. This technical note describes the structure, input data sources,

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Technical notes document the research or analytical methodology underpinning a publication, interactive application, or tool.

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assumptions, and limitations of the India EPS, as well as the setup and key results of its reference scenario, referred to as the business-as-usual (BAU) scenario in the model. It is intended as an update to the first technical note on the India EPS (Mangan et al. 2019) and accounts for the changes incorporated into the model since the first version.

INTRODUCTION

India is a major player in global efforts to combat climate change. It is the world's third-largest emitter of greenhouse gases (GHGs) after China and the United States (WRI 2019), and is set to experience continued growth in its population, economy, and energy consumption. Moreover, India has been consistently ranked among the countries most vulnerable to the effects of climate change (Eckstein et al. 2021). Low-carbon development pathways for India are therefore crucial for achieving the goal of global decarbonization and would also mitigate the domestic effects of climate change over the coming decades.

India communicated its NDC in 2015, the primary target being to reduce the emission intensity of its gross domestic product (GDP) by 33–35 percent relative to 2005 levels by 2030. The NDC also sets a clean energy target of increasing the country's share of non-fossil-based installed electric capacity to 40 percent by 2030 and commits to creating an additional carbon sink of 2.5 billion to 3 billion metric tons of carbon dioxide through additional tree cover (GoI 2016). These commitments build on the National Action Plan on Climate Change (NAPCC), launched in 2008, which outlines eight national missions to address climate change and promote sustainable development, and provides the overarching framework for India's domestic policy on climate change. Key national policies and targets adopted by India in line with its NDC commitments include a target of 175 gigawatts (GW) of renewable energy (RE) capacity by 2022; the Perform, Achieve and Trade (PAT) scheme for energy efficiency in the industrial sector; a National Biofuels Policy, along with fuel-efficiency standards and electric vehicle subsidies in the transportation sector; and the Energy Conservation Building Code (ECBC) and Standards and Labelling (S&L) for appliances to promote efficient energy use in the buildings sector (Dubash and Ghosh 2019).

Although India has implemented several policies toward meeting its NDC commitments, they are designed primarily for the short to medium term. A key objective of the Paris Agreement is to meet the long-term target of limiting the average rise in global temperature to within 1.5°–2°C of pre-industrial levels. In line with this objective, countries have been called upon to submit new or updated NDCs that ratchet up the ambition of previously submitted NDCs by 2020, and every five years thereafter, regardless of the implementation time frames (UNFCCCn.d.a.). Countries have also been called upon to submit long-term low-GHG development strategies covering a time frame through 2050 (UNFCCCn.d.b.). For India too, it is crucial to align short-, medium-, and long-term policies and targets to optimize the path to achieving its climate and development goals, while ensuring efficient use of resources and avoiding the lock-in of carbon-intensive behavior, technologies, and policies.

How can India identify cost-effective policy options for low-carbon development across different economic sectors and time frames? What are the potential trade-offs and co-benefits between climate policies and development priorities such as GDP and employment? What are the abatement potentials and implementation costs or savings of emerging technologies such as hydrogen in the Indian context? How can supporting policies create an enabling environment for climate policies? These are some of the key questions asked by policymakers when designing climate policies that can be answered through the India EPS.

By allowing the creation of multiple what-if policy scenarios through 2050, using combinations of a wide range of decarbonization policy options by sector, the India EPS enables users to assess the implications of their policy choices for several output variables of interest, such as GHG emissions and energy consumption by fuel and sector, emissions of other pollutants and associated co-benefits (for example, avoided premature mortality due to reduced particulate matter pollution), implementation costs of the various policy options, and the change (relative to the business-as-usual [BAU] scenario) in GDP, jobs, and net cashflows of different actors in the economy. Being an economy-wide model, it is also able to capture the co-benefits and trade-offs of policies across sectors, which allows for an integrated assessment and identification of cost-effective cross-sectoral policy packages.

Subsequent sections of this document introduce the India EPS in more detail and describe its structure, input data sources, assumptions, and limitations. The setup and key results of the BAU scenario are also discussed, since this scenario serves as the reference for evaluating the impact on the output parameters of any policy scenario constructed in the model. The last section introduces the two policy scenarios for India—the NDC–SDG Linkages and the Long-Term Decarbonization Scenarios—included in the current version of the model and briefly discusses the prospects for future developments of the model. A separate paper will present a detailed discussion of these two policy scenarios. Finally, it should be noted that this document is intended as an update to the first technical note on the India EPS (Mangan et al. 2019) and describes the changes incorporated into the model since the first version.

ABOUT THE INDIA EPS

The India EPS is a version of the Energy Policy Simulator, a free and open-source computer model developed by Energy Innovation LLC to help users identify policies that can significantly reduce GHG emissions in a cost-effective manner. The simulator is based on the SD framework developed in the software program Vensim and contains a default input dataset for adaptability across regions. The model dataset has been extensively customized to India in collaboration with WRI India.

The India EPS aims to help policymakers, regulators, researchers, and other interested users evaluate a wide range of climate-related policies. Using a Web interface or a downloadable version of the model in Vensim,[1] model users can combine various policies and control the extent of the implementation of these policies, thereby creating their own scenarios to evaluate the impact of policy choices.

Development and Updates

The first version (1.4.2) of the India EPS was launched in 2018 at the National Workshop on Energy and Environmental Modelling jointly organized by WRI India and Centre for Policy Research (CPR) in partnership with the Ministry of Environment, Forest, and Climate Change (MoEFCC). The model has since been updated to include additional improvements and features, and the current baseline input data reflect available data and policies in effect as of 2019. Major updates to the latest model versions (2.1 and 3.0 series of the India EPS) include important new capabilities relevant to the Indian context such as reporting of water consumption by power plants; additional fuel types (liquified petroleum gas [LPG]), crude oil, municipal solid waste); additional vehicle types; subsidies for power plant capacity construction; inclusion of the hydrogen supply sector; greater disaggregation of economic actors in the reporting of cash flow impacts; and policies for industrial material efficiency, reuse and longevity, shifting of industrial fossil fuel use to a mix of hydrogen and electricity, and the production of hydrogen through electrolysis.

To account for the impacts of the COVID-19 pandemic on energy and emissions, the India EPS has been updated to estimate COVID-19 recession impacts by simulating the effects of exogenous GDP changes on the demand for energy and energy-consuming services and products.

We also incorporated a major structural improvement toward the end of 2020 with the inclusion of a macroeconomic input-output (I/O) module within the India EPS. New feedback loops from the I/O module capture the effect of changes in indirect and induced economic activity across sectors on energy demand and emissions, jobs and employee compensation, and GDP. The model now also incorporates additional user flexibility with new Government Revenue Accounting (GRA) levers that allow the user to specify how the government accounts for changes in its revenue; that is, how it spends additional revenue or makes up for a shortfall in revenue caused by a policy package.

Overview of Key Policy Options and Outputs

The policy options in the India EPS span the main sectors of the economy: transportation, buildings, electricity supply, industry (including agriculture, waste, and wastewater), land use, and hydrogen. In addition, there are cross-sectoral policies that can be applied to multiple sectors such as carbon capture and sequestration (CCS), carbon tax (including on process emissions), research and development (R&D), and fuel-specific policies (i.e., subsidies and taxes). The model is simulated in annual time steps between 2019 and 2050.

Some examples of sector-specific policies that can be tested are electric vehicle (EV) sales mandates, vehicle fuel economy standards, building component electrification, building energy efficiency standards, carbon-free electricity production standards, early retirement of fossil power plants, industrial energy efficiency standards, methane capture and destruction, and afforestation and reforestation. Further, the India EPS contains policies that are based on technologies which are still in the early stages of development, but show potential for deep decarbonization in the long run; for example, the shifting of fuel use in industry from fossil fuels to a mix of electricity and hydrogen, material efficiency, longevity and reuse in industries, implementation of hydrogen vehicle sales mandates, and shifting of hydrogen production to potentially less emission-intensive processes (compared to steam reforming of natural gas) such as electrolysis of water. The India EPS also includes a control lever that allows the user to specify the foreseeable impact of a COVID-19-induced economic recession on the GDP growth rate in 2021, which in turn adjusts the energy consumption levels across sectors. Finally, the India EPS also incorporates GRA control levers, allowing users to specify how the government handles changes in cash flow (e.g., whether the government applies carbon tax revenue to regular spending, the national deficit, or changes in taxation).

The impact of policies can be visualized and evaluated annually using the India EPS Web tool across the following financial and social output metrics (additional outputs can be analyzed in the Vensim version of the downloadable model):

- GHG emissions: economy-wide and sectoral totals in carbon dioxide equivalent (CO_2e), disaggregated by gas and by activity within each sector, and per unit of GDP.
- Primary energy consumption by source, by end-use sector, and per unit of GDP. Energy production, exports and imports, and the related revenues and expenditures.
- Fuel and technology costs.
- The relative share of each policy in total GHG abatement, economy-wide and by sector.
- Policy costs, in terms of the average cost per metric ton of carbon dioxide equivalent (CO_2e) abated for each policy, and the total cost (or savings) of a policy scenario (relative to the BAU scenario), disaggregated by type of cost; that is, fuel and operations and maintenance (O&M), capital equipment, and tax rebates.
- Changes (relative to the BAU scenario) in GDP, jobs, and net cash flows of various actors in the economy (such as the government, industry, and consumers) due to a policy scenario.
- Emissions of other pollutants such as nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter (PM_{10} and $PM_{2.5}$). Human health benefits from reduced particulate matter emissions, such as avoided premature mortality, avoided work-loss days, and avoided hospital admissions.
- Monetized estimates of avoided premature mortality and climate benefits.
- Key outputs within each sector, as presented in Table 1.

MODELING APPROACH AND STRUCTURE OF THE INDIA EPS

Systems Dynamics as a Modeling Approach

The EPS is built on the theoretical framework of systems dynamics (SD), a concept first introduced by Jay Forrester in the 1950s at the Massachusetts Institute of Technology. It is an approach used to understand the nonlinear behavior of complex systems over time using feedback loops, stocks, and flows. SD attempts to capture the interactions between the various components within a system that give rise to results that are different from the sum of the changes within the individual parts of the system. Although it was primarily applied to corporate and industrial processes at its inception, SD has been increasingly used for policy analysis and design in the public sector (Radzicki and Taylor 1997).

Representations of energy and economic systems generally fall into two major types: top-down, computable general equilibrium (CGE) models that assume the economy to be a system at equilibrium subject to exogenous impacts, and bottom-up disaggregated technology-based models that quantify the potential emissions abatement possible in different sectors through efficiency gains in technologies. The former may be particularly useful for projecting BAU energy production and consumption trends as they are based on economic interactions. However, they may not represent certain outcomes arising from market failures, non-optimal behavior by economic actors, and so on. The latter models are more useful for quantifying specific abatement potentials from corresponding energy consumption activities in various sectors, but may not provide adequate insight into the policies driving the technical changes (Van Beeck 1999). The EPS uses input data on projections for BAU energy use in the demand sectors derived from both macroeconomic and technology-based models. It then applies an SD framework to capture the interactions between user-selected policies across sectors and evaluate the resulting impact on emissions, cash flows, and other output metrics relative to the BAU case.

As is common in SD models, EPS uses the state of the system calculated in a previous time step as an input for estimating the state of the system in the next time step. This is done by maintaining variables called “stocks,” whose values are retained in the model’s memory every

Table 1 | **Key Sectoral Outputs in the Energy Policy Simulator**

SECTOR	KEY OUTPUTS
Electricity	▪ Installed capacity and generation by technology; i.e., utility-scale and distributed solar photovoltaic, solar thermal, onshore and offshore wind, biomass, municipal solid waste, hydro, coal, lignite, natural gas, and petroleum ▪ Levelized costs of electricity generation by technology ▪ Curtailed generation from variable renewable energy sources ▪ Water withdrawal and consumption by various types of power plant
Transport	▪ Vehicle fleet and sales compositions disaggregated by vehicle technology; i.e., petroleum, diesel, electric vehicle, plug-in hybrids, liquefied petroleum gas, natural gas, and hydrogen ▪ Travel demand by passenger and freight modes ▪ Emissions and fuel use by passenger and freight vehicle type (e.g., cars, buses, two-wheelers, passenger rail, freight rail, etc.)
Industry	Fuel use and emissions by ▪ Major industry type; i.e., cement, mining, iron and steel, chemicals, natural gas and petroleum systems, and other industries ▪ Fuel type ▪ Energy-related and process emissions
Buildings	Energy consumption by ▪ Building type (rural and urban residential, commercial) ▪ Building component (appliances, lighting, cooling and ventilation, and other components) ▪ Primary energy source

Source: Authors.

year. Stocks are affected by variables called "flows," which are either added or subtracted each year. For instance, the total installed capacity of coal power plants at any given time of the model run is a stock variable. This capacity can either increase or reduce gradually, due to construction of new coal power plants (inflows) or retirement of old plants (outflows). The stock variable value is remembered across each subsequent year of the model run after any modifications in the previous year. In contrast, the variable representing the electricity generated by coal power plants in any given year is calculated afresh and is hence not a stock variable. By maintaining information on stocks, variables such as the electricity generation fleet or efficiencies of building components are remembered from one year to the next. As a result, any energy efficiency measures implemented in the early years will lead to fuel savings through the lifetime of the component, until it is retired from service.

The approach followed in the industry sector is different, as the estimation of emissions abatement and cost implications is done specifically for each sector depending on the context: a detailed description is included in the online model documentation.[2] The input data in this sector are available in the form of BAU fuel use and process emissions by industry subtypes and the potential reductions in fuel use and process emissions by policy. Hence, in this case, emissions reductions and the associated costs are implemented gradually rather than by tracking the sector-wide efficiency recursively.

Model Structure

The EPS comprises the sectors shown in Figure 1, where the directions of the arrows depict the order of calculations. The six main sectors are industry and agriculture, buildings, transportation, electricity, district heat and hydrogen, and land use, along with the supporting modules for handling intermediate calculations. This section gives an overview of the model structure and important feedback loops, which are extensively covered in the online model documentation.[3] Since the India EPS adopts the same structure without modification, an exhaustive description of the model structure is beyond the scope of this document, whose purpose is to describe the adaptation of the model to India.

The starting point for the model's calculations is in the fuels module, where the BAU properties of the fuels are set and policies that affect the prices of fuels are applied. Total fuel use is estimated from the demand sectors of transportation, buildings, and industry and agriculture[4] (this includes the demand for hydrogen in these sectors, which is computed in the district heat and hydrogen sector).[5] The amount of electricity required by the system is calculated by summing the electricity demand in these sectors, including the district heat and hydrogen sector. This is then used as an input to the electricity sector for estimating the power supply that needs to be built to meet the demand based on cost and operational considerations, any country-specific constraints such as mandated capacity construction for meeting RE targets, and electricity sector policies.

Emissions due to both direct fuel use (e.g., fossil fuels used in transportation and industrial processes) and indirect fuel use (i.e., fuel consumption in the electricity sector for meeting the electricity demand in other sectors, accounting for transmission and distribution [T&D] losses) are calculated in each sector. Total emissions are summed in the pollutant module in the bottom right of Figure 1, which allows for the calculation of health outcomes due to changes in the levels of particulate pollutants.

The changes in direct (first-order) cash flows of various entities are also calculated at this stage. The model tracks the changes in cash flows for nine entities: government, non-energy industries, labor and consumers, and foreign entities, and five types of energy suppliers (electricity, coal, natural gas and petroleum, biomass and biofuel, and others). In addition, the model also tracks cash flow impacts by 36 International Standard Industrial Classification (ISIC) code categories, based on the format of the 2018 edition of the Input-Output tables by the Organisation for Economic Co-operation and Development (OECD 2018b).

The calculated changes in direct cash flow by ISIC code are then input into a fully integrated macroeconomic IO model, which outputs GDP, jobs, and employee compensation. The IO model calculates how money is re-spent by the government, households, and various industries, which allows it to capture in its outputs the indirect and induced impacts on economic activity caused by selected policies, in addition to direct impacts. The indirect and induced impacts are fed back from the IO model into the main model to adjust the energy demand and cash flows, allowing the EPS to also capture these impacts on economic activity in its energy-use and emissions outputs. For example, suppose the government enacts a carbon tax on the industrial sector and uses the tax revenue to increase its expenditure on goods and services (assuming, for simplicity, that no costs of the tax are passed through to households, leaving their cash flows unchanged). In this case, the indirect effects (i.e., the change in demand for goods and services in the economy from the industrial sector in response to the carbon tax) and induced effects (i.e., the change in demand for goods and services in the economy due to the government re-spending its carbon tax revenues) of this policy would be calculated in the IO model and fed back to the main model to adjust the energy demand and cash flows of each sector or entity.

Apart from the macroeconomic feedbacks on energy demand and cash flows discussed above, there are many other feedback loops incorporated within the model. For example, changes in production costs lead to changes in fuel (including electricity) prices, which then feed into

- industrial demand,
- the cost of energy used in buildings, and
- the demand for transportation.

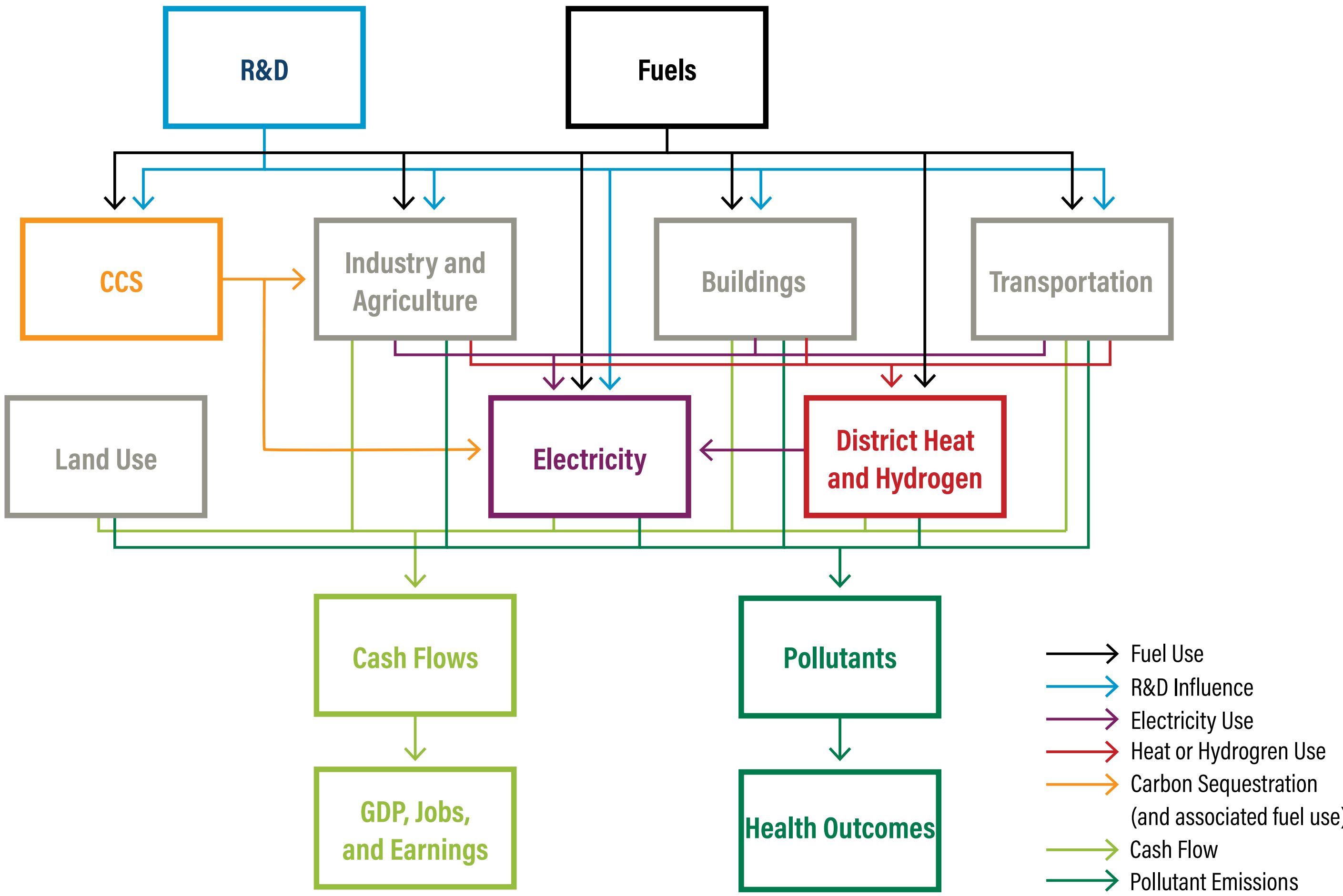
Changes in policies also affect demand. For example, changes in import and export policies will affect fuel production, and changes in peaking capacity will affect electricity generation capacity.

In addition, the following modules represent controls that affect operations across the demand and supply sectors:

- R&D: Allows the users to specify improvements in fuel economy and capital costs for technologies used in the four sectors linked to this module (see Figure 1) as well as to the CCS module.[6]
- CCS: Allows users to specify the amounts of carbon sequestered in the electricity and industry sectors, thereby impacting emissions and the associated cash flows.

The basic structure of the EPS can be visualized as consisting of two layers. The first layer consists of the visible system of equations between the input and output variables. The second layer is the underlying model data structure, where the input data are stored in the form of arrays or matrices. These data elements are used as inputs (along with the policy settings) by the system of equations in the model for performing output calculations.

Figure 1 | **India EPS Model Structure Representation**



Notes: CCS = carbon capture and sequestration; EPS = Energy Policy Simulator; GDP = gross domestic product.
Source: Energy Innovation LLC n.d.

For example, in the transportation sector, the visible structure includes variables that represent policies such as fuel economy standards and BAU input data (e.g., passenger- or freight-distance traveled, and calculated values such as the total amount of fuel used by the vehicle fleet). The underlying arrays consist of vehicle types (light-duty vehicles [LDVs], heavy-duty vehicles [HDVs], aircraft, rail, ships, and two- and three-wheelers), modes (passengers or freight), and fuel and/or technology types (petroleum gasoline, petroleum diesel, electricity, etc.). For all combinations of array elements, the model will perform a separate set of calculations based on the associated input data; for example, calculation of fuel economies for passenger LDVs, HDVs, and so on.

It is important to note that unlike other energy and economy models, the EPS does not endogenously calculate the future BAU energy requirement in the demand sectors to build a reference scenario. It instead uses the BAU demand trajectories from other models as inputs in the default model dataset and applies the policy settings within the SD framework to estimate the potential emissions reductions, cost implications, and social benefits relative to the BAU case. Utilizing the already available demand projections from other independent models that account for growth drivers is more suited to the primary purpose of the EPS model, which is to evaluate a variety of specific policy options that are immediately useful to policymakers.

Input Data

The customized input dataset in the India EPS has significant data requirements. The model includes 220 variables across all sectors, most of which correspond to features of the sector that need to be quantified to set up the BAU scenario, as well as those needed to measure the impacts due to the implementation of any policy in that sector relative to the BAU scenario. For adaptation to a country other than the United States, each input variable is assigned an order of importance; that is, very high, high, medium, or low. A "very high" or "high" importance ranking implies that the model results will be very sensitive to the country specificity of the variable; that is, leaving the default U.S. value in place will lead to large inaccuracies in the result. An example of such a variable is "BAU Components Energy Use," which depends on country-specific building stock and climatic conditions. On the other hand, "low" importance variables are unlikely to vary much by country. An example of this is the "GWP by Pollutant by Timeframe," which refers to the global warming potential of a GHG, a scientific property independent of country. For most "very high," "high," and "medium" importance variables, India-specific data have been sourced. More details about the format and organization of the input data can be found in the online model documentation on the input datasets.[7]

Input data for the current model version were updated by January 2020 and vetted by sectoral experts shortly thereafter. The objective of the vetting exercise was to gather and incorporate expert suggestions on the choice of important data sources used in the model, as well as examining the assumptions underlying long-term projections of key sectoral baseline variables. The main criteria for selection of the experts included policy expertise in their respective sectors, or familiarity with modeling of energy systems for India with comparable data requirements and assumptions, along with their availability. We consulted with a total of 23 experts (with a minimum of 2 per sector) from think tanks, academic institutes, and a few policy implementation agencies. The full list of experts consulted is provided in Appendix A (Table A2).

To the extent available, official data reported for 2019 and 2018 are used.[8] The steps of our approach to sourcing and adapting input data for the India EPS, in order of priority, are as follows:

- To the extent available, publicly and freely available data from Indian government agencies and public models such as NITI Aayog's India Energy Security Scenarios (IESS) and domestic, peer-reviewed databases or publications are used.
- In cases where the above data are not available or are obsolete, we use data from reputed international sources such as the International Council on Clean Transportation (ICCT) for transportation demand trends and the OECD for macroeconomic IO data.
- Where India-specific data for the base year (2018) or future projections were unavailable, input data from other countries or from the base year for India were respectively scaled as needed. The choice of the scaling factor depends on its suitability to the concerned variable. For instance, in the absence of future projections, a variable related to the growth of fuel use in the waste sector is scaled based on population projections since that is the primary driver of waste energy and emissions. In other cases where India-specific capital cost data were not available for specific technologies (e.g., CCS), U.S. costs were adjusted by either the ratio of India-to-U.S. capital costs in a comparable sector (e.g., power plant costs) or the ratio of India-to-U.S. GDP per capita.
- Where Indian data were unavailable and it was not possible to scale global data or data from other countries, the available data were retained. This applies to variables with low geographic specificity, such as the "GWP by Pollutant by Timeframe" mentioned previously, where the data are not country specific, or for a variable such as the expected lifetime of a building component—for example, an air conditioner—which is relatively standardized for the component in the international market.

The source(s) used for the "very high," "high," and "medium" importance input data variables (classified based on their geographic specificity) are listed in Appendix A (Table A1). The details of the sources and the underlying assumptions for each variable are documented in the "About" tab of the variable's Excel file in the downloadable model folder.

Assumptions and Limitations

The assumptions underlying this model are of two types. The first type is the assumptions and simplifications made in the general structure of the EPS to represent a model abstraction that is less complex than the real world.[9] The second type is the assumptions made in the underlying input data specific to the India EPS. It was necessary to make reasonable assumptions in cases of non-availability of base-year data or future projections, data discrepancies, and future progress toward BAU policy targets, and to transform available data that were in a different format from that required by the structure of the EPS. Significant assumptions were vetted by our panel of sectoral experts. Further, the India EPS baseline emissions trajectories in all sectors have been calibrated relative to the baseline emissions in five independent scenario-based modeling studies for India.[10]

Some of the main assumptions and consequent limitations underlying the general structure of the EPS are as follows:

- The effects of the policies in the EPS are quantified based on underlying data that draw from other models or studies. For instance, the taxation on coal can be increased by a percentage specified by the user. But the resulting impact of this policy on coal consumption in the economy is based on the static price elasticity of coal demand, which is based on the results of other studies, which in turn assume a set of real-world conditions under which specific policies are analyzed. These conditions need not reflect the combination of policy settings chosen by the user in the EPS. Further, the selected policies in the EPS are not loaded sequentially; they are simulated simultaneously. These factors inject uncertainty in the model outputs. The model's BAU case is likely to most closely reflect the real-world assumptions of various studies from which the input data are drawn. Hence, the uncertainty of the policy effects in a policy scenario created by the user is likely to be least when few policies are selected and/or policy settings are kept at values close to the BAU values. As the number of policies increases and the policy settings deviate further from the BAU values, the uncertainty is likely to increase.
- It is currently not possible to quantify the uncertainty in the model. However, the EPS model supports Monte Carlo analysis in the Vensim interface, which can help identify inputs to which the sensitivity of the model results is high.
- The EPS is forward simulating rather than goal seeking. In other words, policies in the EPS imply specific actions, or events, that influence actions (such as changing the price of fuel), rather than targets that are met by an optimal set of actions. Several policy scenarios—each involving certain pros and cons—could lead to achievement of a desired target, which makes the model well suited to a what-if approach to policy analysis. Except for the Carbon-free Electricity Standard (the equivalent of India's Renewable Purchase Obligation [MNRE n.d.] policy) and the electric vehicle sales mandates, the EPS policies imply actions rather than targets.
- The pricing policies in the model cannot entirely account for all possible effects, as some effects could also be triggered by other policy levers. The EPS is designed to avoid double counting of effects from policies that interact with each other. To estimate combined pricing effects and non-pricing policy impacts within a package, the model follows two main approaches: either the policy lever is defined to be additive to any price-induced impacts, or the lever is specified as a floor (or ceiling) that comes into play only after any price-induced impacts. Some trade-offs are introduced on account of these techniques to avoid double counting in the model. For instance, additive policies are not similar to real-world policies, as it is not possible for policymakers to foresee the quantity of price-induced impacts and then implement a policy additive to them.
- The IO model within the EPS follows standard IO modeling principles. One limitation of this approach is that it uses static IO tables from a single historical year, the 2018 edition of the OECD IO table (OECD 2018b), and therefore does not capture any shifts in the structure of the economy (e.g., from manufacturing to services) or how industrial supply chains may be altered by policy.

Some broad assumptions and limitations related to the Indian input dataset are listed below. More specific assumptions related to the policies represented in the BAU scenario are discussed in the next section.

- The baseline energy demand projections for most demand sectors are drawn from the IESS model (NITI Aayog 2015b), which uses 2012 as its base year. However, it is at present the most comprehensive source for the demand projections for the long-term horizon of 2050, and it was developed through a consultative process. A newer version of the model is in the pipeline, and the India EPS input data will accordingly be updated to align with the latest projections.
- In some cases, either due to the absence of data in the base year or lack of projections, alternate data from other countries such as the United States have been scaled to represent Indian conditions, thus increasing

uncertainty. The main source of uncertainty is in the costs of nascent technologies such as CCS, hydrogen equipment, battery storage, and demand response.

- In a few instances, data discrepancies exist between input data from multiple Indian sources (e.g., baseline energy demand for the buildings sector). In such cases, we either gave priority to official data, or we attempted to corroborate the data with multiple independent studies to understand the source of the differences and choose the best available combination of data, in consultation with our panel of sectoral experts. In either case, the assumptions and underlying reasoning are documented transparently in the corresponding input data files, which will make it easy to update data when the data sources are improved.

THE BAU SCENARIO

Scenario Description and Setting

The BAU scenario provides the reference case for testing the relative impact of low-carbon policies in our decarbonization scenarios. It represents an emissions trajectory based on the expected growth in India's energy demand across the sectors of buildings, transport, and industry (agriculture and waste are included within industry in the EPS), along with resulting growth in the electricity sector. The scenario includes the effects of key existing policies, which are outlined in the sectoral assumptions discussed in this section subsequently. Net sinks from the land-use, land-use change, and forestry (LULUCF) sector are assumed to stay constant at the 2014 level of approximately –301 million tons of CO_2e in the scenario. This is consistent with the approach adopted in the existing literature in the absence of emissions projections for the sector, and is a conservative assumption given that India's NDC includes an unconditional target for this sector (Forsell et al. 2016).

To project the growth in energy demand through 2050, we follow the general approach of scaling the start year energy demand in 2019 to the future, based on the growth rate projected in the respective sectoral demand trajectories in the IESS.[11] This is because the EPS does not endogenously project the future BAU energy requirement in the demand sectors, as discussed previously (two exceptions to this are described in the next paragraph). Hence, the assumptions underlying the drivers of growth in the IESS energy demand trajectories for the buildings and industry sectors also apply to the growth in energy demand in the respective demand sectors in the India EPS. The broad macroeconomic assumptions that drive demand in the IESS trajectories and are indirectly used for estimating demand growth in the India EPS are listed in Table 2.

There are two exceptions to the general rule of using exogenous demand trajectories. These are in the electricity and transportation sectors, which are both derived

Table 2 | **Macroeconomic Assumptions Underlying IESS Trajectories Used in the India EPS**

	ANNUAL AVERAGE GDP GROWTH RATE (AT FACTOR COST, AT REAL PRICES, IN %)					
	2017-2022	2022-2027	2027-2032	2032-2037	2037-2042	2042-2047
IESS High Growth Scenario (%)	8.1	8.4	8.4	8.2	6.5	5.6
OTHER GLOBAL ASSUMPTIONS						
Share of Manufacturing (%)	21	24	26	29	31	34
Population (million)	1,383.6	1,453.5	1,534.9	1,592.2	1,659.6	1,704.2
Urbanization (%)	36	39	42	45	48	51
Household Size	4.6	4.4	4.3	4.1	4.0	3.8
Urban Population (million)	498.1	566.9	644.3	716.5	796.6	869.1
Rural Population (million)	885.5	886.6	889.6	875.7	863	835.1
Urban Households (million)	108.4	127.7	150.5	173.7	200.8	228.1
Rural Households (million)	192.7	199.7	207.8	212.3	217.5	219.2

Notes: EPS = Energy Policy Simulator; GDP = gross domestic product; IESS = India Energy Security Scenarios.
Source: NITI Aayog 2015a.

demands. Here, the model uses its decision-making logic to construct the BAU case. In the electricity sector, the model builds power plants to meet the BAU electricity demand in a particular year (based on the preceding year's stock), by optimizing capital and operating costs, subject to grid flexibility and any specified policy-based assumption, such as a mandated capacity addition target. Similarly, in the transport sector, the model selects vehicle technologies that meet the BAU travel demand for a given year (based on the preceding year's stock) by optimizing capital and the operating costs of vehicles, subject to any specified policy-based assumptions, such as an EV sales mandate.

With regard to existing policies in the BAU, we assume varying levels of success in implementation of key existing climate policies, such as the 175 GW RE target by 2022, the National Biofuel Policy, and the EV subsidy policies (Dubash and Ghosh 2019), depending on their current level of progress and implementation challenges. Assumptions regarding the level of achievement of the policies are based on a combination of literature reviews (official policy documents and independent assessments of the progress of policies) and consultations with our panel of sectoral experts. The policy and modeling assumptions for the BAU scenario are summarized below for each sector. Key data-related assumptions are summarized in Appendix B (Table B1).

Key Sectoral Assumptions

Electricity

The power generation technologies modeled are solar (utility solar PV, rooftop PV, solar thermal), wind (onshore and offshore), hydro (including pumped hydro), biomass, nuclear, distributed non-solar (diesel pump sets), municipal solid waste, petroleum, hard coal, lignite, and natural gas (peaker and non-peaker).[12] Rather than deploying rooftop PV in response to policies or targets in the electricity sector, it is instead deployed in response to the distributed solar policies in the buildings sector and has the effect of reducing demand from the electricity sector.

The following constraints, based on existing policies in the near term, are assumed to apply in the BAU scenario before the cost-optimization logic is applied to build electricity generation capacity:

- Annual capacity additions for conventional sources (including hydro) and retirements for existing coal and lignite capacity up to 2027 are based on the Central Electricity Authority's National Electricity Plan (CEA-NEP) (CEA 2018).
- 60% of the 175 GW RE target[13] is assumed to be achieved by the end of 2022 (CRISIL 2019).
- We assume that solar PV, solar thermal, on-shore and off-shore wind, and biomass plants qualify as generation sources for meeting any exogenous targets for the Carbon-Free Electricity Standard (CES) policy, per India's Renewable Purchase Obligation policy (MNRE n.d.). Small hydropower is not considered here, because hydropower is not disaggregated by size in the model.
- Must-run status for renewable generation under the Indian Electricity Grid Code is assumed to continue through the model run by prioritizing dispatch from renewable sources over other sources, which are subject to least-cost dispatch later if there is still unmet power demand. However, this does not imply that renewable generation is not curtailed, which depends on the flexibility available to integrate variable renewable energy (VRE) in the grid, as discussed in the subsequent point.
- The flexibility needed to integrate variable generation from wind and solar is estimated at an annual time scale based on the seasonal peak time capacity factors of wind and solar, and the availability of grid flexibility resources including grid battery storage, transmission capacity, peaking sources like natural gas and pumped hydro plants, and demand response capacity. Hence, the model assumes some amount of grid battery storage capacity to be available in the BAU scenario, which can be increased exogenously through a policy intervention. The Central Electricity Authority (CEA) projects a 34 GW battery storage capacity for India by 2030, according to the "Optimal Generation Mix for 2030" report (CEA 2020). This is used as an interim target in the BAU case. With a slow start from 2020/21 due to near-term cost barriers, storage capacity reaches 5 GW by 2022, 34 GW by 2030, and 74 GW by 2050, bounded by the IESS Level 4 trajectory.
- Except for onshore/offshore wind and solar PV, our general approach is to take start year capital costs from various sources and decrease them at the same rate as the cost decreases in the IESS projections. Wind and Solar PV (utility scale and rooftop) are handled differently in the model, relying on endogenous capacity-based learning curves to determine the

cost decreases applied to start year costs (i.e., the year before the first simulated year). We take overall O&M cost shares from the IESS, which does not break O&M costs into variable and fixed components. We then apply the split between variable and fixed O&M from Lazard's levelized cost of electricity (LCOE) estimates for the United States, using expected capacity factors in the BAU scenario to help allocate the O&M costs. The resultant LCOE of various sources in the BAU scenario is summarized in the Results section.

Buildings

The building types modeled are urban residential, rural residential, and commercial. The building energy service components modeled are appliances, cooling and ventilation, lighting, and other components. The following assumptions apply in the BAU scenario to estimate the energy demand:

- Future energy demand projections for building service components in the India EPS are scaled from the actual energy demand in the start year, based on the rate of demand underlying Level 2[14] of the IESS demand trajectory for buildings. At this level, the IESS trajectory assumes the introduction of bylaws for Energy Conservation Building Code (ECBC) compliance in new commercial buildings and mandatory compliance in government buildings. It is also assumed that new residential buildings will adopt more incentive schemes under the ECBC. The growth in demand is influenced by the assumptions associated with the trajectory, such as types of building space and structures, penetration of smart building interventions in new residential buildings, and penetration of efficient appliances. Level 2 assumes that 17 percent of the appliances in 2047 would be highly efficient.
- In the case of future energy demand for cooking needs, we refer to Level 1 of the IESS to scale the demand growth to account for the slow historical progress in clean cooking initiatives thus far. In this trajectory, it is assumed that with continued efforts to promote adoption of modern cooking fuels, 40 percent of rural households will switch to LPG by 2050. 15 and 18 percent of rural and urban households will use electricity for cooking needs, respectively, and traditional biomass usage for cooking will be phased out by 2037. With the increased availability of piped natural gas (PNG), cooking energy needs in urban areas will be met by a mix of PNG and LPG.
- We separately account for the use of agricultural residue in the cooking energy needs of rural residential households. We use estimates of the agricultural residue usage for India in the start year from the GAINS model of the International Institute for Applied Systems Analysis (IIASA) and scale future use based on the IESS level 1 trajectory.

Transport

The vehicle types modeled are passenger (cars, buses, aircraft, rail, ships, two-wheelers, three-wheelers) and freight (light duty trucks, heavy duty trucks, aircraft, rail, ships). The vehicle technologies modeled are petroleum, diesel, LPG, natural gas, plug-in hybrid, and battery electric vehicles. The following assumptions apply in the BAU scenario before the cost-optimization logic is applied to calculate vehicle fleets (by vehicle and technology type) to meet the travel demand:

- Future travel demand for the different passenger and freight vehicle types in the India EPS are projected from the travel demand in the start year, which is estimated by interpolating the total passenger and freight distance traveled between 2012 and 2022 under the BAU trajectory (level 1) of the IESS.[15] In this trajectory, a steady increase in the per capita intercity and intra-city travel demand for passengers (measured in passenger-kilometers) is estimated due to increase in economic activity and improved access to transportation infrastructure. In the freight transportation sector, growth in industrial activity increases the demand for movement of goods and materials.
- The future transportation mode shares and travel distance projections are scaled relative to the start year, based on the rate of growth of passenger and freight distance traveled by the different vehicle types included in ICCT's Roadmap model results for India.
- The fuel economy of new petroleum and diesel vehicles is expected to improve up to 2022 according to India's fuel efficiency standards in ICCT's Roadmap model. We scale the improvements for EVs and plug-in hybrids in proportion to the percentage reduction in fuel use from electrification. The fuel economy improvements for petroleum and diesel vehicles are listed in Appendix B (see Table B2).
- The National Policy on Biofuels targets 20 percent blending of ethanol in petrol by 2030 (MNRE 2018). Due to feedstock supply procurement and land availability constraints, progress toward this target has

been slow. We assume a target of 14 percent ethanol blending in petrol to be achieved by 2030 based on the trends observed between 2013 and 2019.

- We assume subsidies for on-road electric vehicles to apply through 2021 per the incentives and timelines in Phase 2 of the Faster Adoption and Manufacturing of hybrid and EV (FAME II) subsidy scheme rolled out by Department of Heavy Industries (Ministry of Heavy Industry n.d.).

Industry

The industry types modeled are cement, mining, iron & steel, chemicals, natural gas & petroleum, waste & wastewater, agriculture, and other industries. Both energy-related and process emissions are modeled, based on the following assumptions in the BAU scenario:

- To track the future demand of fuel from the various industry categories, we estimate the fuel-use consumption in the start year based on official reporting categories. Since the categories of industry in official reports differ from those within the EPS, we first map the sub-categories of industries between the official sources and the India EPS to ensure that all fuel use is accounted for and there is no double counting.
- To estimate the future fuel demand, the start year fuel consumption is scaled for future growth by industry and by fuel type, based on the respective growth rates in Level 2 of the IESS, which assumes a gradual penetration of energy efficiency measures among industrial units (under the Perform-Achieve-Trade scheme [BEE n.d.]) and autonomous energy efficiency improvements in specific energy consumption.
- In the Agriculture sector, the growth of fuel consumption is as per Level 1 of the IESS. This assumes no additional improvements in fuel efficiency of tractors and no demand side incentives for improving energy efficiency.
- The EPS tracks both end-use energy combustion activity and process emissions in industries. It uses global datasets from U.S. EPA (2019) and Potsdam Institute for Climate Impact Research (Gütschow et al. 2019) to estimate BAU process emissions. We scale India data from these datasets to bring them in line with the estimates from GHG Platform India (GHGPI n.d.), since large differences were observed in emissions estimates for various sectors between different data sources. We also account for emissions from burning of agricultural residue.

Fuels

The fuel types modeled are coal, lignite, natural gas, nuclear, wind, solar, biomass, petroleum, diesel, biodiesel, jet fuel, kerosene, crude oil, heavy fuel oil, LPG, municipal solid waste, and hydrogen. The following assumptions apply to fuel prices and supply in the BAU scenario:

- In the start year, the actual fuel prices (including sales taxes, value-added taxes, and excise taxes) are estimated from official sources for the various fuel types, by end-use industry. The pre-tax components of the prices for most fuels are projected to rise in the future, based on the expected growth rates of the respective fuel prices in U.S. Energy Information Administration's Annual Energy Outlook (U.S. EIA 2021). We assume the share of taxes in fuel prices to remain constant at start year levels over time.
- The existing direct subsidies for domestic LPG and natural gas are assumed to continue in the model run. We do not account for any existing subsidies for VRE sources (e.g., preferential tariffs, viability gap funding) because falling technology costs have led to VRE sources becoming cost-competitive in the market.
- To estimate the future domestic supply of fossil fuels, we estimate the production of different fuels in the start year and scale it for the future based on the expected growth rates in the level 2 trajectory of the respective IESS fuel supply sectors. This trajectory assumes planned increases in coal production per the 12th five-year plan until 2022 and a slower rate of growth of proven coal reserves thereafter. With some improvements in mining technologies, coal production is expected to peak around 2037 and decline marginally by 2047. Oil discoveries currently under various stages of approvals are expected to progress to production after 2021. Moderate development of coal-based methane and continuation of the present gas price and utilization policies are assumed for natural gas production.

Gross Domestic Product

The assumption about the BAU GDP in the India EPS is implicit in the corresponding sectoral IESS demand projections that it relies on to construct its BAU demand trajectories (see Table 2). To calculate and report macroeconomic changes resulting from policy scenarios created in the model in relative terms (for example, the percentage change in GDP from the BAU scenario), the IO model requires a BAU GDP projection. The long-term growth forecast from OECD for India through 2050 (OECD 2018a) is used for this purpose, although these GDP values are not used to drive the BAU demand trajectories in the model.

COVID-19 Recession Impacts

To account for the impacts of the COVID-19 pandemic on energy consumption and the resulting emissions, the India EPS estimates the effect of a GDP shrinkage (relative to a counterfactual BAU GDP in 2020) on the energy consumption across all demand sectors. As of January 2021, India's National Statistical Office (NSO) estimated a 7.7 percent contraction in GDP growth for FY2020–21. We use this shrinkage value along with the estimated reduction in energy demand in 2020 to estimate the impacts on energy and emissions in the BAU scenario.[16] The GDP growth rate is assumed to follow a V-shaped recovery trajectory, with the impacts decreasing by 50 percent in each subsequent year to reach counterfactual BAU GDP levels only by 2030.

Key Results

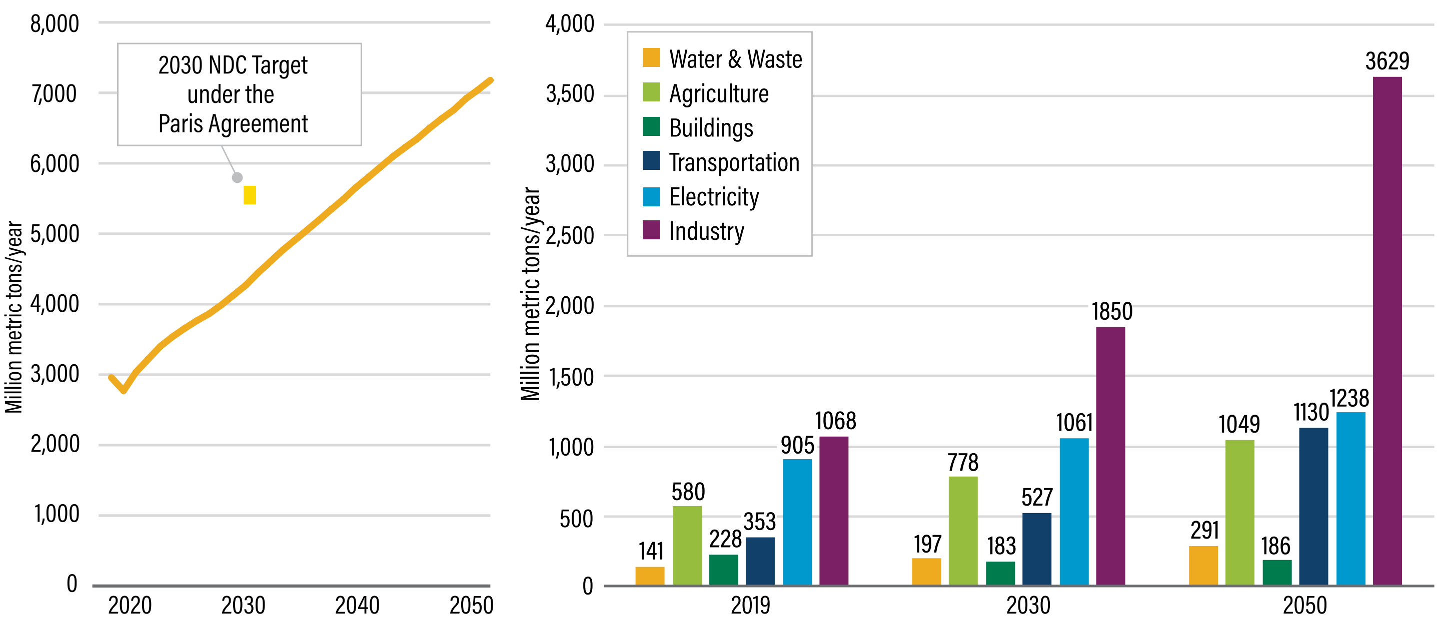
Total Emissions

Total CO_2e emissions in the BAU scenario (accounting for sinks from the land-use sector) steadily rise to about 7,220 million metric tons (MMT) by 2050, about a 143 percent increase (2.4 times) from 2019 levels. The COVID-19-induced recession introduces a dip in BAU emissions in 2020 of about 6 percent, but this is a temporary effect, with the upward trend in emissions resuming by 2021 (see Figure 2a). Without accounting for carbon removals from the land-use sector, CO_2e emissions rise to 7,500 MMT by 2050. The increase in BAU emissions is largely driven by the industry sector, which accounts for nearly 50 percent of the total emissions in 2050. This is followed by the electricity (16 percent), transport (15 percent), and agriculture (14 percent) sectors. The mid-term and long-term growth of sectoral emissions are shown in Figure 2b.

Emissions by Pollutant

In addition to reporting emissions in CO_2e, the model also provides estimates of emissions of different pollutants. These include emissions of different GHGs that contribute to the CO_2e total, as well as that of other pollutants such as nitrogen oxides (NO_x), sulfur oxides (SO_x), and particu-

Figure 2 | **(a) Total CO_2e Emissions Growth, (b) CO_2e Emissions by Sector in BAU Scenario**



Notes: BAU = business as usual.
Source: Authors.

late matter (PM_{10} and $PM_{2.5}$). Although these pollutants do not contribute to overall CO_2e emissions, they are detrimental to air quality and human health.

In the current BAU scenario, there is a rise in most pollutant emissions except for organic carbon (OC) and volatile organic compounds (VOCs), as shown in Table 3 below. The largest increase is in emissions of fluorinated gases (f-gases), which grow almost ten-fold by 2050, followed by CO_2 and NO_x, which grow nearly three-fold. The reason for the decline in OC and VOC emissions is the reduction in residential consumption of biomass (the largest contributor to these emissions) over time, as biomass is substituted by other fuels such as LPG.

Some policies that were announced but not implemented at the time of setting up the BAU scenario are available as exogenous policy levers that can be tested in the model. For example, the Bharat Stage VI (BS-VI) emissions norms for on-road vehicles (Dellmann and Bandivadekar 2016) can be tested exogenously to explore their effect on pollutant emissions that are regulated under the norms.

Primary Energy and Electricity Consumption

Primary energy consumption across the economy rises over threefold from about 52,400 petajoules (PJ) in 2019 to 1,65,350 PJ in 2050. As seen in Figure 3, most of the consumption is driven by the industry and electricity sectors, which contribute about 48 and 33 percent of the total energy consumption, respectively, in 2050. The energy consumption by the buildings sector decreases by nearly 40 percent over the model run. This can be attributed to the reduced use of primary energy (mostly from phasing out a large amount of initial biomass use by 2030) and increasing rates of energy-efficient electrification within the buildings sector in the BAU scenario.

Among the energy sources, fossil fuels (petroleum products, crude oil, natural gas, coal and lignite) account for about 70 percent of the primary energy supply in 2050 in the BAU scenario (see Figure 4).

Electricity demand increases in the BAU scenario across most sectors (see Figure 5). The biggest increases in 2050 are seen in the electrification of vehicles (15 times over 2019 levels) and of building service demand (6 times over 2019 levels).

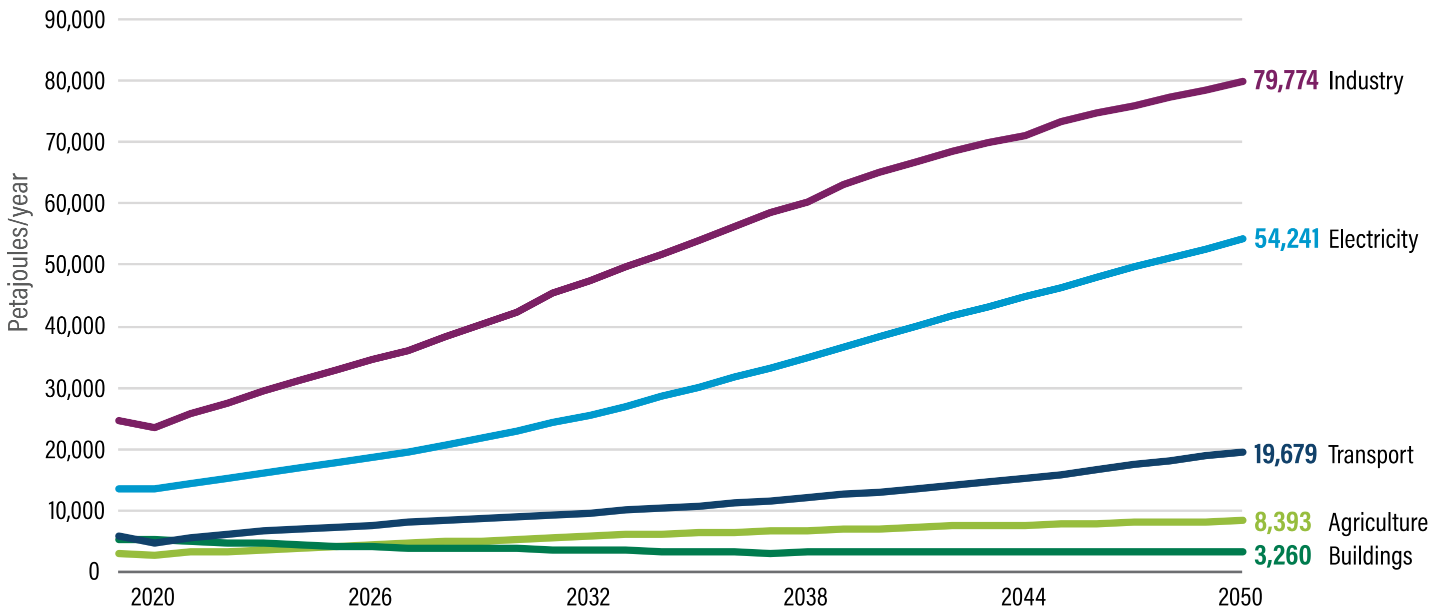
Due to the increasing cost-effectiveness of EV technologies, there is some default penetration of EVs in the sales of new vehicles in the BAU scenario. The Ministry of Power has set an aspirational target (note that this is not a mandated target) to achieve 30 percent share of EVs on the roads by 2030 under the National Electric Mobility Mission Plan, which is partially achieved in the BAU scenario itself, depending on the vehicle type. The percentages of EVs in the sales of different vehicle types by 2050 are presented in Table 4.

Table 3 | **Pollution Growth in BAU Scenario**

POLLUTANT	% INCREASE/ REDUCTION (–) IN 2050 OVER 2019 LEVELS	POLLUTANT	% INCREASE/ REDUCTION (–) IN 2050 OVER 2019 LEVELS
Carbon dioxide	168	Black carbon	63
Methane	60	Organic carbon	–46
Nitrous oxide	68	Nitrogen oxides	194
Fluorinated gases	851	Volatile organic compounds	–32
PM 2.5	41	Sulfur oxides	112
PM 10	118	Carbon monoxide	36

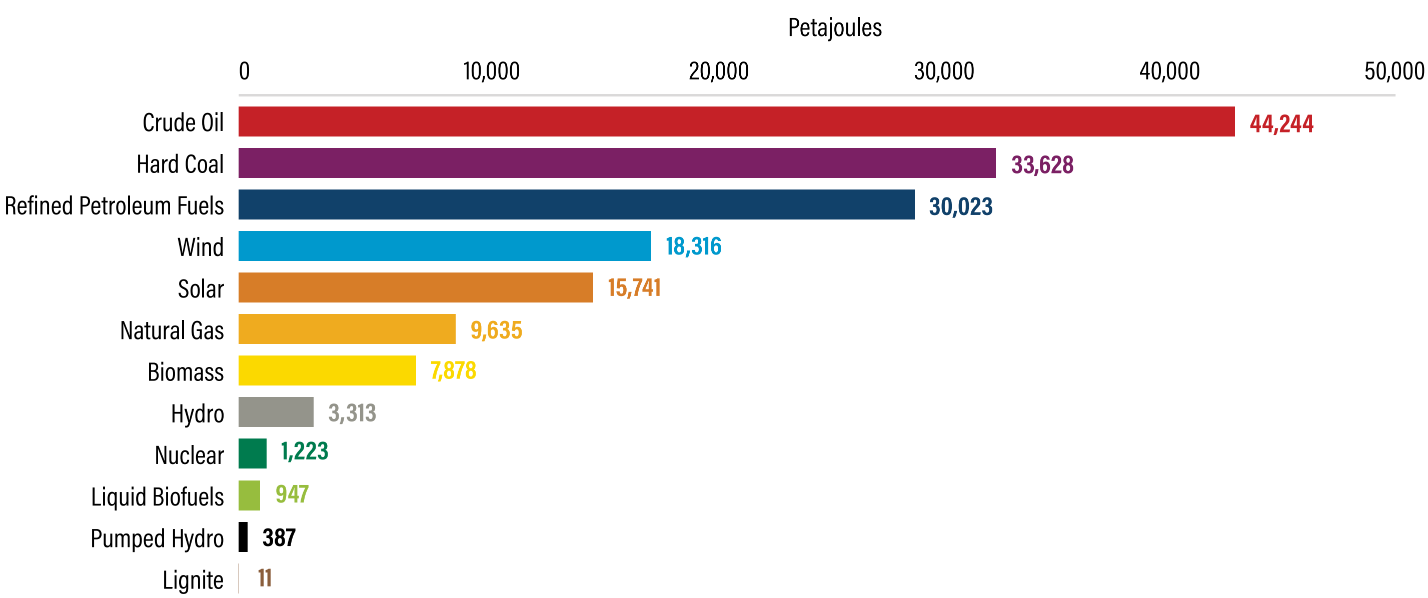
Notes: BAU = business as usual; PM = particulate matter.
Source: Authors.

Figure 3 | **Energy Consumption by Sector in BAU Scenario**



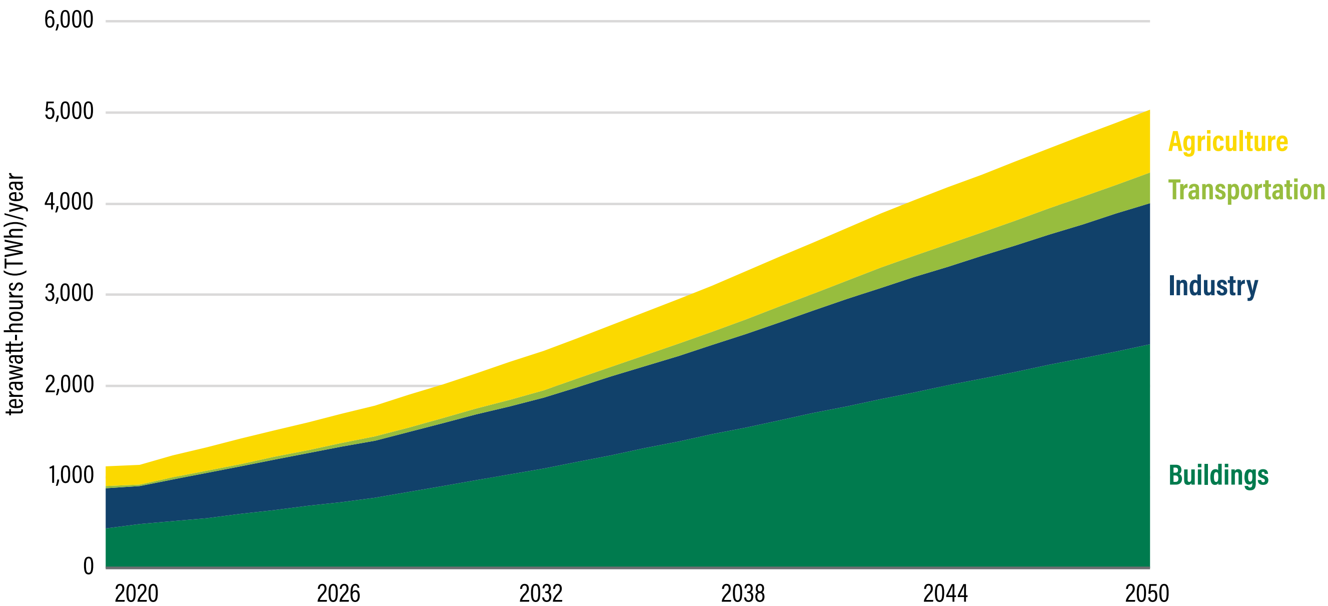
Notes: BAU = business as usual.
Source: Authors.

Figure 4 | **Primary Energy Supply Sources in 2050 in the BAU Scenario**



Notes: BAU = business as usual.
Source: Authors.

Figure 5 | Electricity Demand by Sector in the BAU Scenario



Notes: BAU = business as usual.
Source: Authors.

Table 4 | EV Penetration in New Vehicle Sales in 2050 in the BAU Scenario

VEHICLE TYPE	% OF EV PENETRATION IN NEW VEHICLE SALES IN 2050
Passenger LDVs (cars and SUVs)	35
Passenger HDVs (buses)	23
Passenger rail	100
Two-wheelers	38
Three-wheelers	30
Freight LDVs (light freight trucks)	14
Freight HDVs (medium and heavy freight trucks)	4
Freight rail	100

Notes: BAU = business as usual; EV = electric vehicle; HDV = heavy duty vehicle; LDV = light duty vehicle; SUV = sports utility vehicle.
Source: Authors.

Electricity Supply Profile

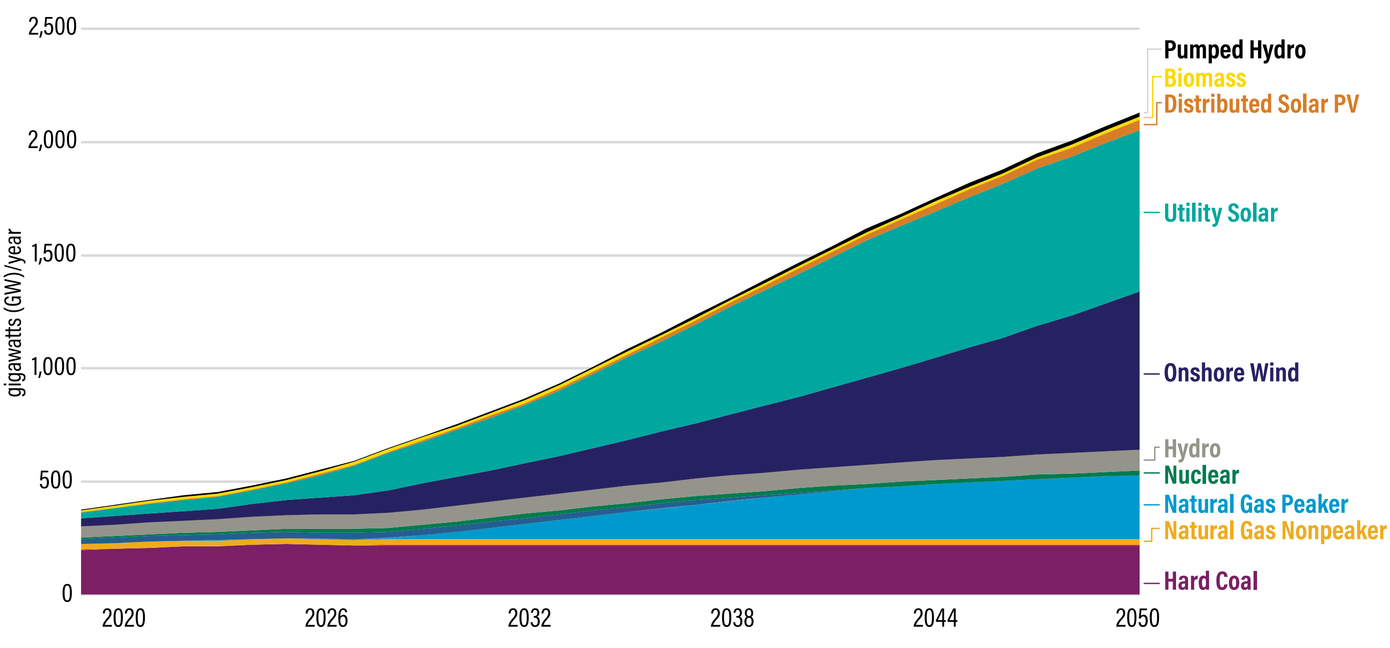
Due to the falling costs of VRE generation technologies (i.e., utility-scale onshore wind and solar PV) combined with rising coal prices in the long run, a significant amount of RE generation capacity is deployed within the model in the BAU scenario, especially after 2030 (see Figure 6).

In 2030 itself, about 44 percent of the capacity mix comprises VRE (utility-scale wind + solar PV). If we include large hydro as an RE source, the installed capacity of VRE sources and large hydro together will amount to about 410 GW by 2030. This suggests that market-driven progress in deploying RE in the BAU, though significant, will in and of itself be insufficient to achieve India's recently announced target of installing 450 GW RE capacity by 2030[17] (GoI 2021).

The share of non-fossil sources (i.e., utility-scale solar PV, wind, hydro, nuclear, and biomass) in the capacity mix in 2030 reaches 58 percent, which surpasses India's conditional target of achieving 40 percent non-fossil share of cumulative power generation capacity by 2030 in its NDC under the Paris Agreement. In 2050, about 72 percent (1,540 GW) of the installed power capacity in the model is from non-fossil sources, while 66 percent (1,410 GW) comprises VRE. This is accompanied by about 285 GW of natural gas peaker plants and 74 GW of grid battery storage to ensure sufficient flexibility in the grid to absorb the high share of VRE generation. The complete source-wise installed capacity mix in 2050 is listed in Appendix B (Table B3).

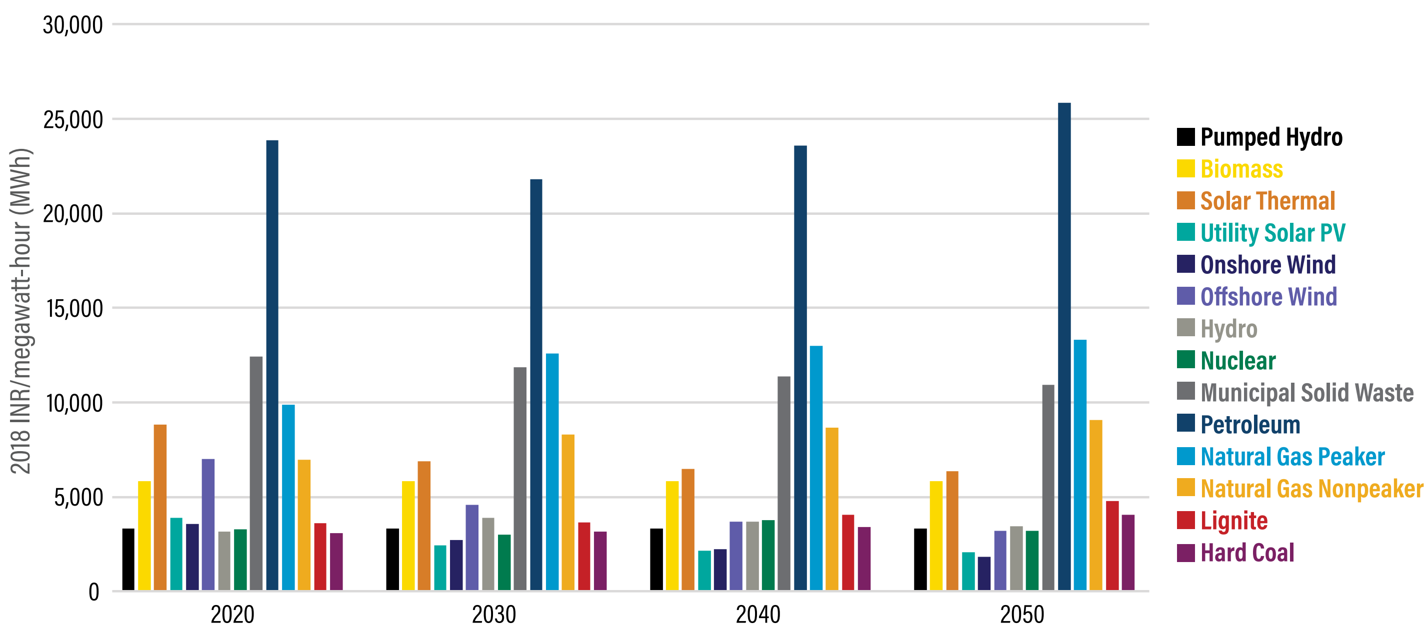
In terms of electricity generation, nearly 70 percent of the electricity generated in 2050 is from non-fossil sources, while 60 percent of it is from VRE. The LCOE of coal and natural gas peaker plants increases by 32 and 35 percent, respectively, between 2020 and 2050 due to rising fuel costs. On the other hand, the LCOE of utility solar PV and wind reduces significantly by 46 and 49 percent, respectively, due to falling technology costs. However, the generation-weighted average LCOE of the overall capacity mix remains approximately the same at 2018 INR 3.2/kWh between 2020 and 2050, as the lower costs associated with the increasing share of VRE sources is accompanied by the need for more expensive natural gas peaker generation to manage the higher share of VRE in the grid. The change in the LCOE of individual generation sources in the BAU scenario (after accounting for subsidies) is shown in Figure 7.

Figure 6 | **Electricity Capacity Mix in the BAU Scenario**



Notes: BAU = business as usual; PV = photovoltaic.
Source: Authors.

Figure 7 | **Levelized Cost of Electricity of Various Generation Sources in the BAU Scenario**

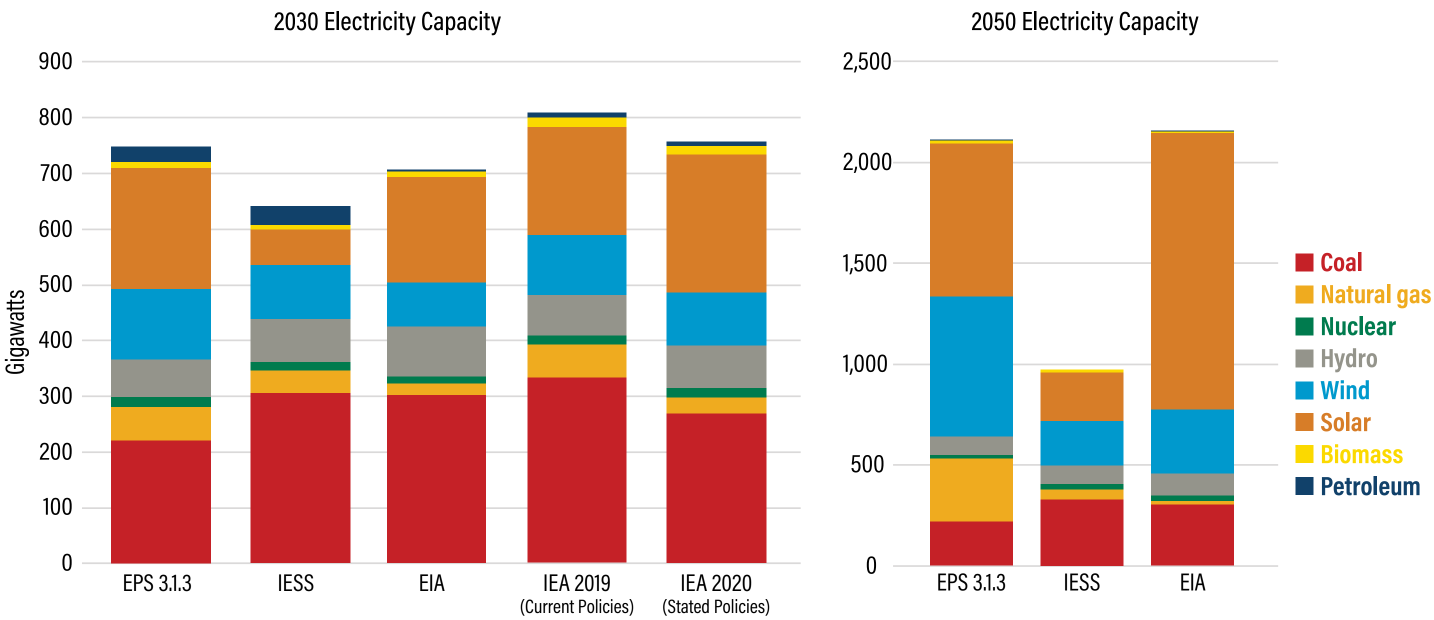


Notes: BAU = business as usual.
Source: Authors.

Comparison of Results with Other Models

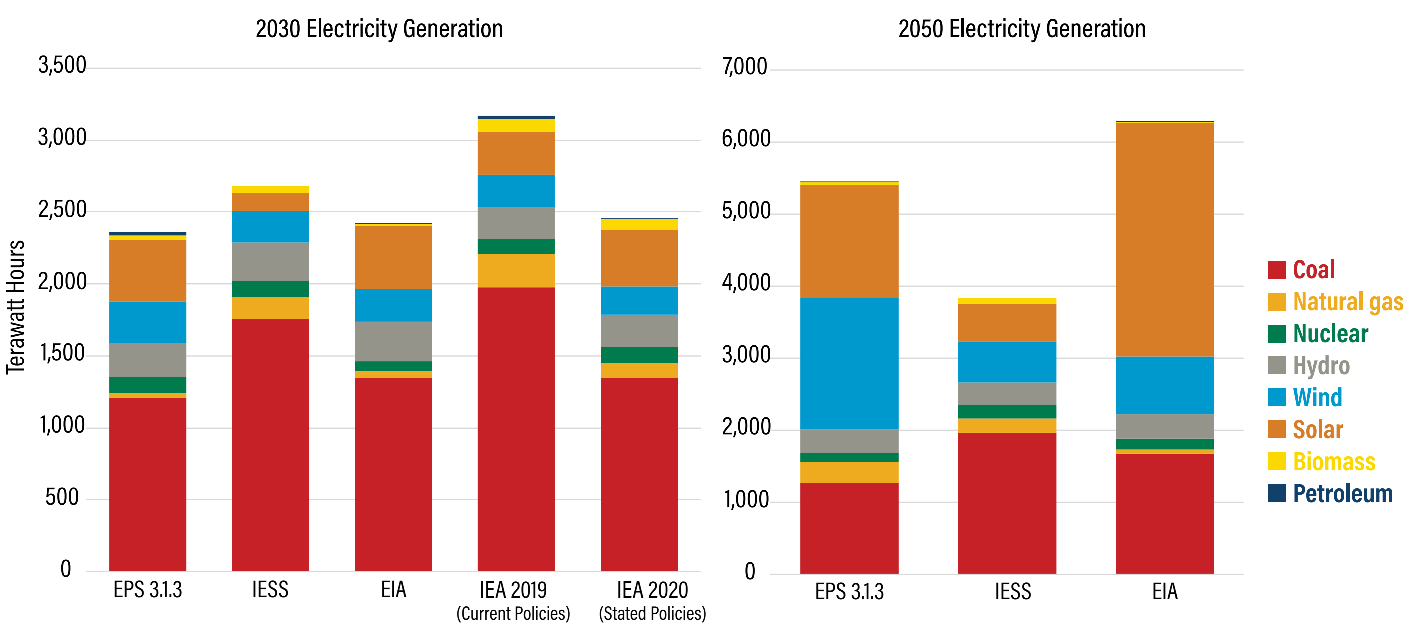
We compared the main BAU results from the India EPS with other recent modeling studies in the public domain. Although it was possible to identify some reasons for variations in projections due to differing approaches to accounting, the models also differ in terms of several other important underlying assumptions. For instance, model results in the electricity sector would be sensitive to the recency of rapidly evolving cost projections for solar-PV-based generation. A detailed review of the variations in assumptions is outside the scope of this document, but the trajectories are presented here for reference. Figures 8 through 11 present a comparison of the BAU electricity capacity mix, electricity generation mix, electricity demand, and total emissions (CO_2e), respectively, between the India EPS, IESS, U.S. Energy Information Administration (U.S. EIA), and International Energy Agency (IEA) estimates.

Figure 8 | **Comparisons of BAU Electricity Capacity Mix in 2030 and 2050**



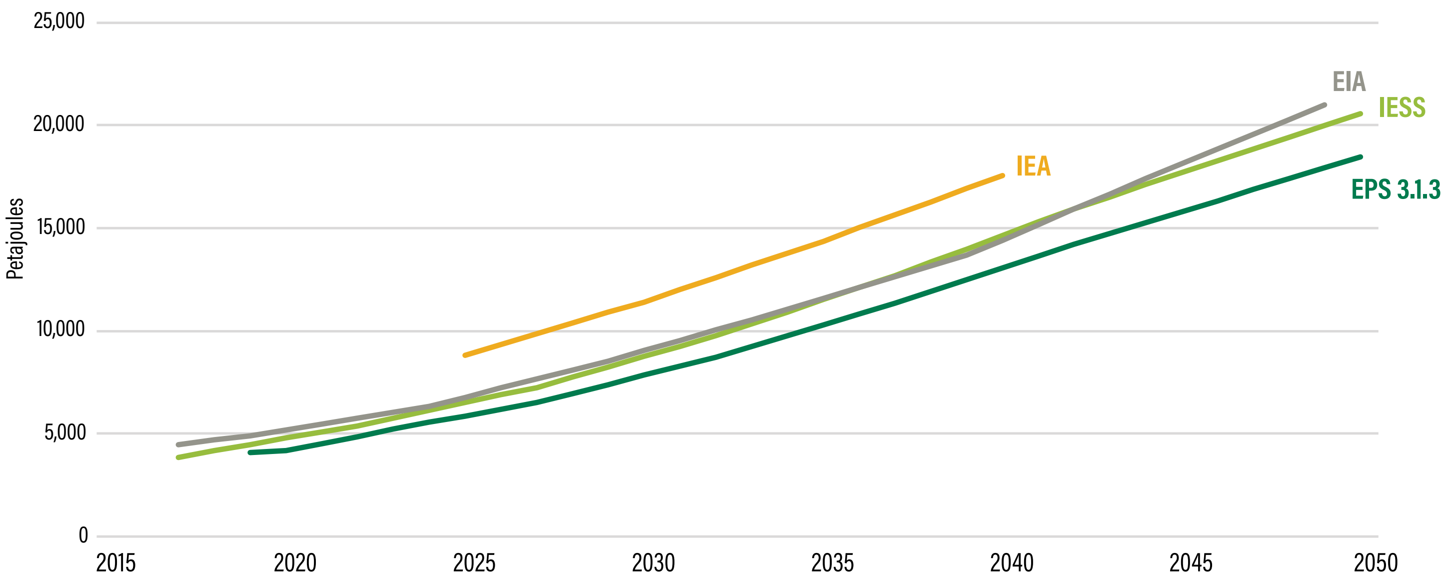
Notes: BAU = business as usual; EPS = Energy Policy Simulator; IEA = International Energy Agency; IESS = India Energy Security Scenarios; U.S. EIA = U.S. U.S. Energy Information Administration. Petroleum capacity in the EPS consists almost entirely of distributed backup generators, which may be counted in the buildings sector in other sources. EIA coal capacity numbers might include the capacity used to generate electricity consumed on-site at industrial facilities. Results for the IESS model do not include the "Electricity Balancing Requirement", which is estimated separately in the IESS.
Source: Authors, using data from NITI Aayog 2015a, Pavarani 2019, U.S. EIA 2019.

Figure 9 | **Comparisons of BAU Electricity Generation Mix in 2030 and 2050**



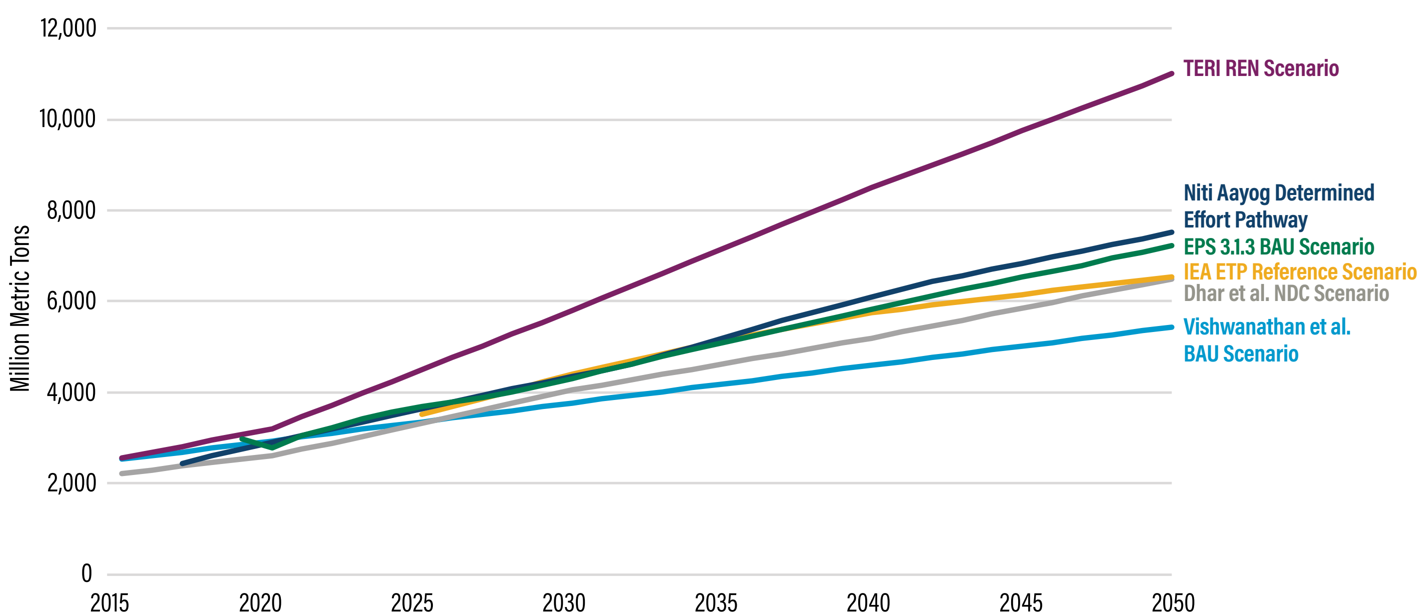
Notes: BAU = business as usual; EPS = Energy Policy Simulator; IEA = International Energy Agency; IESS = India Energy Security Scenarios; U.S. EIA = U.S. Energy Information Administration. The EIA coal capacity numbers may include the capacity used to generate electricity consumed on-site at industrial facilities. Results for the IESS model do not include the "Electricity Balancing Requirement", which is estimated separately in the IESS.
Source: Authors, using data from NITI Aayog 2015a, Pavarani 2019, U.S. EIA 2019.

Figure 10 | **Comparison of Total BAU Electricity Demand**



Notes: BAU = business as usual.
Source: Authors, using data from NITI Aayog 2015a, Pavarani 2019, U.S. EIA 2019.

Figure 11 | **Comparison of Total CO_2e Emissions**



Notes: BAU = business as usual; EPS = Energy Policy Simulator; ETP = Energy Technology Perspectives; IEA = International Energy Agency; REN = Renewable Energy Scenario.
Source: Authors, using data from Dhar et al. 2018, NITI Aayog 2015b, Pavarani 2019, TERI and WWF (2013), U.S. EIA 2019, Vishwanathan et al. 2017.

Assessment of Progress toward India's Climate Targets

India ratified the Paris Agreement in 2017, thereby converting its initially submitted Intended Nationally Determined Contribution (INDC) to UNFCCC in 2016 to its first official NDC under the Paris Agreement. The main quantifiable targets (unconditional and conditional) stated in the NDC as India's voluntary goals under the Paris Agreement (GoI 2016) are presented in Table 5.

The progress toward these targets in the BAU scenario using comparable metrics in the India EPS is also evaluated in the table.

Apart from its NDC commitments, India has recently announced domestic goals toward climate mitigation and low carbon development. In Table 6, we track the progress toward these aspirational targets in the India EPS BAU scenario.

Table 5 | **Progress toward Meeting NDC Targets under the Paris Agreement**

	STATED TARGET IN THE NDC	STATUS OF METRICS IN INDIA EPS BAU	PROGRESS IN INDIA EPS BAU
2030 Unconditional target	Reduce emissions intensity of GDP by 33–35% relative to 2005 levels in 2030	2005 level (18.5 gCO_2e/2018 INR) 2030 Emissions intensity (9.5 gCO_2e/2018 INR)	Surpassed target, with 48.6% reduction
2030 Conditional target[a]	40% Non-fossil share of cumulative power generation capacity by 2030	*Share of non-fossil sources in 2030 total electricity generation installed capacity:* 58% (Solar + Wind + Biomass + Hydro + Nuclear)[b] 56% (Solar + Wind + Biomass + Hydro) 44% (VRE: Solar + Wind)	Surpassed target, with minimum 40% capacity for all non-fossil qualifying source combinations

Notes: BAU = business as usual; EPS = Energy Policy Simulator; NDC = Nationally Determined Contribution; [a] Condition: transfer of technology and low-cost international finance including from GCF; [b] Solar includes utility-scale PV, Wind includes both utility-scale on-shore and off-shore, and Hydro includes large hydro and pumped hydro.
Source: Authors.

Table 6 | **Progress toward Recently Announced Domestic Climate Targets in the BAU Scenario**

DOMESTIC ASPIRATIONAL TARGET	STATUS OF METRICS IN INDIA EPS BAU	PROGRESS IN INDIA EPS BAU
450 GW RE by 2030	*Total installed utility-scale non-fossil/RE capacity in 2030:* 440 GW (Solar + Wind + Biomass + Hydro + Nuclear) 422 GW (Solar + Wind + Biomass + Hydro) 334 GW (VRE: Solar + Wind)	Not meeting the target for all RE qualifying source combinations
30% EV sales penetration by 2030 for all on-road vehicles	*% of EV penetration in new vehicle sales in 2030:* Passenger LDVs (cars and SUVs): 18% Passenger HDVs (buses): 10% Two-wheelers: 21% Three-wheelers: 15% Freight LDVs (light freight trucks): 6% Freight HDVs (medium and heavy freight trucks): 1%	Not meeting the target for all on-road vehicle types

Notes: BAU = business as usual; EPS = Energy Policy Simulator; EV = electric vehicle; GW = gigawatts; HDV = heavy duty vehicle; LDV = light duty vehicle; RE = renewable energy; SUV = sport-utility vehicle; VRE = variable renewable energy.
Source: Authors.

FUTURE DEVELOPMENT

At present, the India EPS encompasses the BAU scenario described in the previous section and two policy scenarios modeling low-carbon pathways for India's mid-term and long-term future. The mid-term scenario, known as the "NDC-SDG Linkages Scenario," considers policies that leverage the existing interconnections between India's climate actions toward its NDC commitments and the socioeconomic development goals under the 2030 Agenda for Sustainable Development. These policies are fully implemented at moderate ambition levels by 2030, considering the implementation challenges and constraints in the near term. The long-term scenario, known as the "Long Term Decarbonization Scenario," considers policies that show a high potential for GHG emissions abatement and implements them to ambitious levels by 2050, based on international best practices. Taking a long-term view, this scenario also considers post-2030 implementation of technologies that are currently nascent, such as hydrogen.

The India EPS Web interface allows users to create their own what-if scenarios or policy packages by implementing a wide range of sectoral decarbonization policies. Within any scenario, each policy can be implemented to a level of ambition and phased in according to an implementation schedule between 2019 and 2050 defined by the user. Such scenarios can be saved and shared with others, and their outputs downloaded. Users can thus assess the implications of policy choices in a particular scenario relative to the BAU scenario, for the key output parameters discussed previously, such as emissions, policy package cost, GDP, jobs, and health and social benefits. These capabilities highlight the potential applications of the model in exploring the scope or ambition of potential targets for India's next NDC, as well as the implications of potential pathways to these targets for key economic and social parameters.

In a future stage of this project, the Web interface may be enhanced to allow additional policy scenarios—for example, scenarios exploring the implications of deep decarbonization pathways or sectoral carbon budgets for India. The model may also be updated to use different or revised data sources, include new policy levers, and include results on the sensitivity of key model outputs to input data and assumptions.

APPENDIX A: SOURCES OF BAU INPUT DATA

The data sources used for the important input data variables in the India EPS are summarized in Table A1 below:

Table A1 | **Data Sources for Input Variables**

SECTION FOLDER	ABBREVIATION	MEANING	INDIA-SPECIFIC VALUES?	SOURCES
add-outputs	HOIbTP	Health Outcome Incidence per Ton Pollutant	No (U.S. data with population scaling for India)	U.S. EPA (2018)
add-outputs	VoaSL	Value of a Statistical Life	Yes	Majumder and Madheswaran (2018)
bldgs	BASoBC	BAU Amount Spent on Building Components	Yes	GBPN (2014); NITI Aayog (2015a)
bldgs	BCEU	BAU Components Energy Use	Yes	NITI Aayog (2015a); MoSPI (2019); MoPNG (2018); IIASA (2018); TERI (2016)
bldgs	BDEQ	BAU Distributed Electricity Quantities	Yes	NITI Aayog (2015a); Trivedi et al. (2018)
bldgs	BRESaC	Building Retrofitting Energy Savings and Costs	Yes	NRDC and ASCI (2013)
bldgs.	CL	Component Lifetime	No (U.S.)	U.S. HUD (2000); ENERGY STAR (n.d.)
bldgs	DSCF	Distributed Solar Capacity Factor	Yes	NITI Aayog (2015a); MNRE (2016)
bldgs	EoBSDwEC	Elasticity of Building Service Demand w.r.t. Energy Cost	No (U.S.)	U.S. EIA (2015)
bldgs	EoCEDwEC	Elasticity of Component Energy Demand w.r.t. Energy Cost	No (U.S.)	U.S. EIA (2014b)
bldgs	EoDSDwSP	Elasticity of Distributed Solar Deployment w.r.t. Subsidy Percentage	No (U.S.)	BNEF (2015)
bldgs	FoBObE	Fraction of Buildings Owned by Entity	Yes	CARE Ratings (2018); MoHRD (2018); Kumar et al. (2019)
bldgs	ICpUEfEBE	Incremental Cost per Unit Energy for Electrified Building Equipment	Residential Buildings: Yes; Commercial Buildings: No (U.S. data with GDP per capita adjustment for India)	NITI Aayog (2015a); U.S. EIA (2018); NREL (2018a)
bldgs	SoBRCBbG	Share of Building Retrofit Costs Borne by Government	No (U.S.)	U.S. DOE (2020)
bldgs	SYCEU	Start Year Components Energy Use	Yes	NITI Aayog (2015a); TERI (2016); MoPNG (2018); IIASA (2018); MoSPI (2019)
bldgs	SYDEC	Start Year Distributed Electricity Capacity	Yes	NITI Aayog (2015a); Trivedi et al. (2018)
ccs	BFoCPAbS	BAU Fraction of CCS Potential Achieved by Sector	Yes	Rao and Kumar (2014); NITI Aayog (2015a); IEA (2017)
ctrl-settings	EoSEUwGDPiR	Elasticity of Sectoral Energy Use w.r.t. to GDP in Recession	Yes	MoC (2020); PPAC (2020); POSOCO (2020)

Table A1 | **Data Sources for Input Variables (Cont.)**

SECTION FOLDER	ABBREVIATION	MEANING	INDIA-SPECIFIC VALUES?	SOURCES
ctrl-settings	GDPGR	GDP Growth Rates (to model the effect of the SARS-CoV-2 pandemic)	Yes	NSO (2021)
elec	BCRbQ	BAU Capacity Retirements before Quantization	Yes	CEA (2018)
elec	BDPbES	BAU Dispatch Priority by Electricity Source	Yes	CERC (2010b)
elec	BECF	BAU Expected Capacity Factors	Yes	NITI Aayog (2015a); U.S. EIA (2017); CEA (2018)
elec	BHRbEF	BAU Heat Rate by Electricity Fuel	Yes	NITI Aayog (2015a)
elec	BPMCCS	BAU Policy Mandated Capacity Construction Schedule	Yes	CEA (2018)
elec	BRPSPTY	BAU RPS Percentage This Year	Yes	MoP (2018)
elec	BTaDLP	BAU Transmission and Distribution Loss Percentage	Yes	NITI Aayog (2015a); CEA (2018)
elec	BTC	BAU Transmission Capacity	Yes	MoP (2016)
elec	CCaMC	Capacity Construction and Maintenance Costs	Yes	NITI Aayog (2015a); CEA (2018); Lazard (2019)
elec	DRC	Demand Response Capacities	Yes	TPDDL (2015); CEA (2018); CPI (2020)
elec	EIaE	Electricity Imports and Exports	Yes	Planning Commission (2014); IRADe (2018)
elec	ELF	Equipment Load Factors	No (U.S. data scaled for India)	NREL (2018b); Parray and Tongia (2019); Energy Transitions Commission (2020)
elec	EoTCCwTC	Elasticity of Transmission Connectivity Coefficient w.r.t. Transmission Capacity	Yes	NREL (2017)
elec	GBSC	Grid Battery Storage Capacities	Yes	CEA (2020); Pavarni (2019)
elec	MCGLT	Max Capacity Growth Lookup Table	Yes (except solar PV and wind, which use data from China as a proxy for India)	WRI (2018b); China Energy Portal (2018); CEA (2020)
elec	MPCbS	Max Potential Capacity by Source	Yes	MNRE (2017); CEA (2017a); NREL (2020)
elec	PTCF	Peak Time Capacity Factors	Yes	CEA (2018)
elec	RQSD	RPS-Qualifying Source Definitions	Yes	MoP (2018)
elec	SYC	Start Year Capacities	Yes	CEA (2017b); CEA (2018)
elec	TCAMRB	Transmission Capacity Across Modeled Region Border	Yes	CEA (2019)
elec	TCCpUCD	Transmission Construction Cost per Unit Capacity Distance	Yes	CERC (2010a)

Table A1 | **Data Sources for Input Variables (Cont.)**

SECTION FOLDER	ABBREVIATION	MEANING	INDIA-SPECIFIC VALUES?	SOURCES
fuels	BFPaT	BAU Fuel Prices and Taxes	Yes	Planning Commission (2014); MoPNG (2018); PPAC (2018); Coal India (2018); MoSPI (2019); BNEF (2020); U.S. EIA (2021); IEA (2021b)
fuels	BFPIaE	BAU Fuel Production Imports and Exports	Yes	NITI Aayog (2015a); PPAC (2018); MoC (2018); MoPNG (2019); PPAC (2020)
fuels	BS	BAU Subsidies	Yes	MoPNG (2018); PPAC (2018)
fuels	IMFPbFT	International Market Fuel Price by Fuel Type	Yes	MoPNG (2018); IEA (2021b);
fuels	PEI	Pollutant Emissions Intensities	Yes	Kurokawa et al. (2013); Jain et al. (2014); U.S. EPA (2016); Argonne National Laboratory (2016); GHGPI (2018); IIASA (2018).
fuels	PoFDCtAE	Percentage of Fuel Demand Change That Alters Exports	Yes	PPAC (2019); IBEF (2019)
hydgn	BHPSbP	BAU Hydrogen Production Shares by Pathway	No (Global)	IEA (2021a)
indst	BIFUbC	BAU Industrial Fuel Use before CCS	Yes	Jain et al. (2014); NITI Aayog (2015a); Argonne National Laboratory (2016); GHGPI (2018); MoPNG (2018); MoSPI (2019)
indst	BPEiC	BAU Process Emissions	Yes	Purohit and Höglund-Isaksson (2017); Energy Transitions Commission (2018); GHGPI (2018); U.S. EPA (2019); Gütschow et al. (2019)
indst	BPoIFUfE	BAU Proportion of Industrial Fuel Used for Energy	Yes	MoPNG (2018); MoC (2018)
indst	BSoAIGtAP	BAU Share of Agriculture Industry Going to Animal Products	Yes	Kumar et al. (2012); ICAR (n.d.); FAO (2016); IFPRI (2017); GHGPI (2018)
indst	CoNEPPpCAPS	Calories of Nutritionally Equivalent Plant Products per Calorie Animal Products Shifted	No (U.S. data used with animal production data from India)	Shepon et al. (2018); Vet Extension (2020)
indst	EoDfIP	Elasticities of Demand for Industrial Products	No (U.S.)	Ho et al. (2008)
indst	PPRiFUfERoIF	Potential Percentage Reduction in Fuel Use from Early Retirement of Inefficient Facilities	No (U.S.)	U.S. EIA (2014a)
indst	PPRiFUfICaWHR	Potential Percentage Reduction in Fuel Use from Increased Cogeneration and Waste Heat Recovery	Yes	IEA (2008); IEA and WBCSD (2013)
io-model	BEbIC	BAU Employment by ISIC Code	Yes	WIOD (2016); OECD (2018b)
io-model	BECbIC	BAU Employee Compensation by ISIC Code	Yes	OECD (2018b)

Table A1 | **Data Sources for Input Variables (Cont.)**

SECTION FOLDER	ABBREVIATION	MEANING	INDIA-SPECIFIC VALUES?	SOURCES
io-model	BGDP	BAU Gross Domestic Product	Yes	OECD (2018a)
io-model	BObIC	BAU Output by ISIC Code	Yes	WIOD (2016); OECD (2018b)
io-model	BPEaCP	BAU Population Employment and Compensation Projections	Yes	World Bank (2020); St. Louis Federal Reserve Bank (2020)
io-model	BVAbIC	BAU Value Added by ISIC Code	Yes	WIOD (2016); OECD (2018b)
io-model	DCSoCbIC	Domestic Content Share of Consumption by ISIC Code	Yes	WIOD (2016); OECD (2018b)
io-model	DLIM	Domestic Leontief Inverse Matrix	Yes	WIOD (2016); OECD (2018b)
io-model	DToPaSoVAbIC	Domestic Taxes on Production as Share of Value Added by ISIC Code	Yes	WIOD (2016); OECD (2018b)
io-model	FoGPbEaIC	Fraction of Goods Purchased by Entity and ISIC Code	Yes	WIOD (2016); OECD (2018b)
io-model	GaHEbIC	Government and Household Expenditures by ISIC Code	Yes	WIOD (2016); OECD (2018b)
io-model	HSR	Household Savings Rate	Yes	Anila et al. (2020)
io-model	LPGRbIC	Labor Productivity Growth Rate by ISIC Code	Yes	OECD (2018b)
io-model	IRoND	Interest Rate on National Debt	Yes	MoF (2018)
io-model	PoNDHbE	Percentage of National Debt Held by Entity	Yes	MoF (2018)
io-model	SIOM	Standard Input Output Matrix	Yes	WIOD (2016); OECD (2018b)
io-model	URPbIC	Union Representation Percentage by ISIC Code	Yes	Ministry of Labour and Employment (2015)
io-model	WMITR	Worker Marginal Income Tax Rate	Yes	MoF (2017); OECD (2018b)
land	AOCoLUPpUA	Annual Ongoing Cost of Land Use Policies per Unit Area	Yes	MoEFCC (2014)
land	BLAPE	BAU LULUCF (Land-Use, Land-Use Change, and Forestry) Anthropogenic Pollutant Emissions	Yes	Forsell et al. (2016); MoEFCC (2021)
land	CApULAbIFM	CO_2 Abated per Unit Land Area by Improved Forest Management	Yes	Singh (2012); GHGPI (2018)
land	CSpULApYbP	CO_2 Sequestered per Unit Land Area per Year by Policy	Yes (U.S. data used for felling cycle length)	MoEFCC (2017); North Carolina Forestry Association (n.d.)
land	FoFObE	Fraction of Forests Owned by Entity	Yes	FAO (2010)
land	ICoLUPpUA	Implementation Cost of Land Use Policies per Unit Area	Yes (U.S. data used for cost of forest management)	MoEFCC (2014); Moulton and Richards (1990)
land	PLANAbPiaSY	Potential Land Area Newly Affected by Policy in a Single Year	Yes	GoI (2016); MoEFCC (2017); WRI (2018a)
trans	AVLo	Average Vehicle Loading	Yes	NITI Aayog (2015a); ICCT (2017)

Table A1 | **Data Sources for Input Variables (Cont.)**

SECTION FOLDER	ABBREVIATION	MEANING	INDIA-SPECIFIC VALUES?	SOURCES
trans	BAADTbVT	BAU Average Annual Distance Traveled by Vehicle Type	Yes	NITI Aayog (2015a)
trans	BCDTRtSY	BAU Cargo Distance Transported Relative to Start Year	Yes	ICCT (2017)
trans	BESP	BAU EV Subsidy Percentage	Yes	Ministry of Heavy Industry and Public Enterprises (2019)
trans	BLP	BAU LCFS Percentage	Yes	MoPNG (2019)
trans	BNVFE	BAU New Vehicle Fuel Economy	Most (India/U.S.)	Iyer (2012); U.S. EIA (2014a); ICCT (2017); Ministry of Railways (2017)
trans	BNVP	BAU New Vehicle Price	Most (India/U.S.)	NITI Aayog (2015a)
trans	BPoEFUbVT	BAU Percentage of Each Fuel Used by Vehicle Technology	Most (India/U.S.)	MoPNG (2019); U.S. DOE, (n.d.)
trans	BRAaCTSC	BAU Range Anxiety and Charging Time Shadow Cost	No (U.S.)	Lin and Greene (2010)
trans	EoDfVUwFC	Elasticity of Demand for Vehicle Use w.r.t. Fuel Cost	No (U.S.)	U.S. EPA and U.S. NHTSA (2012)
trans	EoFoNVFE	Effect of Feebate on New Vehicle Fuel Economy	No (U.S.)	Greene et al. (2005)
trans	EoNVFEwFC	Elasticity of New Vehicle Fuel Economy w.r.t. Fuel Cost	No (U.S.)	Small (2010); Harrington and Krupnick (2012); U.S. DOE (n.d.)
trans	FoVObE	Fraction of Vehicles Owned by Entity	No (U.S.)	U.S. GSA (2011); U.S. Bureau of Transportation Statistics (2015); Author assumptions.
trans	MPNVbT	Max Percentage New Vehicles by Technology	Yes	Ministry of Heavy Industry and Public Enterprises (2019)
trans	SRPbVT	Separately Regulated Pollutants by Vehicle Type	Yes	ARAI (2018)
trans	SYFAFE	Start Year Fleet Avg Fuel Economy	Yes	ICCT (2017)
trans	SYVbT	Start Year Vehicles by Technology	Yes	MoRTH (2016); NITI Aayog (2015a)
trans	VBDR	Vehicle Buyer Discount Rate	Yes	Cropper et al. (2011)

Notes: A list of the abbreviations used in the table appears in the Abbreviations section at the end of the document; w.r.t. = with respect to.
Source: Authors.

Table A2 | **List of Sectoral Experts Consulted for Vetting of Input Data and Assumptions**

S. NO.	NAME	ORGANIZATION	SECTOR
1	Anantha Lakshmi Paladugula	Center for Study of Science, Technology, and Policy (CSTEP)	Transport
2	Ashish Verma	Indian Institute of Science	Transport
3	Ashwini Hingne	World Resources Institute (WRI)	Additional outputs (social cost of carbon, health benefits)
4	Deepak Krishnan	WRI	Fuels
5	Disha Agarwal	Shakti Sustainable Energy Foundation	Electricity
6	Indu K. Murthy	CSTEP	Land
7	Kajol	WRI	Industry
8	Kamna Waghrey	The Energy and Resources Institute (TERI)	Additional outputs (social cost of carbon), fuel sector elasticities
9	Madhu Verma	WRI	Land
10	Nihit Goyal	National University of Singapore	Additional outputs (social cost of carbon, health benefits)
11	Nikit Abhyankar	Lawrence Berkeley National Laboratory	Transport & buildings
12	Prachi Gupta	NITI Aayog	Overall modeling
13	Probal Ghosh	Integrated Research and Action for Development (IRADe)	Transport & carbon capture and sequestration (CCS)
14	Ritu Mathur	TERI	Additional outputs (social cost of carbon), fuel sector elasticities
15	Riya Rachel Mohan	CSTEP	Buildings
16	Roshna N	CSTEP	Electricity
17	Saumya Pandey	NITI Aayog	Overall modeling
18	Shatakshi Suman	Bureau of Energy Efficiency	Buildings
19	Shweta Srinivasan	CSTEP	Electricity
20	Sishir Garemella	Sunvest Capital	Buildings
21	Srihari Dukkipati	Prayas Energy Group	Electricity & fuels
22	Sumedha Malaviya	WRI	Buildings
23	Vaibhav Chaturvedi	Council on Energy, Environment, and Water (CEEW)	Electricity & industry

Notes: Stakeholders' organization or affiliation is as of February 2020, when the consultations were carried out.
The Input Output Model was integrated into the India EPS subsequently, and has not been vetted through stakeholder consultations at the time of this writing.
Source: Authors.

APPENDIX B: ADDITIONAL BAU ASSUMPTIONS AND RESULTS

Key assumptions underlying the important input data variables of the BAU scenario in the India EPS are summarized in Table B1 below:

Table B1 | **Key Data-Related Assumptions in the BAU Scenario**

EPS DATA VARIABLE ABBREVIATION	EPS DATA VARIABLE MEANING	SUMMARY OF BUSINESS AS USUAL (BAU) ASSUMPTION
ELECTRICITY		
BCpUC	Battery Cost per Unit Capacity	The cost for the start year is based on projected Li-ion battery costs per kilowatt-hour for the United States by Rocky Mountain Institute, scaled for India based on the ratio of average power plant construction costs for India vs. the United States. The remaining years are handled through the endogenous learning capability built into the Energy Policy Simulator (EPS). Endogenous learning is not applied to the Balance of System costs (e.g., land acquisition and permitting fees), which are calculated based on National Renewable Energy Laboratory (NREL 2018a) data for the United States, scaled similarly for India and assumed to remain constant through the model run.
BCRbQ	BAU Capacity Retirements before Quantization	Plants with their generation lifetime expiring before 2050 would retire within the model run. Future retirements for fossil plants are per planned retirements until 2027 in Central Electricity Authority's (CEA) National Electricity Plan (CEA 2018). Actual retirements in 2019 are considered for fossil plants.
BDPbES	BAU Dispatch Priority by Electricity Source	Solar and wind are assigned priority 1 per the must-run status accorded in the Indian Electricity Grid Code, 2010. The remaining sources follow least cost dispatch and are uniformly given priority 2. However, this does not imply that renewable generation is not curtailed, which is a function of the available flexibility provisions (e.g., battery storage capacity) to integrate variable renewable energy in the grid.
BPHC	BAU Pumped Hydro Capacity	Start year pumped hydro capacity is from CEA's data for September 2019. Its growth over the model run is assumed to be limited by a cap in the "Maximum Capacity Growth Lookup Table" variable (elec/MCGLT). The growth cap is per CEA's Optimal Generation Mix report for 2029–30, which bases capacity addition on an appraisal of CEA's pipeline of current and planned pumped hydro projects.
BTaDLP	BAU Transmission and Distribution Loss Percentage	Technical (physical) losses are considered here, starting from 21% in 2018 to reach 9.3% by 2050. Values from the India Energy Security Scenarios (IESS; NITI Aayog 2015a) Level 2 trajectory are used. Beyond 2047 (the IESS model limit) the slope is extended per the downward trend.
BTC	BAU Transmission Capacity	The expected transmission capacity for 2022 is taken from the National Electricity Plan (NEP) and the start year—i.e., 2019; transmission capacity from CEA is interpolated until 2022. From 2022 until 2036, capacity is scaled using scaling factors estimated using Ministry of Power's (MoP) Perspective Transmission Plan Report, 2016. After 2036, the amount is held constant since the growth rate in the preceding period is negligible.
CCaMC	Capacity Construction and Maintenance Costs	Except for onshore/offshore wind and solar PV, our general approach to capital costs is to take start year costs and cause them to decrease at the same rate as costs decreased in projections in the India Energy Security Scenarios (IESS) level 2 trajectory. Wind and Solar PV are handled differently in the model, where we provide first-year costs and then rely on endogenous learning curves to determine capital cost decreases using data on historical price decreases in accordance with the doubling of global capacity. Operation and maintenance costs are taken from the IESS level 2 trajectory and are assumed to be constant through 2050.

Table B1 | **Key Data-Related Assumptions in the BAU Scenario (Cont.)**

EPS DATA VARIABLE ABBREVIATION	EPS DATA VARIABLE MEANING	SUMMARY OF BUSINESS AS USUAL (BAU) ASSUMPTION
DRC	Demand Response (DR) Capacities	Start year DR potential is estimated by combining estimated DR capacity (%) data from Tata Power Delhi Distribution Limited and data for India peak demand from CEA. This is scaled linearly until the year 2030, for which the mid-range estimate by Climate Policy Initiative (CPI 2020) is used. Between 2030 and 2050, the potential is scaled based on growth in peak demand within the model.
DRCo	Demand Response Costs	Data from the U.S. Energy Information Administration (U.S. EIA 2020) is used to estimate DR costs per megawatt (MW) to energy utilities, with the costs being adjusted for India based on GDP per capita for India vs. the United States.
EIaE	Electricity Imports and Exports	The volume and prices of electricity imports and exports are based on projections from Integrated Research and Action for Development (IRADe 2018), which uses an integrated least-cost modeling approach to estimate the optimal economic trade potential that can be achieved in a multilateral trading agreement in the BBIN (Bangladesh-Bhutan-India-Nepal) region. The only source of imports considered is hydro, as India has only hydroelectricity contracts with neighboring countries, while the source of exported power is based on the prevailing energy mix for India in the model.
WUbPPT	Water Use by Power Plant Type	Current and projected average freshwater withdrawal and consumption values, weighted by the cooling technology type, are calculated for each generation source, based on India-specific data by WRI and IRENA (2018). Wind and hydro are typically assumed to have negligible water usage and hence assigned values of zero.
FUELS		
BFPIaE	BAU Fuel Production Imports and Exports	The general approach is to project start year fuel production, import, and export values per suitable scaling factors based on IESS level 2 trajectory projections. Bio-ethanol production is apportioned between bio-gasoline and bio-diesel per blending targets of 20% and 5%, respectively, by 2030. Municipal solid waste (MSW) generation is projected based on data from the Planning Commission (2014) and apportioned between bio-gasification (organic component) and refuse-driven fuel (non-organic component), assuming collection efficiency reaches 100% by 2022. Biomass, biofuels, and MSW have no imports/exports as they are still very nascent.
BFPaT	BAU Fuel Prices and Taxes	In the start year, the actual fuel prices (including sales taxes, value-added taxes, and excise taxes) are estimated from official sources for the various fuel types, by end-use industry. The pre-tax components of the prices for most fuels are projected to rise in the future based on the expected growth rates of the respective fuel prices in U.S. Energy Information Administration's (EIA) Annual Energy Outlook (AEO). We estimate the share of the tax component in the price build-up for the start year, and scale it for the future based on the corresponding growth rate of the pre-tax prices.
BS	BAU Subsidies	The direct subsidy currently provided on domestic LPG consumption as well as that on natural gas (in the Northeastern states) is considered. Coal subsidies are not considered as they are not direct subsidies. Since India has a declared capacity target for renewables, partial capacity construction based on this target is considered in the BAU scenario in the model, and hence subsidies for renewables by way of state feed-in tariffs or viability gap funding are not accounted for here.
BHPSbP	BAU Hydrogen Production Shares by Pathway	Hydrogen production within the BAU scenario is negligible. Current international production shares by pathway—95% by natural gas reforming and 5% by electrolysis—are considered, based on IEA data, and assumed to remain constant through the BAU scenario.

Table B1 | **Key Data-Related Assumptions in the BAU Scenario (Cont.)**

EPS DATA VARIABLE ABBREVIATION	EPS DATA VARIABLE MEANING	SUMMARY OF BUSINESS AS USUAL (BAU) ASSUMPTION
BCTR	BAU Carbon Tax Rate	The BAU coal cess in India has recently been converted to the "Goods and Services Tax (GST) Compensation Cess," applied on production and subsequent sales of coal and lignite and some solid fuels manufactured from them. However, it is a nominal rate (INR 400/metric ton, which translates to a little less than US$4/t$CO_2$e [2018]). The primary purpose of this cess is not an economy-wide carbon tax; it is used mainly for compensating tax revenue deficits at the state level. Hence, we do not consider a carbon tax in the BAU scenario.
INDUSTRY		
BIFUbC	BAU Industrial Fuel Use before CCS	All purchased energy consumed by the industry sector (except energy use for carbon capture and sequestration [CCS], if any) is accounted here using India-specific data from multiple sources, which is adjusted with IESS data, ensuring that the totals sum to forecasted totals in the first year modeled in the IESS. Start year values as obtained above are then scaled for future years per growth rates in Level 2 of the IESS trajectory. Scaling is based on the summed growth rate of the fertilizer and chlor-alkali industry for the chemicals sector; on population projections for the waste sector; and on projected fuel use quantities for natural gas, petroleum, and mining.
BPEiC	BAU Process Emissions	The U.S. EPA (2019) dataset and the PRIMAP-hist dataset by Potsdam Institute for Climate Impact Research (Gütschow et al. 2018) include data for non-CO_2 and CO_2 process emissions, respectively, for every country in the world. India-specific data from the two datasets are used here. Multipliers are used with the EPA dataset for India to bring it in line with the estimates from GHG Platform India (GHGPI) vetted by experts, since large differences were observed in emissions estimates for various sectors between different data sources. The PRIMAP-hist dataset does not include projections for future years; hence, CO_2 process emissions are scaled based on country-level projections of cement and steel production from the Energy Transitions Commission and population projections from the United Nations.
BUILDINGS		
BASoBC	BAU Amount Spent on Building Components	The number of residences (or commercial square meters) adding or replacing a component of a particular type in a year is estimated based on the number of net additions to the number of residences (or units of commercial floor space) in that year from the IESS Level 2 trajectory, plus (1/component lifetime) times the number of preexisting buildings (or units of commercial floor space). This, along with the average cost and number of components of each type per residence (or unit of commercial floor space), is then used to calculate the amount spent on each component type in that year.
TRANSPORT		
EVCC	EV Charger Cost	The cost of CHAdeMO and combined-charging-system-type chargers is considered based on MoP's 2018 notification *Charging Infrastructure for Electric Vehicles – Guidelines and Standards*. A constant cost of INR 1,450,000 per charger has been assumed.
FoVObE	Fraction of Vehicles Owned by Entity	In the absence of any good data on vehicle fleet ownership in India, we make the following assumptions, based on U.S. data (see Table A1) and our judgment, vetted by expert consultation (see Table A2): most passenger light duty vehicles (LDVs; cars, two-wheelers, three-wheelers) are owned by private consumers. In terms of government vs. private ownership, we assume the following shares to be government owned: 75% of buses (school, transit, and inter-city), 14% of commercial aircraft (i.e., Air India segment), 65% of passenger ships, and 100% of passenger and freight rail. Of the remaining vehicle types, most freight LDVs and heavy duty vehicles (HDVs) are privately owned. Seventy percent of freight ships are owned by the private non-energy industry, 20% by the private energy industry, and 10% by the government.

Table B1 | **Key Data-Related Assumptions in the BAU Scenario (Cont.)**

EPS DATA VARIABLE ABBREVIATION	EPS DATA VARIABLE MEANING	SUMMARY OF BUSINESS AS USUAL (BAU) ASSUMPTION
LAND		
BLAPE	BAU LULUCF Anthropogenic Pollutant Emissions	Based on Forsell et al. (2016), we assume that India's net emissions from the LULUCF sector stay constant over time at 2014 levels of approximately –300 million metric tons of CO_2e, as reported in India's *Second Biennial Update Report*.
CROSS-SECTOR AND INPUT-OUTPUT MODEL		
BFoCPAbS	BAU Fraction of CCS Potential Achieved by Sector	Since there are no CCS-related policies in India currently, the level 1 (least effort) trajectory of CCS capacity (in MW) in the IESS is used to represent the BAU case. CCS capacity (in metric tons CO_2/yr) is then determined from this, based on Rao and Kumar (2014). The CCS capacity calculated as above for each year is apportioned between the Electricity and Industry sectors using IEA's (2017) CCS fractions by sector for non– Organisation for Economic Co-operation and Development (OECD) countries.
CC	CCS Calculations	This variable captures the per metric ton capital and O&M costs, as well as energy use of CCS deployed, which are calculated based on U.S. cost estimates from Morris et al. (2021) and assumed to remain constant through the model run. The costs are scaled for India based on the ratio of average power plant construction costs for India vs. the United States.
BGDP	BAU Gross Domestic Product	This variable is used to estimate the impacts of exogenous policies tested in a non-BAU scenario, on a counterfactual BAU trajectory of GDP growth. The BAU projections for GDP are based on long-term-growth real GDP forecasts by OECD for India (OECD 2018a).
BPEaCP	BAU Population Employment and Compensation Projections	This variable is used to estimate the impacts of exogenous policies tested in a non-BAU scenario, on a counterfactual BAU trajectory. To project the future number of employees in the BAU, country population projections from the World Bank are combined with the average share of the population that is employed historically. No adjustment for productivity increases is made, since the share of employed population historically has remained relatively stable despite significant productivity increases, and this trend is assumed to continue in the future. For calculating BAU compensation, we start with 2015 country total employee compensation data from OECD and scale this value by the forecasted real GDP growth per capita for future years.
LPGRbIC	Labor Productivity Growth Rate by International Standard Industrial Classification of All Economic Activities (ISIC) Code	This variable is used to estimate the impacts of exogenous policies tested in a non-BAU scenario, on a counterfactual BAU trajectory. The BAU labor productivity growth rate for each ISIC category is calculated based on the historical (1996–2019) average labor productivity growth rate in the United States for that category from OECD data. This is scaled for India for the period of the model run by a factor equaling the ratio of the average annual expected growth in GDP per capita (2019–2050) to the U.S. historical average annual growth in GDP per capita (1996–2019).

Source: Authors.

Important sectoral results from the BAU scenario are summarized in Tables B1 – B3 below:

Table B2 | BAU Fuel Economy Improvements Considered in New On-Road Vehicles

VEHICLE TYPE	FUEL ECONOMY IMPROVEMENT (%) BY 2022 (OVER 2019 LEVELS)
Passenger LDVs (cars and SUVs)	9
Passenger HDVs (buses)	19
Two-wheelers	No improvement
Three-wheelers	No improvement
Freight LDVs (light freight trucks)	No improvement
Freight HDVs (medium and heavy freight trucks)	17

Notes: HDV = heavy duty vehicles; LDV = light duty vehicles.
Source: Authors.

Table B3 | BAU Source-Wise Installed Capacity Mix in 2050

SOURCE	INSTALLED CAPACITY (GW) IN 2050
Pumped Hydro	19.4
Biomass	11.5
Solar Thermal	0
Distributed Solar PV	45.3
Utility Solar PV	713.6
Onshore Wind	695.6
Offshore Wind	0.3
Hydro	93.7
Nuclear	18.3
Distributed Non-solar	0
Municipal Solid Waste	0.1
Petroleum	0.7
Natural Gas Peaker	284.1
Natural Gas Non-peaker	24.8
Lignite	0.3
Hard Coal	221.4
Non-fossil Sources (Solar + Wind + Hydro + Nuclear)[a]	1,541
Variable RE (Wind + Solar)	1,410
Wind + Solar + Hydro	1,523

Notes: BAU = business as usual; GW = gigawatts; PV = photovoltaic; RE = renewable energy;
[a] Solar includes utility-scale PV, Wind includes both utility-scale on-shore and off-shore, and Hydro includes large hydro and pumped hydro. Solar thermal capacity is not installed in the BAU scenario.
Source: Authors.

ABBREVIATIONS

ARAI	Automotive Research Association of India
ASCI	Administrative Staff College of India
BAU	business as usual
BLS	U.S. Bureau of Labor Statistics
BNEF	Bloomberg New Energy Finance
BTS	U.S. Bureau of Transportation Statistics
CCS	carbon capture and storage
CEA	Central Electricity Authority, Government of India
CERC	Central Electricity Regulatory Commission, Government of India
CES	Centre for Ecological Sciences
CGE	computable general equilibrium
CO_2e	carbon dioxide equivalent
CPI	Climate Policy Initiative
CPR	Centre for Policy Research
CSTEP	Centre for Study of Science Technology and Policy
DGCA	Directorate General of Civil Aviation, Government of India
DOE	U.S. Department of Energy
ECBC	Energy Conservation Building Code
EIA	U.S. Energy Information Administration
EPA	United States Environment Protection Agency
EPS	Energy Policy Simulator
EV	electric vehicle
FAO	Food and Agriculture Organization of the United Nations
GCPC	Gujarat Cleaner Production Centre
GHGPI	GHG Platform India
GRA	Government Revenue Accounting
GW	gigawatt
HDV	heavy duty vehicle
IATA	International Air Transportation Association
IBEF	India Brand Equity Foundation
ICAR	Indian Council of Agricultural Research
ICCT	International Council on Clean Transportation
ICRIER	Indian Council for Research on International Economic Relations
IEA	International Energy Agency
IESS	India Energy Security Scenarios
IGFRI	Indian Grassland and Fodder Research Institute
IIASA	International Institute for Applied Systems Analysis
IO Model	Input-Output Model
KERC	Karnataka Electricity Regulatory Commission
LCOE	levelized cost of electricity
LDV	light duty vehicle
LPG	liquified petroleum gas
LULUCF	Land Use, Land Use Change and Forestry
MMT	million metric tons
MNRE	Ministry of New and Renewable Energy, Government of India
MoC	Ministry of Coal, Government of India
MoEFCC	Ministry of Environment, Forests & Climate Change, Government of India
MoF	Ministry of Finance, Government of India
MoHRD	Ministry of Human Resource Development, Government of India
MoP	Ministry of Power, Government of India
MoPNG	Ministry of Petroleum and Natural Gas, Government of India
MoRTH	Ministry of Road Transport and Highways, Government of India
MoSPI	Ministry of Statistics and Program Implementation, Government of India
NDC	Nationally Determined Contribution
NHTSA	U.S. National Highway Traffic Safety Administration
NRDC	Natural Resources Defense Council
NREL	National Renewable Energy Laboratory, U.S. Department of Energy.
NSO	National Statistical Office, Government of India
O&M	operations and maintenance
OC	organic carbon
OECD	Organisation for Economic Co-operation and Development
PJ	petajoule
PNG	piped natural gas
POSOCO	Power System Operation Corporation, Government of India
PPAC	Petroleum Planning & Analysis Cell, Government of India
R&D	research and development
RE	renewable energy
SD	system dynamics
SEI	Stockholm Environment Institute
SSEF	Shakti Sustainable Energy Foundation
T&D	transmission and distribution
TERI	The Earth and Resources Institute
TNERC	Tamil Nadu Electricity Regulatory Commission
TPDDL	Tata Power Delhi Distribution Limited
VOC	volatile organic compound
VRE	variable renewable energy
WBCSD	World Business Council for Sustainable Development
WIOD	World Input-Output Database

ENDNOTES

1 The Web interface of the India EPS can be accessed at https://india.energypolicy.solutions/. The model folder can be downloaded as part of the free and open-source EPS India model package at https://india.energypolicy.solutions/docs/.

2 The approach adopted for the industry sector is explained in the online model at https://us.energypolicy.solutions/docs/industry-ag-main.html.

3 Details of the model structure, including a detailed description of each module depicted in Figure 1, is available online in the full model at https://us.energypolicy.solutions/docs/.

4 The land-use sector is assumed to not consume any fuel or electricity; auxiliary consumption is not accounted for in the electricity sector.

5 District or space heating is not considered for the India adaptation. Only hydrogen demand is accounted for in the district heat and hydrogen sector.

6 Costs associated with this additional R&D (such as investments in laboratories or engineers' salaries) are not included in the model.

7 Model documentation on input data can be accessed at https://us.energypolicy.solutions/docs/input-data.html.

8 The first simulated year in the model is 2019.

9 The model-structure-related assumptions are common across all country versions of the EPS.

10 Model baseline has been calibrated in comparison with baseline scenarios of EIA, IESS, ICCT, IEA, and LBNL models for India.

11 In the IESS, we select the level of demand trajectories representing determined efforts toward implementing existing policies. These GDP growth rates correspond to the high growth trajectory underlying the sectoral IESS demand projections up to 2047. The India EPS relies on them to construct the BAU demand trajectory. The resulting BAU energy demand is adjusted for a COVID-19-induced recession in 2020, based on the elasticity of sectoral energy consumption with GDP growth.

12 Captive power plants are not modeled within the India EPS.

13 The 175 GW target has been allocated among wind, solar, biomass, municipal solid waste, and small hydropower by the Ministry of New and Renewable Energy. The India EPS does not model small hydropower separately from large hydropower. Hence, we do not consider hydropower to contribute to the achievement of this target in the model.

14 The IESS constructs four separate sets of trajectories, based on policy ambition. Listed in increasing order of ambition, these are "Least Effort (Level 1)," "Determined Effort (Level 2)," "Aggressive Effort (Level 3)," and "Heroic Effort (Level 4)." The Level 2 trajectory represents the level of effort that is deemed most achievable by implementing current government policies.

15 Travel demand in the start year is estimated based on the existing fleet of different vehicle types and the average loading assumptions for the respective vehicles in IESS.

16 Actual monthly statistics on consumption of fuel and electricity were available only for months in the period April–Dec 2020/Jan 2021 at the time of calculation. To estimate the reduction due to the recession, we compare the consumption for the same months in the previous financial year.

17 The 450 GW RE target announcement was not accompanied by a source-wise breakdown. Our estimate assumes that in light of the new hydropower policy of 2018, large hydro would be accounted as an RE source within the 450 GW target.

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ABOUT WRI

World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity, and human well-being.

Our Challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

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.