ASSESSING IMPACTS OF ECONOMIC GROWTH TRAJECTORIES ON CLIMATE GOALS: A CGE-TIMES FRAMEWORK FOR INDIA

CSTEP
CENTER FOR STUDY OF SCIENCE, TECHNOLOGY & POLICY

SHAKTI
SUSTAINABLE ENERGY FOUNDATION

Assessing Impacts of Economic Growth Trajectories on Climate Goals

A CGE-TIMES Framework for India

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Executive Summary

India aspires to achieve sustained economic growth of 6%–8% per year, as part of its long-term development agenda. Accordingly, India's development policies have focused on specific sectors to drive economic growth, create more jobs, and generate higher incomes. The government has announced a range of policies such as *Make in India* (the government's programme to boost manufacturing in sectors such as textiles, food processing, automobiles, iron & steel, and chemicals industries), doubling farmers' income by 2022 over 2016 levels, and reaching a USD 5 trillion economy by 2025. Meanwhile, India's position in global climate-change negotiations reinforces its commitment to a sustainable-growth paradigm. Several manufacturing industries are energy and emission intensive; hence, for India to achieve its objective of sustainable development, there is an urgent need to accelerate the decoupling of sectoral value added from emissions. A modelling-based assessment enables us to quantify linkages between macroeconomic drivers and sectoral policy formulation in a holistic manner. In this context, this study takes a long-term view of India's economic growth and specifically models the role of sectoral investments as a key driver for growth.

Approach: Modelling long-term growth trajectories using a consistent macroeconomic framework

Our economic framework comprises a multi-period Computable General Equilibrium (CGE) model of the Indian economy. Specifically, we simulate alternative investment trajectories[1] and examine the implications on gross domestic product (GDP), structural change, trade, sectoral activity, and institutional income. Next, we assess the impacts of sectoral growth trajectories on energy demand, emissions, and emission intensity of GDP by soft-linking the outputs from the CGE model into an energy-demand assessment framework, namely, India's multi-region TIMES (The Integrated MARKAL EFOM System) model. A consistent macroeconomic framework enables a system-wide assessment of consumption growth that drives energy and emission footprints in the economy. The development of a CGE model with base year 2012–13 and its core databases are the main contributions of this study to the extant literature on CGE models for India.

Growth scenarios are assessed employing investment (capital-stock growth by industry), factor productivity, and labour-force growth as the main exogenous drivers for economic growth. Sector-specific investment choices simulate low-investment (average 5.4% p.a.[2]) and high-investment (average 7.0% p.a.) trajectories for the Indian economy. Short-term cyclical variations are not considered, nor are the effects of monetary-policy changes.

Key Insights

The service sector continues to drive India's economy, but rise in income inequality will need to be countered with progressive policy support.

Our results suggest that in all scenarios, the service sector continues to be the main driver of economic growth. The reference scenario considers investment growth of 6.6% p.a. (lower than the historical trend rate of 7.1% p.a.) and yields a GDP growth of 6.3% p.a. Subdued investment, especially in the service sector, and low productivity in manufacturing decelerate growth across

[1] The results in this study are largely driven by exogenous investment trajectories, which are based on published historical trends and aligned with the government's sectoral vision targets for 2030.

[2] Growth rates are indicated for the period of 2017-30, unless specified otherwise.

the economy; projected growth contracts to 5.5% between 2017 and 2030. If investments in the service sector increase, real GDP growth is pushed up to an average of 6.8% p.a.

The GDP per capita (a measure of a country's standard of living) in 2030 is projected to improve modestly to $3,174–$3,777 (INR 1,68,245–2,00,200), around 60% lower than China's 2018 levels.

We project the share of the service sector in the overall GDP to increase to 68% in the low-investment and 72% in the high-investment scenario. Industry's share declines to 18% in the low and 16% in the high scenario, well below the 25% target set for manufacturing sectors in the *Make in India* policy.

On the demand side, we project rising average real-income levels in all scenarios. However, the stagnation of income growth at historical levels (5% for rural households and 6% for urban) is of concern. High growth in services benefits the highest urban-income classes, which record an annual average growth of 6.5% over the period to 2030. Effectively, this aggravates inequality; the Gini index (a measure of inequality) rises in all scenarios across rural and urban households.

Productivity improvements are crucial for a USD 5 trillion economy by 2025.

We find that the current levels of investment and productivity are insufficient to expand output and demand as envisaged in the government's growth targets. Policy simulations suggest that high growth in the service sector, besides leading to lopsided development, cannot alone guarantee the USD 5 trillion target. Sustained high investments in agriculture (6.6% p.a.) and manufacturing (7.6% p.a.) alongside growth in total factor productivity at a trend rate of 1.2% p.a. are required to expand economic growth from an average 7% p.a. to 9% p.a. to achieve the growth target. Hence, we suggest that an inclusive growth trajectory that prioritises productivity gains in manufacturing and agriculture is essential for boosting potential output growth over the medium term.

India is on track to meet 2030 NDCs in the wake of enhanced implementation of energy-efficiency measures and a services-oriented economy. However, structural growth changes, alongside decoupling of energy demand and emissions growth, are key to ratcheting up future mitigation targets.

From a climate standpoint, our results suggest strong growth in energy-emission intensive sectors and commodities demand. Illustratively, demand for industry materials grows 2–2.5 times to about 250 MT of iron and steel and 400 MT of cement in 2030, driven by high demand from the construction sector. Aluminium demand increases 1.7 times to 5-6 MT by 2030 due to the moderate pace of demand from the automobiles (4.1% p.a.) and machinery (2.3% p.a.) sectors. Transport demand reflects a subdued growth outlook; passenger road transport activity grows at 4.8% p.a., while rail activity is projected to grow at 4.5% p.a. Freight demand for road transport remains subdued at 5.9%, while that of rail grows at an average rate of 6.0% p.a.

Final energy demand doubles to 8,200–9,200 TWh, driven by key industries and the transport sector. Total primary energy demand (TPED) grows at compound annual growth rates (CAGRs) of 2.7%–3.8% to about 11,600-13,000 TWh in 2030. Energy supply is dominated by coal and oil, mainly because of technology lock-ins in power generation, industrial production, and transport. However, the rate of growth of coal and gas demand is relatively lower, driven by efficiency measures. Consequently, even under GDP-growth trajectories where the economic size grows nearly 5 times, overall greenhouse gas (GHG) emissions will almost double to 2,600 MT-3,000 MT CO_2e in 2030.

Hence, our assessment suggests that with current and planned levels of emission and energy intensity, India is on track to meet the 2030 NDC targets—emission intensity of GDP will likely decline 43%–50% over 2005 levels.

From a policy standpoint, these simulations clearly indicate that energy-efficiency measures (as identified in CSTEP's recently published work[3]) and accelerated adoption of low-carbon technologies increase the scope for India to augment its long-term low-carbon targets.

[3] See *Roadmap for Achieving India's NDC Pledge* (CSTEP, 2018).

Contents

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Abbreviations

BIG	Baseline Inclusive Growth
BPO	Business Process Outsourcing
BRICS	Brazil, Russia, India, China, South Africa
CAD	Current Account Deficit
CAGR	Compound Annual Growth Rate
CC	Climate Change
CEA	Central Electricity Authority
CES	Constant Elasticity of Substitution
CET	Constant Elasticity of Transformation
CGE	Computable General Equilibrium
CIS	Change in Stocks
CPI	Consumer Price Index
CSO	Central Statistics Office
CUF	Capacity Utilisation Factor
ECBC	Energy Conservation and Building Code
EXR	Exchange Rate
FDI	Foreign Direct Investment
GAMS	General Algebraic Modelling System
GDP	Gross Domestic Product
GFCF	Gross Fixed Capital Formation
GHG	Greenhouse Gas
GTAP	Global Trade Analysis Project
GVA	Gross Value Added
IESS	India Energy Security Scenarios
IFPRI	International Food Policy Research Institute

IMF	International Monetary Fund
IMRT	India Multi-Region TIMES Model
INDC	Intended Nationally Determined Contributions
I-O/IOT	Input-Output, Input-Output Table
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Process and Product Use
IT	Information Technology
LCIG	Low-Carbon Inclusive Growth
LES	Linear Expenditure System
LULUCF	Land Use, Land Use Change and Forestry
MNRE	Ministry of New and Renewable Energy
MoEFCC	Ministry of Environment, Forest and Climate Change
MoSPI	Ministry of Statistics and Programme Implementation
MPS	Marginal Propensity to Save
MSME	Micro, Small and Medium Enterprises
NAS	National Accounts Statistics
NCAER	National Council of Applied Economic Research
NMEEE	National Mission for Enhanced Energy Efficiency
NMP	National Manufacturing Plan
NSSO	National Sample Survey Organisation
PAT	Perform, Achieve and Trade
RBI	Reserve Bank of India
RE	Renewable Energy
ROW	Rest of the World
SAM	Social Accounting Matrix
SGM	Second Generation Model
SME	Small and Medium Enterprises

SUT	Supply and Use Table
TFP	Total Factor Productivity
TIMES	The Integrated MARKAL EFOM System
TPED	Total Primary Energy Demand
TPP	Thermal Power Plants
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WEO	World Economic Outlook

1. Introduction

In the landmark 2015 Paris Agreement, India announced targets for reducing its emission intensity of GDP by 33%–35% in 2030 from 2005 levels. Alongside, the Indian government has ratcheted up its development priorities, by pushing for ambitious inclusive economic growth. There is a special focus on key economic sectors that are poised to drive economic growth, contribute to more jobs, and generate higher incomes. To this end, the government has announced a range of policies such as *Make in India* (the government's programme to boost manufacturing in India), doubling farmers' income by 2022 over 2016 levels, and reaching a USD 5 trillion economy by 2025.

In this context, this study aims to model India's long-term economic-growth trajectories and assess the effects on emissions. We employ a multi-period, multi-sector Computable General Equilibrium (CGE) model to assess growth trajectories till 2030. Specifically, we simulate alternative investment trajectories[4] and examine the implications on gross domestic product (GDP), trade, structural change, sectoral activity, and institutional income. Outputs from the macroeconomic model are soft-linked to an energy-demand assessment framework, which uses a bottom-up approach to assess energy demand, energy supply, and greenhouse gas (GHG) emissions.

The rest of the report is structured as follows: Section 2 describes our modelling framework, including an outline of our multi-period model and the India Multi-Regional TIMES model (IMRT). Section 3 discusses our policy simulations, and associated assumptions. Key results are presented in Section 4. Section 5 concludes with our policy recommendations and future work.

Overview of CGE models

As Kuznets identified as early as 1966, 'modern economic growth' comprises large shifts in structures of production, employment, investment, and trade in an economy (Robinson, 1982). Policy planners emphasise that structural adjustments to both domestic and external events are important aspects of development policy. Hence, multi-sector models provide a useful framework to analyse structural change. In the 1950s and 1960s, Leontief, among others, pioneered the use of input-output (IO) and linear programming models for planning in developing countries. The accounting framework draws from the global System of National Accounts (SNA) and is based on national income accounts, production, income distribution, and institutional accounts, which are then integrated into a broader social accounting matrix (SAM)[5].

Later, in the 1980s, research efforts shifted to formulating applied general equilibrium models[6] that could effectively describe market mechanisms, institutional features, and realistic decentralised economies. Empirical general equilibrium models are useful, in that they bridge the gap between economic theorists and policymakers (Dervis et al., 1982).

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[4] The results in this study are largely driven by exogenous investment trajectories, which are based on published historical trends and aligned with the government's sectoral vision targets.

[5] While both input-output tables (IOTs) and SAMs are models in their own right, they have limitations that preclude their use in our context. Firstly, these models are usually linear, and consist of fixed coefficients in their production system. Secondly, they do not explore behavioural relationships among consumers, producers, and institutions. Moreover, there is no role for prices in this framework (Burfisher, 2017).

[6] See Robinson et al., (Robinson, 1982) for an extensive introduction to general equilibrium models and their diverse applications in development planning.

Long-run policy issues require a different set of theoretical and analytical tools compared to short-run issues. This is particularly true of assessing impacts of medium- and long-term development strategies on growth, structural change, investment, production, employment, and income distribution (Dervis et al., 1982). Factors comprising capital accumulation, rural-urban migration, labour-force growth, productivity change, investment allocation, and structures of demand and trade are influential in determining the development process of a country (Dervis et al., 1982). Thus, the analytical framework extends the Leontief input-output model to an economy-wide multi-sector model, which includes feedbacks through price mechanisms to achieve equilibrium between demand and supply in the economy. Applied CGE models are not 'short-run projections models' and do not assess cyclical variations; rather, they are useful tools to assess medium- to long-term trends (Dervis et al., 1982).

In the Indian context, the applications of CGE[7] models are diverse, ranging from analyses of oil price shocks and household welfare (Pradhan & Sahoo, 2000) to agricultural subsidies and climate-change impacts (Dixon, Rimmer, Chadha, Pratap, & Tandon, 2016). We distinguish our study from the extant literature on India's long-term growth prospects by adopting an integrated macroeconomic modelling framework that provides insights into the interdependencies prevalent in modern market economies. This feature is extremely important in policy formulation, because it quantifies the effects of any single policy change or a combination of policy changes across the entire economy (Dervis, Robinson, & Melo, 1982). Furthermore, the choice of available policy strategies and inherent trade-offs in achieving them requires a meticulous investigation of their implications. Thus, India's future development strategies are best assessed in a framework that captures the behaviour of all essential economic agents within a holistic economic system.

We improve on the existing literature by first updating the Indian input-output table (IOT) and social accounting matrix (SAM) databases to a new base year of 2012–13. Our CGE model employs the standard and dynamic features of models developed by the International Food Policy Research Institute (IFPRI) (Lofgren et al., 2002; Thurlow, 2008). Our multi-period simulation model solves for the economy on an annual basis and simulates growth trajectories based on exogenous drivers (such as capital accumulation, labour supply, and productivity growth). We distinguish our study by linking the macroeconomic model with a bottom-up energy model that is more comprehensive in its approach for analysing sector-wise emissions, efficiency improvements, and technologies. It is important to clarify that our CGE model is a structural model designed for policy analysis using simulations, and does not make predictions or forecasts; this is in contrast to larger, temporally disaggregated macroeconomic forecasting models[8] (Dervis et al., 1982). Further, the analytical framework does not incorporate any uncertainties relating to prospective trade wars, global financial crises, or new technologies that may gain prominence over the next ten years. Finally, in the tradition of Walrasian general equilibrium models, there is no distinct role for money—a limitation we acknowledge while using this class of models for policy analysis (King, 2015). Given the sheer size and computational requirements of CGE

[7] CGE models are simulation models that combine the Walrasian general equilibrium models formalised by Arrow and Debreu (Arrow & Debreu, 1954) with realistic economic data to solve numerically for equilibrium levels of supply, demand, and prices across a specified set of markets. The core concept is a *circular flow of income and spending*, where households, firms, governments, and the external world are key players and interact with each other through a series of monetary transactions. These models are useful for simulating changes in the economy in response to a policy shock.

[8] The latter framework makes it difficult to trace causal mechanisms, whereas the same is easy in general equilibrium models because their structure is rooted in economic theory.

modelling, this study presents a crucial step in demonstrating the utility of these models in policy planning. As a modelling application, we undertake a brief analysis of India's long-term growth trajectories and the implications on the emission intensity of GDP. Future research aims at exploring the nuances of the analysis presented in this report in greater detail by improving the representation of energy sectors and accounting for resource constraints in the CGE model.

2. Methodology

As shown in Figure 1, the key exogenous drivers for our macroeconomic model are investment, population projections, and future urbanisation rates. Because our IO table does not explicitly disaggregate energy sectors into thermal and renewable sectors, we are unable to directly assess emissions and resource constraints within the model. We overcome this limitation by linking key results from the CGE model such as GDP and sectoral output to a detailed energy model for assessing GHG emissions.

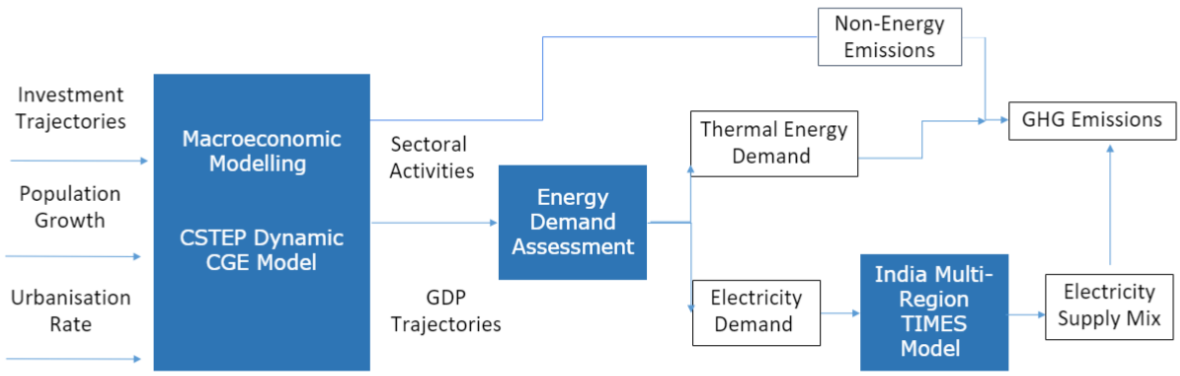

Figure 1: Modelling approach

Source: Authors' representation

2.1 CGE Model Framework

The core databases for a CGE model comprise an input-output table and a social accounting matrix. The SAM is a balanced database that serves as an input to the CGE model and represents the 'benchmark general equilibrium' (Burfisher, 2017). For India, the Central Statistics Office (CSO), Government of India, constructs IOTs; the latest one pertains to the base year 2007–08 and consists of 130 commodity sectors. Furthermore, India has a rich anthology of SAMs, with the earliest databases dating to the 1980s. Again, the latest SAM available to researchers is for the base year 2007–08. In this study, we have compiled and validated an updated set of IO and SAM matrices for 2012–13, using Supply and Use Tables (SUTs) published by the CSO for the same base year.

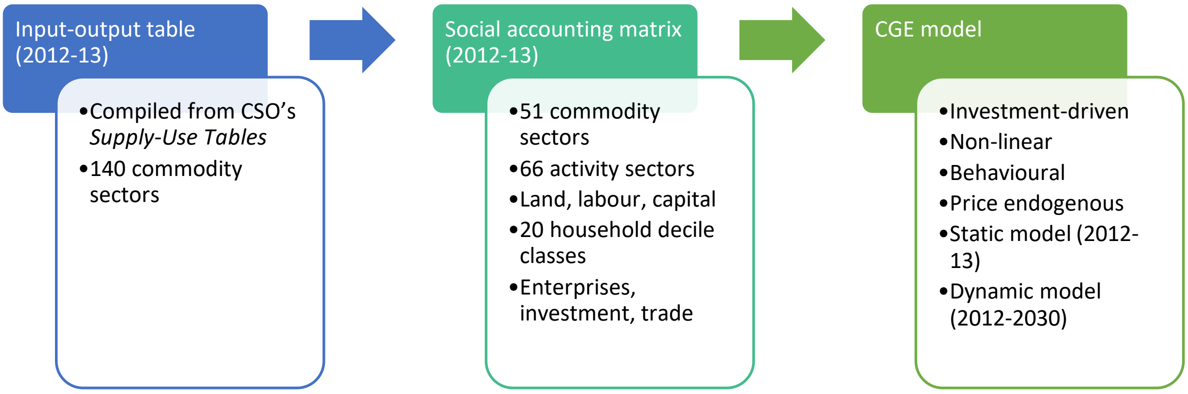

Figure 2: Key features of model databases

Figures 2 and 3 present key features of our CGE model and its underlying databases.

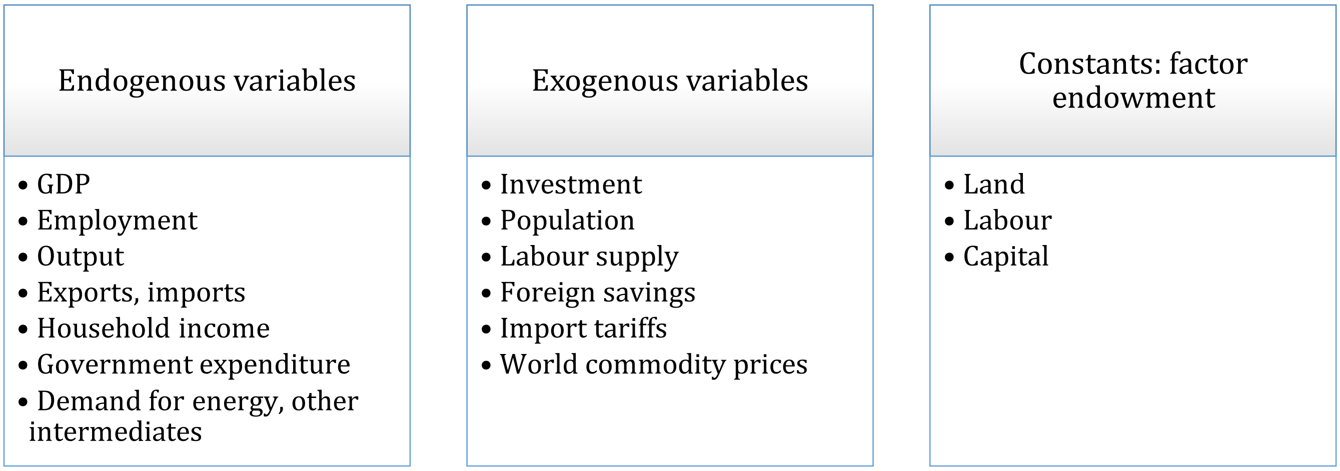

Figure 3: Model variables

In addition, our study uses the approach formulated by Adelman and Sherman Robinson for constructing a CGE model for India (see Table 1).

Table 1: Historical evolution of CGE models

	Johansen	Adelman & Sherman Robinson	Jorgansen
Year of publication	1960	1973	1992
Country of concern	Norway	Korea	USA
Algorithm	Linear equation systems	Non-linear	Non-linear
Behavioural equations	Cobb-Douglas	Cobb-Douglas & CES	Translog
Parameters	Published literature	Expert consultation, published literature	Calibration approach to integrate econometric data
Followers	Monash University	World Bank	US universities

Software	GEMPACK	GAMS	GAMS

Source: Authors' literature review

2.1.1 Standard Model Features

Our static model for India employs the standard model developed by IFPRI (Lofgren et al., 2002). This structure differentiates between accounts for activities (i.e., the entities that undertake production) and commodities (Lofgren et al., 2002). It differs from our core SAM database, which comprises only commodity accounts. Hence, we restructure the SAM according to the prescribed format; our final database includes 66 activity accounts and 51 commodity sectors. Figure 4 lists the features of the standard IFPRI model[9] that we incorporate into our own framework.

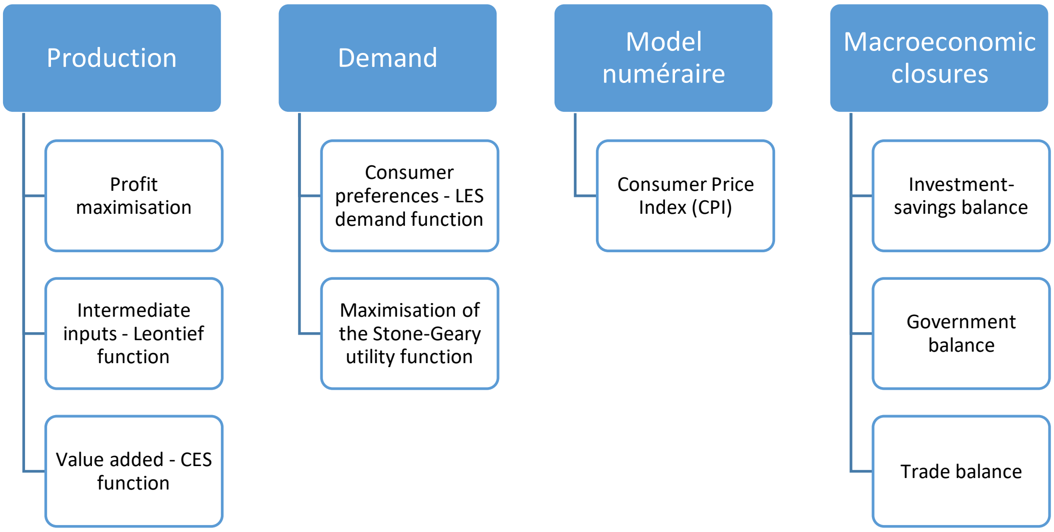

Figure 4: Standard model features

Source: Authors' representation, sourced from Lofgren et al., 2002

At a systemic level, it is essential that equilibrium is achieved across the macroeconomic accounts of savings and investment, government, and the current account. Dervis, Melo and Robinson (Dervis et al., 1982) discuss modelling issues in the treatment of investment, in their seminal work on the application of general equilibrium models for development policy. Two important considerations are the volume of investment and its sectoral allocation. In the classical tradition of modelling aggregate investment and savings, total investment is endogenously determined by savings behaviour. Importantly, the authors recognise that aggregate investment is a significant part of a dynamic planning model, and the classical approach is only one method to treat the investment–savings relation.

Thus, the authors outline an alternative approach—in models directed towards policy planning issues, it is reasonable to specify real investment exogenously. In this case, the presupposition is that policies will be accordingly formulated to achieve the desired level of investments. Hence, real capital stock growth is now exogenous; this automatically implies that savings rates will adjust endogenously so that sufficient savings generate the required capital (Dervis et al., 1982).

[9] For a detailed review of the features of the IFPRI standard model, see *Lofgren et al., 2002*.

Our investment–savings modelling approach adopts this treatment. Table 2 specifies the macro closure rules for allowing adjustments in the three accounts (Thurlow, 2008).

Table 2: Macroeconomic closure rules

Macroeconomic Closures	Exogenous	Endogenous
Investment-Savings	Fixed investment Fixed government consumption	Scaled MPS* for selected institutions
Government	Fixed government savings Fixed government consumption	Scaled direct and indirect tax rates for selected institutions
Rest of the world	Fixed foreign savings	Flexible real exchange rate

*MPS = marginal propensity to save[10]

2.1.2 Multi-Period Model

Our multi-period simulation model is an extension of the static model, adapted from the recursive dynamic framework described in James Thurlow's model for South Africa (Thurlow, 2008). In a dynamic framework, economic conditions during a specific time frame are endogenously dependent on the past. Demographic changes such as population and technological changes are updated exogenously based on projected trends. The recursive nature of the model implies that agent behaviour is based not on forward-looking expectations (predictions about future economic conditions) but on adaptive expectations (based on past experiences) (Thurlow, 2008).

Capital Accumulation

We exogenously model the process of capital accumulation based on the government's policy targets and historical trends. Our framework comprises an investment-driven model where investment is fixed and savings endogenously adjust to achieve equilibrium. Investment from previous periods generates new capital stock for subsequent periods.

Population Growth

The rate of population growth in India is exogenously imposed on the model based on projections by the Population Foundation of India. The model separately accounts for both rural and urban population trends. Further, we assume that a steadily growing population increases consumption demand. This implies an increase in the discretionary income spent by households. Moreover, new consumers are assumed to exhibit the same preferences as existing consumers. The model reflects household income changes over the years and the subsequent effects on consumption patterns.

Labour Supply and Productivity Trends

Total labour supply is fixed and is exogenously updated between periods (based on both population and labour force growth rates) (Annabi et al., 2004). This implies full employment and flexible wages, in line with classical economic theory[11]. Wage rates are linked to sector-specific

[10] MPS is the increase in savings per unit increase in disposable income (Froyen, 2012).

[11] Classical economists view unemployment as a short-lived adjustment period, resulting from declining wages and prices, or people voluntarily choosing not to work. However, Keynes rejected the theory that the economy self-corrects over time to achieve full employment. He argued that unless aggregate spending is adequate, an economy can face a prolonged period of unemployment (Tucker, 2012).

labour productivity. In this study, we exogenously impose total factor productivity (TFP) growth rates for our model's sectors; however, we do not analyse how various investment decisions can lead to endogenous productivity growth. We also note that unemployment is exogenous, and, thus, the model is limited in its labour market specification. Future research aims to improve this feature by specifying a non-linear treatment of labour demand and supply.

Other Adjustments

Based on current government policies, future changes in the current account balance are exogenously imposed between periods, as are changes in the government's fiscal deficit. Finally, we assume an increase in government cash transfers to lower-income households in both rural and urban areas.

Box 1: Static and Dynamic CGE Models

Standard CGE models comprise static models, which analyse an economy during a single period. They compare the state of an economy before and after a policy change or 'shock' (Burfisher, 2017). Such models are characterised by fixed endowments of factors of production (i.e., the size of the labour force and quantity of capital equipment are fixed), unless specifically changed as a model experiment. Although useful for a range of short-term economic analyses, the standard framework is fraught with limitations. For instance, the aggregation of households into a 'representative' unit may not portray the inherent diversity in income sources and consumer preferences. Similarly, producers are diverse in the way they produce a product and the technologies they use. Moreover, such deterministic CGE models do not represent stochastic or variable conditions. Another major disadvantage is that the models do not describe how an economy adjusts from the old to the new equilibrium after a policy shock (Burfisher, 2017). While medium-run adjustment periods can be analysed (e.g., changes in industry output, consumption expenditure), these time-periods are too constrained for long-run changes, like examining the growth of an economy's labour force. Periods of severe unemployment that may result from a sudden policy change are not evident in static models.

Over the years, economists have found a range of solutions towards tackling the limitations mentioned above. For instance, SAM databases disaggregate representative households to delineate sources of income. Researchers have also transformed the single-period structure into a dynamic framework. Additionally, the development of stochastic models, which account for randomness or variability in an economic environment, has seen important applications in long-term climate change analyses (Burfisher, 2017).

Dynamic models maintain that an economy's reaction to a shock will change its long-run growth trajectory. The process is as follows. First, the model identifies a baseline path in which supply and productivity of an economy's stock of capital and labour increase without a policy shock. Subsequently, the introduction of a shock leads to changes in the growth trajectory by changing the level of capital stock. This, in turn, affects savings and investment behaviour. Hence, the results of a dynamic model describe differences between the baseline and economic shock paths (Burfisher, 2017).

There are two types of dynamic models. The first is a recursive dynamic model, which lays out a time path by sequentially solving a static model, one period at a time. Then, the solution values are used as the variables' initial values for the next period (Burfisher, 2017). The model is re-solved to determine a new equilibrium condition for the economy. Inter-temporal models are the second type, which solve for prices and quantities in all periods simultaneously. Such models are often aggregated and encompass stylised representations of an economy, commonly used for studies of trade and tax policies (Burfisher, 2017).

2.2 Energy System Modelling Framework

A long-term energy-system model, namely IMRT, is used for evaluating the future GHG emissions from various scenarios. For projecting sectoral energy demand pertaining to various growth trajectories, we use an energy demand assessment framework.

The energy demand assessment framework is built on the spreadsheet-based accounting model of the NITI Aayog - India Energy Security Scenarios 2047 (IESS version 2.2). It has detailed techno-economic and policy representation of various sectors. We have retained the structure of the tool, modified several static assumptions, and introduced new levers to enable technological representations in greater detail. Modelling of specific sectors, such as industry, is undertaken separately and linked to the IESS framework using suitable levers. Outputs of the CGE model pertaining to variables such as household income, growth in steel consumption, demand for transport services (road and rail, passenger and freight), and demand for commercial services are used to calculate sectoral growth rates. These growth rates are further used as inputs to the demand assessment framework, which in turn estimates energy demand at five-year intervals.

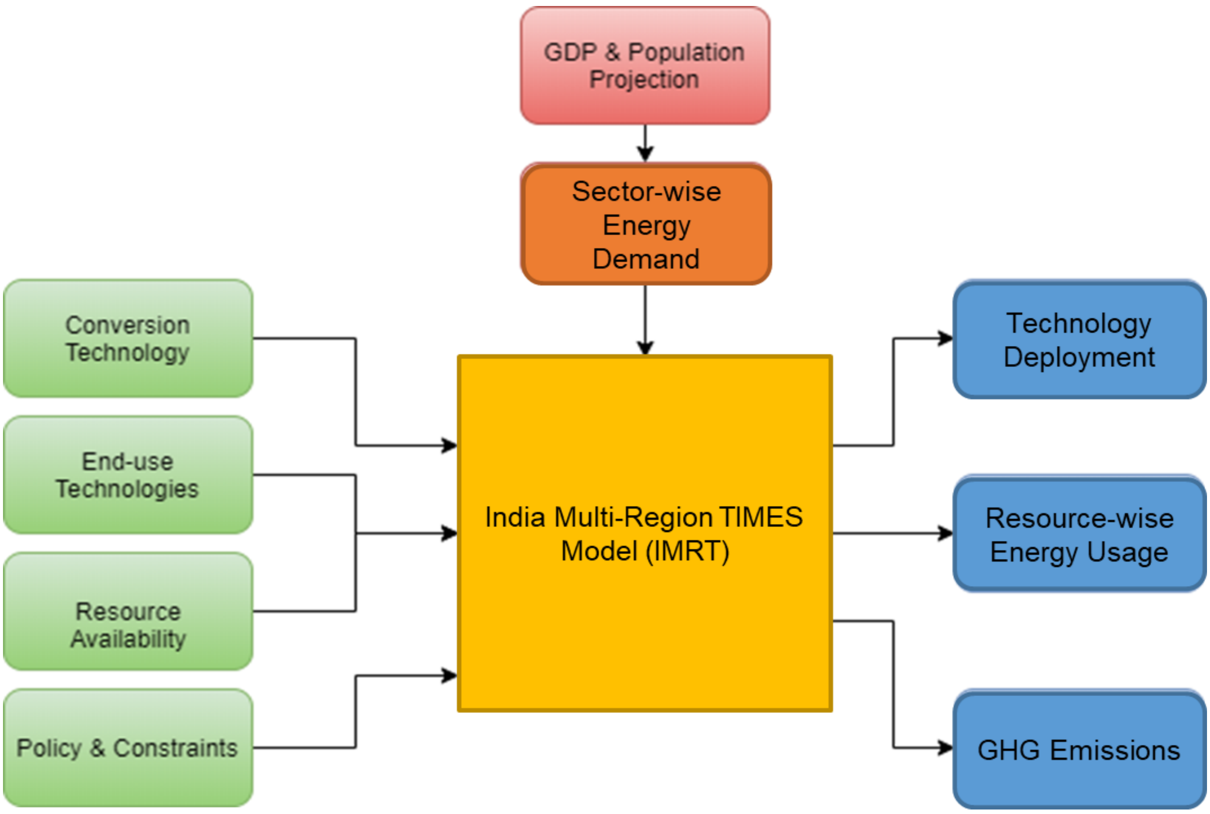

Figure 5: India Multi-Region TIMES model

Source: Authors' representation

CSTEP's IMRT model is built on the TIMES modelling framework (Loulou et al, 2005). TIMES is a technology-rich, bottom-up dynamic energy-system model generator, which is widely used for global and regional energy sectors. IMRT has a detailed representation of technologies ranging from energy supply to end use, with high spatial (each Indian state is a region) and temporal details (36 annual time steps) (CSTEP, 2015). Additionally, it has various constraints addressing renewable energy (RE) intermittency issues, availability of technology, and NDC targets.

IMRT has unit-level information of all existing and proposed coal and non-coal conventional utility-scale power plants in the country. Key characteristics of these technologies are their capacity, capacity factor, efficiency, life, expected year of commission, and retirement. For RE resources, regional total installed capacity is tracked during 2012-18 for the base year and historical year calibration. For RE technologies, region-wise capacity potential and time slice–wise capacity factors are also provided to the IMRT model. Moreover, the IMRT has detailed representation of sub-sectoral technologies on the demand side (e.g., iron & steel, cement in industry sector, freight and passenger demand in transport sector). The demand is calculated using CSTEP's CGE model and demand assessment framework, as described earlier.

To assess non-energy emissions (for Agriculture & Livestock, Waste, IPPU[12], and LULUCF[13] sectors), we link our economic model outputs with the emission-estimation methodologies described in the GHG Platform India (GHGPI, 2017). For the LULUCF sector, we account for additional sink targets based on analyses conducted by the Forest Survey of India (FSI) (MoEFCC, 2019). Emission-estimation methodologies for each sector are provided in the Annexures. We note that our current modelling framework does not account for feedback loops between the IMRT and CGE model that would be required to assess, for example, the impact of energy efficiency improvements in industrial sectors.

2.3 Long-Term Policy Drivers

Scenario definitions necessitate a vision building exercise that help identify exogenous levers for shaping India's economic trajectory up to 2030. Investment is a significant policy lever through which the government aims to achieve a plethora of objectives such as higher potential GDP, higher incomes, self-sufficiency, and sustainability. From a global perspective too, substantial and steady investment, particularly by emerging economies, is key for long-term sustainable economic growth.

The *Agriculture Vision 2050* and the *Make in India* policy initiatives feature important medium- to long-term outlooks for key economic sectors. The outlook for agriculture focuses on enhancing farm mechanisation; in the medium-term, the government targets the doubling of farmers' income from 2016 levels to reduce income inequality. In addition, the sector should receive an immense boost from substantial growth in allied manufacturing sectors like textiles and food processing (ICAR, 2015). For manufacturing, the National Manufacturing Plan (NMP) articulates the vision of the Department of Industrial Policy and Promotion—it aims to increase the share of manufacturing in India's GDP from 16% to 25% by 2025. To achieve this, the NMP has identified special focus sectors that need sector-specific policy interventions to drive domestic growth and exports. Examples include textiles, food-processing industries, leather products, automobiles, iron and steel, and chemicals industries. Similarly, an action plan for 12 champion service sectors

[12] Industrial Process and Product Use

[13] Land Use, Land Use Change and Forestry

was identified by the Ministry of Commerce and Industry (March, 2018), with the objective of promoting gross value added (GVA), exports, and jobs.

3. Simulations

3.1 Macroeconomic Modelling Assumptions

Growth scenarios till 2030 are assessed in an investment-driven model that employs investment (capital stock growth by industry), factor productivity, labour-force growth, and projected urbanisation rates as the main exogenous drivers for economic growth. We source capital-stock growth rates and factor productivity data for our sectors from the India KLEMS database version 2017[14], published by the RBI (RBI-KLEMS, 2018). Table 12 in the Annexures lists the capital stock[15] assumptions for our model's broad economic sectors. We note that the government has taken several measures to boost productivity across sectors in India. However, due to limited data availability on the impact of any individual policy on productivity improvement, we have relied on historical trends for estimating future productivity growth. Moreover, we do not assess the impact of additional investments on endogenous productivity growth that could lead to higher potential output in sectors[16]. Macroeconomic assumptions are common across all scenarios and are in line with short-term projections by the government and institutional agencies. The current-account balance is retained at rates marginally higher than projected (at 3.5% of GDP), keeping in mind the weak export demand and uncertain global cues resulting from the USA–China trade tariff dispute; the fiscal deficit is at 3% of GDP. In addition, we assume a 3% increase in government cash transfers to lower income households in both rural and urban areas. We note that our model does not assess the impact of unemployment on sectoral growth and GDP.

Table 3: Macroeconomic simulations

Simulations	Legend	Description
Reference	Reference	Historical investment and productivity trends project a baseline growth path for the economy.
Policy	SIM 1 – Primary sector-driven economy SIM2 – Service sector-driven economy	Sector-specific investment choices simulate low investment (average 5.4% p.a.) and high investment (average 7.0% p.a.) trajectories for the Indian economy. TFP is fixed at a historical average trend rate of 0.6% p.a. (2000-2015).
	SIM3 & SIM4	Alternative trajectories for a USD 5 trillion economy - growth expansion in agriculture and manufacturing; *Make in India* focus. Capital stock growth rate (overall average 7.9% and 9.3% p.a. respectively); TFP in SIM 3 is assumed at a higher average trend rate of 1.2% p.a. (2000-2008).

Source: Authors' compilation

[14] The India KLEMS database was compiled to support research in the areas of economic growth and policies that support acceleration of productivity growth in the Indian economy. The 2017 database version includes measures of economic growth, employment, capital formation, and productivity. Input measures include capital (K), labour (L), energy (E), materials (M), and services (S) inputs.

[15] Capital input is one of the variables in the multi-factor productivity database for 27 industries, annual time-series 1980-81 to 2015-16. Updated estimates are based on the revised National Accounts Statistics (NAS) with base year 2011-12. Capital input comprises growth rates of capital stock, capital services, and capital income share in GVA.

[16] The endogenous growth theory is fundamental to dynamic CGE models; investments in innovation and human capital enable productivity improvements in the future. For example, labour skills and efficiencies improve by the process of learning by doing at a natural rate of improvement. This rate depends on several assumptions. Further, productivity growth also depends on the type of investment, and not merely its volume. Hence, we note that analysing the link between investment and endogenous productivity growth is beyond the scope of this study.

Sectoral investment growth varies across scenarios, and structural change is modelled as a policy simulation. Our investment assumptions for the reference scenario are closely aligned with historical sectoral trends (2010-15), albeit at lower levels of investment demand across the economy (6.6% p.a. as compared with historical investment growth of 7.1% p.a.), keeping in mind the ongoing economic slowdown. This scenario assumes a lower level of investment growth in services (7.7% p.a. compared with historical investment growth of 9.4% p.a.)[17].

The first simulation (SIM1) charts a growth trajectory characterised by a further downturn in service sector investment growth (average 5.9% p.a.), and dampened overall investment demand in the economy (average 5.4% p.a.). This simulation accounts for prolonged weakness in the manufacturing sector due to low productivity, which also affects demand in the service sector. In contrast, the second simulation (SIM2) builds on recent growth trends and expands overall investment demand to an average trend rate of 7.0% p.a.; this scenario primarily focuses on service sector-led growth to propel real GDP in the economy. Accordingly, we assume service sector investment growth at an average 8.9% p.a., higher than reference levels. Capital stock growth trend rate for industry in both simulations is assumed at an average 5.2% p.a. and 5.9% p.a. respectively, marginally higher than historical levels. Agriculture investment demand remains subdued at averages of 3.6% p.a. and 3.9% p.a. in SIM1 and SIM2. Additional policy simulations (SIM3, SIM4) target more ambitious investment-led growth, and productivity enhancements in light of recent government policy announcements.

3.2 Energy Modelling Assumptions

To track the energy and emission implications, two policy scenarios are explored—which involve demand and power sector interventions for each of the growth trajectories (SIM1 & SIM2) that correspond to low growth (LG) and high growth (HG) scenarios respectively. Policy Scenario 1 (PS 1) depicts a pathway that considers implementation of proposed government policies with their suitable timelines. Policy Scenario 2 (PS 2) illustrates an additional push to achieve current global best practices, in addition to the proposed policies (Table 4).

For the demand sector, policy interventions are mainly focused on energy-efficiency improvements. In PS 1, progressive implementation of policies such as energy conservation building codes (ECBC), appliance labelling, and achieving Indian best practices across industrial-production sectors (especially iron and steel) are considered. PS 2 focuses on implementing more aggressive energy-efficiency measures, regulation, and recycling. For the power sector, scenarios of cost-reduction trajectory, efficiency, and plant-life improvement of renewable energy (RE) technologies are mainly explored. PS 2 considers more aggressive cost reduction of RE, compared with PS 1. Lifetime extension and efficiency improvement of RE technologies are assumed to be similar across policy scenarios.

[17] We have changed the investment assumptions across simulations, but retained productivity growth at historical levels. The latter choice is largely due to insufficient information about how the rate of sectoral productivity growth is likely to shift in the future.

Table 4: Energy modelling assumptions

<table>
<tr><th></th><th>Reference</th><th>Policy Scenario 1 (PS 1)</th><th>Policy Scenario 2 (PS 2)</th></tr>
<tr><td>Efficiency pathways on the demand side</td><td>Based on historical trends; targets and aspirations proposed under various policies for key industrial sectors, buildings, transport, and appliances.</td><td>Progressive policies like ECBC, Standards & Labelling (for appliances), and a push for achieving Indian best practice benchmarks across industrial production sectors (especially iron and steel).</td><td>Aggressive energy efficiency across end-use sectors is enabled with stringent manufacturer-end regulation and consumer incentives, global benchmarks, push for recycling through enabling policies.</td></tr>
<tr><td rowspan="2">Power sector assumptions</td><td>Capital cost of renewables/storage technologies.
Cost reduction with economies of scale, supply chain and technology improvements at a global level.</td><td>Implementation of national policies, supply chain improvements, reverse bidding, tax and cess exemption at the national level.</td><td>Aggressive implementation of domestic policies, supply-chain improvements in Indian markets, and indigenous manufacturing of RE.</td></tr>
<tr><td colspan="3">CUF (capacity utilisation factor)/Efficiency of renewables:
CUF improvement with technology improvements of equipment globally. It is kept same across all scenarios, as it is technology-specific.

Plant life of renewables:
Plant life improvements with technology improvements globally. It is kept same across all scenarios, as it is technology-specific.</td></tr>
<tr><td>Common parameters</td><td colspan="3">Sectoral activity growth and household income growth for a given economic growth scenario.
Ujala, Ujjwala Scheme, PAT targets achieved during 2022-2030.
MNRE renewable targets, NDC fossil-free installed capacity target (2030), pollution norms for coal TPPs.</td></tr>
</table>

Source: Authors' compilation

4. Results

Key Highlights

- A downturn in service-sector investments results in a low economic growth trajectory for India, with average annual growth decelerating to 5.5% by 2030. In contrast, accelerating investment demand in the economy pushes growth up to 6.8% by 2030. However, current levels of investment and productivity are insufficient to expand output and demand to reach a USD 5 trillion economy by 2025.

- GDP per capita remains modest at $3,777 in 2030, 60% lower than China's 2018 levels. Inequality rises over time, requiring policy intervention to ensure equitable distribution of growth.

- Services continue to drive economic growth. By 2030, we project that the share of agriculture and industry in India's GDP will fall to 14%–12% and 18%–16% respectively, while that of services will increase to 68%–72%.

- Enhanced investments in agriculture and manufacturing, and a faster pace of productivity growth from 0.6% to 1.2% p.a. are required to achieve a USD 5 trillion economy and *Make in India* targets. Demand-side policy incentives are essential to expand aggregate demand.

- Emission intensity of GDP declines 50%-43% over 2005 levels, primarily due to enhanced energy efficiency measures across the demand sectors (industries, buildings and transport). Higher levels of economic growth, alongside structural changes in the economy will require accelerated uptake of energy efficiency measures and low-carbon technologies.

- While India has been able to decouple its economic growth and energy demand, our analysis suggests that despite the concerted effort to improve efficiency, there is a substantial need to decarbonise India's energy system.

- For decarbonisation, the system requires an accelerated deployment of clean energy technologies across various sectors, particularly in transport and industries. We recommend that the decoupling of energy and emissions growth is imperative to achieve India's goals of energy security and environmental sustainability. Additionally, this will also play a key role in demonstrating the success of committed climate policies.

4.1 Economic Implications

Impacts are assessed at the macroeconomic level (GDP, GDP per capita, trade), sector level (sectoral activity, share of GDP), and institution level (household and enterprise income; inequality trends). We conclude with a brief examination of alternative growth trajectories for achieving a USD 5 trillion economy by 2025.

Macroeconomic impacts

Real GDP growth

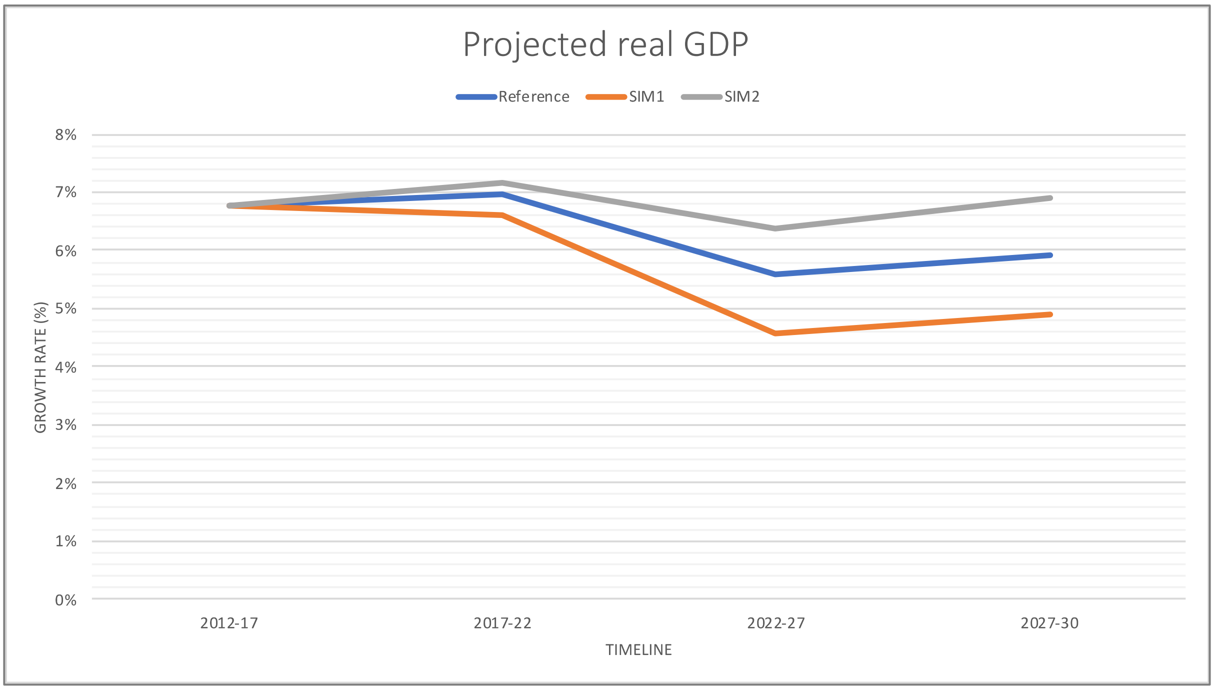

Figure 6: Projected GDP

Source: Authors' results

Our base year is 2012, and results for the period 2012–2017 reflect actual observed growth in the Indian economy (6.8% according to the Central Statistics Office, Government of India, 2018). Model projections are over the time horizon 2017–2030. We note that our projections for 2017–19 may be estimated at higher rates, compared with recent data published by the government. All projected growth rates are annual average growth rates, unless specified otherwise.

Growth scenarios assess primary-sector and service–sector driven trajectories, capturing trade-offs in terms of economic growth. Real GDP growth in the reference scenario is an average of 6.3% p.a. between 2017 and 2030 (Figure 6) as a result of lower investment levels in the service sector. Further, the sustained impact of depressed investment demand in services sharply lowers the growth projection in SIM1, which is only 5.5% p.a. over the modelling horizon. Given that official quarterly projections have downgraded India's growth to around 5% p.a., we reflect that SIM1 could potentially be a more realistic trajectory for India. Alternatively, SIM2 is positioned against the backdrop of a service sector–driven economy, in line with historical trends. In this case, we project average economic growth to accelerate to 6.8% p.a. between 2017 and 2030. While the outlook improves in SIM2 as a consequence of higher investment demand in services, GDP growth remains at levels observed during 2012–17. This indicates a need for scaling up investment levels and accelerating productivity growth across the economy to boost potential output.

GDP per capita

A recent report by PwC (PwC, 2017) assesses global growth prospects till 2050. The report projects that average levels of GDP per capita are unlikely to rise at the same pace in Asia as in developed countries (like the USA and UK). This presents a stark contrast to total GDP levels, where projected growth is primarily driven by emerging economies like China and India. The report concludes that while China is projected to be the largest economy in the world in 2050, the country only achieves a GDP per capita similar to UK's levels today (PwC, 2017).

Similarly, our projections for 2030 indicate a modest growth in average GDP per capita at 5.6% p.a. between 2017 and 2030; in 2030, we project the number to be $3,174 in SIM1 and $3,777 in SIM2, which is well below most developed countries and emerging economies today (around 60% lower than current levels in China and Brazil).

Trade impacts

Figure 7 shows projected export and import trends in the three scenarios. While both trends are positive, the rate of export growth is higher. Again, it is clear that a higher inflow of investments into the economy is crucial for boosting economic activity; in such a scenario, we project robust export growth at 7.9% p.a. between 2017 and 2030 (SIM2), in comparison with 6.9% p.a. in SIM1. In SIM1, we see a decline in the volume of both merchandise (8.7%) and invisibles (18.3%) in 2030 from the reference.

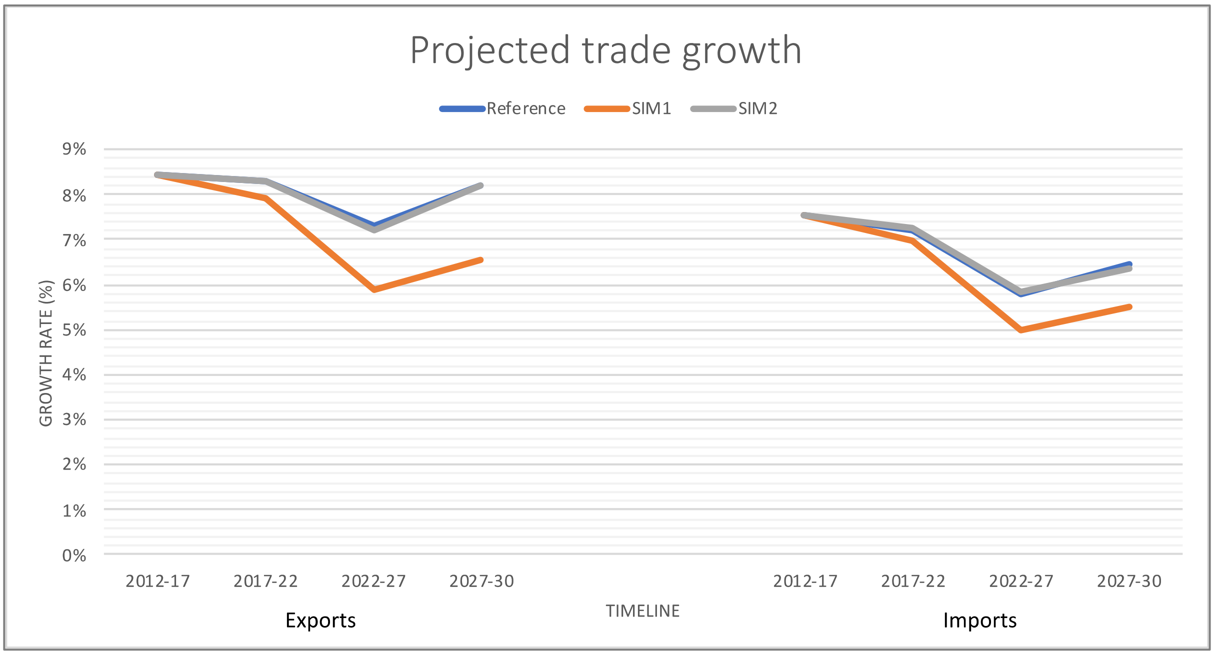

Figure 7: Projected trade impacts

Source: Authors' results

Similarly, import growth is projected at 6.5% p.a. in both the reference and SIM2 scenarios, but decelerates to 5.8% p.a. in SIM1 between 2017 and 2030; merchandise imports decline by 5.7% and invisibles by 16.9%, respectively, from the reference in 2030. Overall, we project an improved current account deficit (CAD) situation in SIM 2 (CAD/GDP ratio is -1.3%) compared with SIM1 (CAD/GDP is -2.5%)[18] in 2030. Finally, the similarity between export and import trends up to

[18] According to latest RBI data (RBI, 2018), the ratio of current account deficit to GDP (CAD/GDP) was -4.8 in 2012; export/GDP ratio was 16.8 and import/GDP ratio was 27.5.

2030 can be attributed to the import intensity of exports in India's trade[19]. Future research can aim to model alternative scenarios that explore this feature in detail at the sectoral level.

Sectoral impacts

Sectoral activity

Our reference projections indicate a deceleration of growth for all three sectors—agriculture, industry, and services—over the period to 2030 (Figure 8). In agriculture, the lack of sustained investments lowers the sector's growth projection; in SIM2, an increase in overall investment demand boosts potential output, but average growth still remains below par at 3.7% p.a. between 2017 and 2030. This implies that the sector would require sustained structural reforms over the medium term to enhance potential output and productivity.

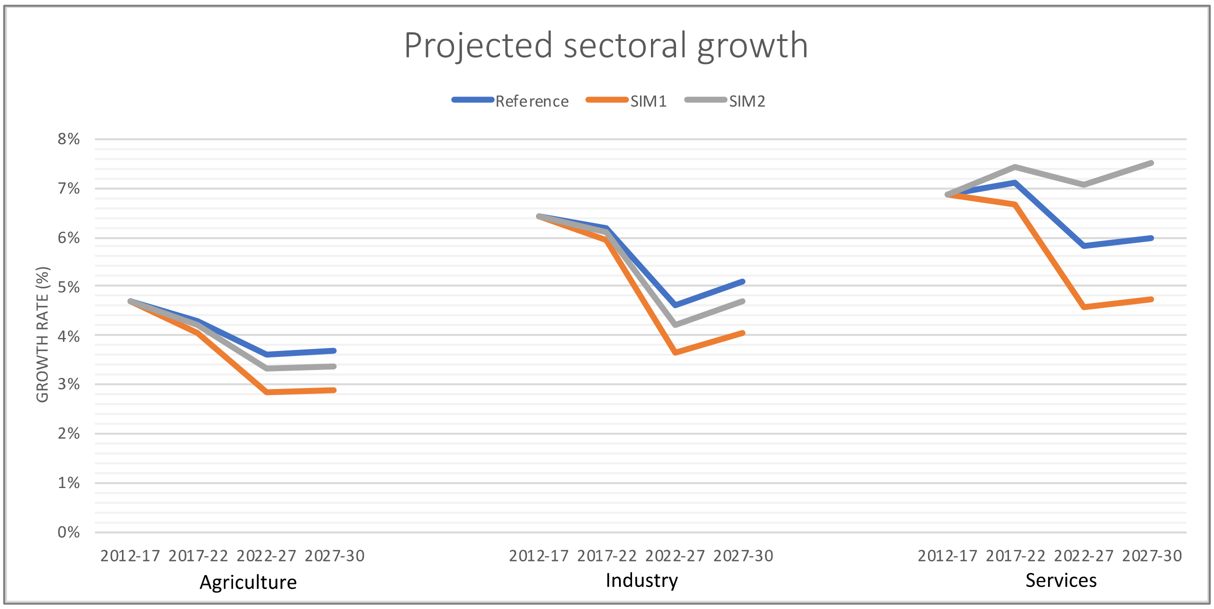

Figure 8: Projected sectoral growth

Source: Authors' results

The reliance of service-sector growth on steady inflow of investments is evident by the stark difference between our growth projections for SIM1 (5.5% p.a.) and SIM2 (7.3% p.a.). This sector continues to be the main driver of economic growth up to 2030 in both simulations. However, industry growth remains subdued (4.6% p.a. in SIM1 and 5.1% p.a. in SIM2), largely due to a moderate pace of productivity growth and insufficient investment levels. Importantly, the World Economic Outlook (WEO) report (IMF, 2019) notes that the service sector continues to remain strong amidst the global growth slowdown and is supporting employment creation. Yet, it expresses a valid concern—which we concur with—that projected weak growth in manufacturing is concerning because a spillover of such trends into services could have adverse effects on the latter's growth prospects (IMF, 2019). Thus, it is essential that structural issues in agriculture and manufacturing are adequately addressed to boost value added activity.

[19] A broad definition of import intensity of exports by the RBI includes the following– *the degree of value addition of an imported item that subsequently gets exported (e.g., gems and jewellery); includes those exports that depend on imported inputs; indirect effects of imported products that augment exports.*

Figure 9 summarises our projections for select subsectors within industry and transport.

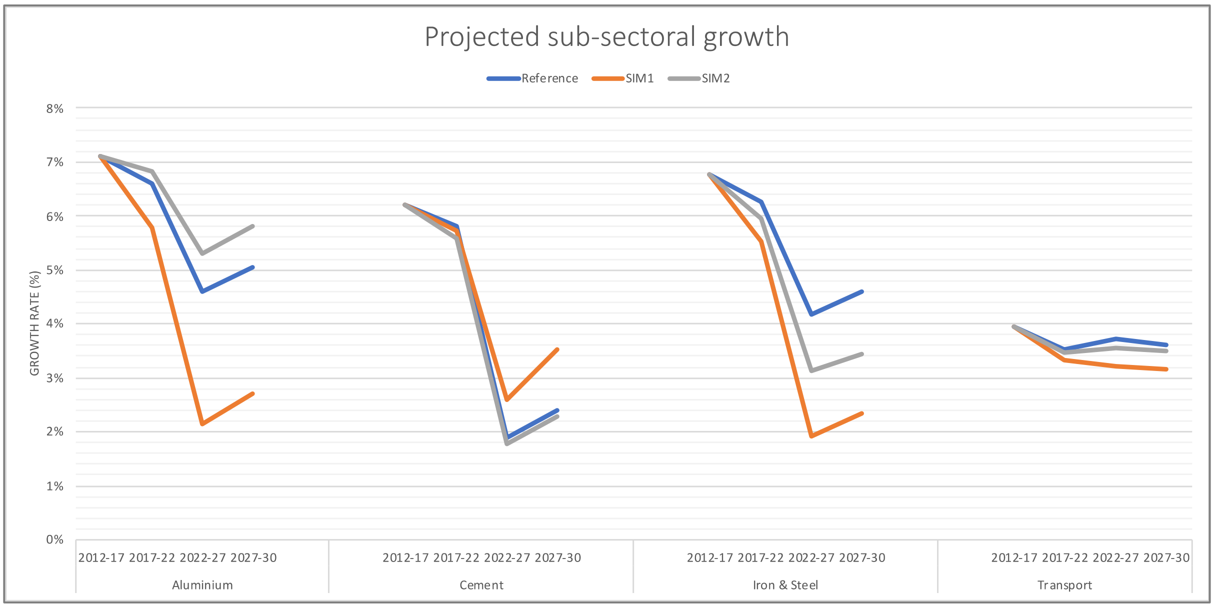

Figure 9: Projected sub-sectoral growth

Source: Authors' results

In terms of industry material demand, feedback from steel-industry experts indicates a target of 300 MT production capacity for the sector by 2030. Our projections for the iron and steel sector are within this range, at about 225 MT and 250 MT respectively in SIM1 and SIM2 scenarios. Cement demand rises to 420 MT in 2030 in SIM1, driven by high demand from the construction sector (wherein growth momentum picks up in 2017–30 to an average 6.6% p.a.). However, demand falls below 400 MT in SIM2, owing to a structural shift towards other service sectors like communication (average 12% p.a.) and trade (average 10.6% p.a.). Aluminium demand averages 5–6 MT by 2030 in both scenarios as a result of moderate pace of demand from the automobiles (4.1% p.a. in SIM2) and machinery (2.3% p.a.) sectors. Transport demand reflects a subdued growth outlook; passenger road transport grows at an average of 4.8% p.a. between 2017 and 2030 in SIM2; rail growth is projected at an average of 4.5% p.a. Freight demand for road transport remains subdued at 5.9%, while that of rail grows at an average 6% p.a.

Sectoral share of GDP

According to provisional estimates published by the CSO, the share of economic sectors in total GVA for 2017–18 is as follows: agriculture (17.1%), industry (19.2%), and services (63.8%)[20]. By 2030, we project services to remain the highest contributor to economic activity (72% in SIM2 and 68% in SIM1), at shares higher than current levels.

Table 5: Projected sectoral share of GDP (%)

Sector	2020	2025	2030	2020	2025	2030	2020	2025	2030
	Reference			SIM1			SIM2		
Agriculture	16	15	14	16	15	14	16	14	12

[20] Data sourced from NAS Back Series 2004-05 to 2011-12, CSO, MoSPI.

Industry	19	19	18	19	19	18	19	18	16
Services	65	66	68	65	66	68	65	68	72

Source: Authors' results

Industry's share declines to 18% by 2030 in SIM1 and further to 16% in SIM2, well below the 25% target set for manufacturing in the *Make in India* policy. The share of agriculture also reduces to 14% in SIM1 and 12% in SIM2. These results imply that raising productivity and addressing structural issues are imperative for sustaining manufacturing and agriculture growth, alongside sustained higher levels of capital formation. Regarding the *Make in India* policy target, we note that an increase in the share of industry implies a reduction in that of services. This implies a reduction in value-added activity in services, which, in turn, would reduce the overall GDP growth. Unless an equivalent amount of value added from industry accrues to propel high growth, the industry sector's share in GDP is not likely to increase. Future research can simulate this conundrum in more detail, exploring implications for structural growth and potential output in the formulation of sectoral growth planning.

Institutional impacts

Enterprise income

Table 6 summarises how incomes are likely to grow for enterprises like private corporate firms and public non-departmental enterprises. SIM2 indicates a moderate pace of growth of 7.6% p.a. over the period to 2030. SIM1 presents a more subdued outlook at 6.4% p.a.

Table 6: Projected enterprise income growth (%)

Enterprise income	2012-17	2017-22	2022-27	2027-30	Average (2017-2030)
Reference	8.4	7.8	6.9	7.1	7.6
SIM1	8.4	7.4	5.6	5.6	6.4
SIM2	8.4	7.9	7.2	7.3	7.6

Source: Authors' results

Household income

Tables 7 and 8 present the annual average real growth rates of rural and urban household income. The model's labour mobility assumptions imply that all household classes get opportunities for jobs and are also employed. The annual average income growth between 2017 and 2030 across all households is projected at 5.4% p.a. in the reference and SIM2 scenarios, and 5.0% p.a. in SIM1. Thus, while our projections suggest that average real income levels steadily rise across all household classes over the modelling horizon, the deceleration or stagnation of income growth at historical levels is of concern.

Table 7: Projected rural household income growth (%)

Rural household income	2012-17	2017-22	2022-27	2027-30	Average (2017-2030)
Reference	5.4	5.2	4.7	4.8	5.0

SIM1	5.4	5.0	4.1	4.2	4.7
SIM2	5.4	5.2	4.7	4.8	5.0

Source: Authors' results

Improved economic performance (SIM2) and an increase in government cash transfers to lower-income households reduce income-growth disparity among the lowest five rural decile classes. In the highest deciles, our projections indicate a shift towards an expansion in service sector-related job opportunities; marginally higher growth rates are projected for the highest rural deciles (average 5.5% p.a. between 2017 and 2030), largely attributed to their ownership of capital. The PwC report alluded to earlier (PwC, 2017) projects average income levels to remain lower in emerging markets (compared with the G7 countries) in 2050, although real income progressively converges. They project India's average real-income levels in 2050 to be similar to that of Russia today. Although population growth is projected to be a major driver of GDP growth in emerging countries, we concur with the report's recommendation that job creation is essential to lift average income levels (PwC, 2017).

Table 8: Projected urban household income growth (%)

Urban household income	2012-17	2017-22	2022-27	2027-32	Average (2017-2030)
Reference	6.2	6.1	5.5	5.8	5.9
SIM1	6.2	5.8	4.6	4.8	5.3
SIM2	6.2	6.1	5.7	5.8	6.0

Source: Authors' results

In the case of urban households, the high growth in services benefits the highest urban income classes; we project a growth of 6.5% p.a. between 2017 and 2030 for the highest three income deciles in SIM2. Again, these results can be attributed to the fact that the higher-income classes own a majority of the capital income and also receive high returns on their investments. Effectively, this aggravates inequality. To this end, we analyse the Gini index[21], which is a measure of economic inequality or an economy's income distribution across the population. While historical Gini recorded an average of 0.33 between 1983 and 2011 (World Bank, 2018), our projected Gini steadily increases in all scenarios. In the reference scenario, the Gini index in 2030 is 0.44 for rural households and 0.59 for urban households. Our projections indicate similar indices for SIM2 and marginally lower indices for SIM1 by 2030.

Table 9: Projected Gini for households

Household	2012	2020	2030	2012	2020	2030	2012	2020	2030
	Reference			SIM1			SIM2		
Rural	0.38	0.40	0.44	0.38	0.40	0.43	0.38	0.40	0.44
Urban	0.55	0.57	0.59	0.55	0.56	0.58	0.55	0.56	0.59

Source: Author's results

[21] This coefficient ranges between 0 and 1; 0 represents perfect equality, while 1 is perfect inequality. Thus, a higher Gini index implies higher inequality, with higher-income individuals receiving larger portions of the total income, compared with the rest of the population.

From a policy-planning perspective, these results have important implications—additional policy effort is required to curb rising inequality and ensure equitable distribution of growth effects. We opine that income inequality rises over time because capital ownership does not change. For instance, at present, only the higher-income classes own capital income. Lower-income households receive only labour income and not capital income. Hence, a distribution in assets for both capital and labour in a way that allows lower decile households to own both labour and capital would be a key step forward in addressing the inequality. Future research can explore the feasibility of this approach, drawing insights from relevant global case studies.

Reflecting the subdued trends in income growth, the SIM2 scenario projects an equally subdued growth in household commodity consumption, at 5.4% p.a. between 2017 and 2030. Given the marginal impacts on household income and consumption trends, we find that the current level of investments is insufficient to significantly expand aggregate demand growth; industries are unable to expand output and jobs without productivity growth and additional policy stimulus.

In conclusion, the investment simulations modelled thus far reflect a range of modest to subdued growth outlooks for India till 2030. Even in a high-investment scenario, slow productivity growth has a major impact on potential output growth in sectors such as industry and agriculture. These trajectories are not sufficient to propel the Indian economy to higher levels of growth and employment, as envisioned by current government policies. Therefore, we conclude this assessment by simulating medium-term policy scenarios that are more ambitious in investment and productivity assumptions[22]. Box 2 in the following page examines our alternative growth trajectories for achieving a USD 5 trillion economy by 2025.

[22] Regarding the feasibility of our modelled TFP choices (the doubling of overall TFP from 0.6% to 1.2% p.a.), we would like to note that in the course of modelling, we have run several scenarios with varying assumptions—for example, when the maximum TFP for sectors was considered, the model rendered an infeasible solution, yielding the following insights: (a) investment should be compatible with productivity growth, and (b) although sectors are interlinked, an increase in the productivity of one sector may not lead to an increase in the productivity of the other sectors. Future research can undertake more work in this area.

Box 2: Simulating India's USD 5 Trillion Economic-Growth Trajectories

In August 2019, the Indian Prime Minister announced a target of achieving a USD 5 trillion economy in the next 5 years. EY's recent *Economy Watch* report (EY India, 2019) observed that India would need to grow by 9% p.a. for 5 years (FY21–FY25), assuming a 4% inflation rate and 2% annual average depreciation of the rupee vis-à-vis the US dollar. To examine this issue, we simulate distinct investment choices in the CGE model and examine two alternative growth pathways till 2030.

Table 10: Simulations for a USD 5 trillion economy

Simulations	Policy narrative	Annual average real growth rate (2017-2030)	Year
SIM2	Higher investment demand in service sectors	6.8%	2028
SIM3	Boost in investments in *Make in India* sectors (overall 7.9% p.a.) and enhanced productivity (1.2% p.a.) across the economy	8.4%	2026
SIM4	Boost in agriculture (6.6% p.a) and manufacturing (7.6% p.a) investments (overall 9.3% p.a.)	9.5%	2025

Source: Authors' compilation

Our simulations indicate that under ambitious investment-growth trajectories that vary across sectors, the government target will likely be achieved in 2025–26 with at least an average 8.4% p.a. growth in the next six years (2020–2026). Even if historical trends are replicated, the USD 5 trillion target is ambitious, and will require aggressive policy interventions given the current growth recession. However, pursuing an investment strategy that enhances investments into agriculture and key manufacturing sectors (e.g., steel, machinery, and textiles) will most likely bring the government target to fruition. This investment can cater to both domestic infrastructure demand and exports.

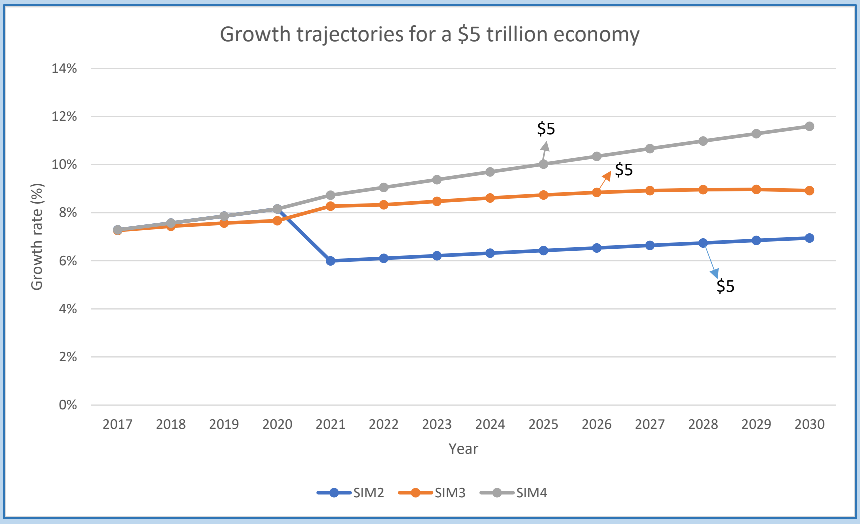

Figure 10: Growth trajectories for a USD 5 trillion economy

Source: Authors' results

Box 2: *(Continued)*

In all simulations, we project improved economic performance, with accelerated value added activity in agriculture and industry. Importantly, we find that raising productivity plays a crucial role in boosting potential output, particularly in manufacturing. Hence, in SIM 3, the share of industry in India's GDP increases to 27% (22.7% share for the manufacturing sector), in range with the *Make in India* target of 25%. Average growth of GDP per capita improves to 8.2%–8.8% p.a. between 2017 and 2030, compared with the 5.6% p.a. growth seen in SIM2. GDP per capita in 2030 improves to $4,679 in SIM3 and $5,312 in SIM4. Average real income growth for households improves to 5.6% p.a. (SIM3) and 6.2% p.a. (SIM4) between 2017 and 2030. Yet, inequality persists in the midst of strong growth momentum; as an example, in SIM4, the Gini index increases to 0.46 in rural households and 0.60 among urban households in 2030.

In conclusion, it is worth noting that the Economic Survey 2018-19 projects India's real GDP growth rate to be 6.8% in FY19 and 7.0% in FY20 (2019 quarterly projections present a subdued picture at 4.5% for the September quarter). In the context of our analysis, we recommend that enhanced investment activity must be accompanied by structural reforms like raising productivity to boost potential output and inclusive growth over the medium term. Given weak global growth signals—global recession and uncertainty on global trade cues—missing the target real growth rate in 2021-22 would push the USD 5 trillion target further away. As EY observes, this could be further delayed if the exchange-rate depreciation breaches 2% p.a. and the inflation rate is lower than 4% (also see EY 2019, pp. 9-10). While formulating cohesive policies to realise the USD 5 trillion target, we also recommend that policymakers be mindful of the sectoral choices available as investment destinations and the consequent implications of such alternative growth trajectories.

Source: Authors' analysis; Economy Watch report (Ernst & Young LLP, 2019)

4.2 Energy and Emission Implications

Final Energy Demand

India's final energy demand is dominated by the industries sector, which is the most energy-intensive of all sectors. Between 2012 and 2030, this demand grows by a compound annual growth rate (CAGR) of 3% and 3.5%, respectively, in the low- and high-growth scenarios (corresponding to SIM1 and SIM2 respectively)[23]. The growth in demand is due to the expansion of India's iron & steel and cement sectors, alongside other industries. Nevertheless, these energy-intensive industries have been at the forefront of adopting energy-conservation and effciency

[23] We note that only SIM1 and SIM2 trajectories are used for analysing energy demand and emissions growth. Assessing the simulated USD 5 trillion trajectories is currently beyond the methodological scope of this report and will be undertaken in future research.

measures to reduce their energy and carbon footprint. The Perform Achieve and Trade (PAT) scheme—being implemented by the Government of India under the National Mission for Enhanced Energy Efficiency (NMEEE)—has been instrumental in driving these measures in Indian industries and thereby reducing their energy demand.

Because of increasing urbanisation and diposable incomes, India's transport demand is expected to increase; the energy demand is expected to grow at about 5-5.5% p.a. between 2012 and 2030. In contrast, energy demand in the buildings sector is expected to have a much slower growth rate, due to efficiency gains from shifting to cleaner and more efficient cooking technologies (compared with biomass-based cook stoves).

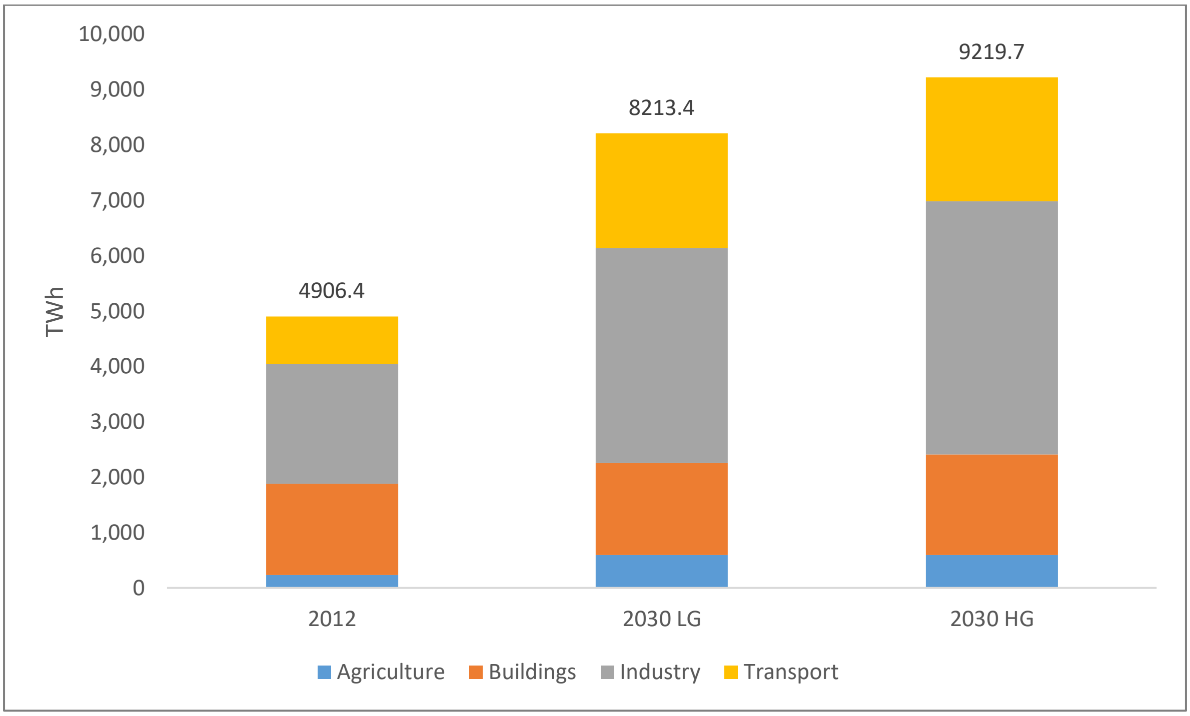

Figure 11: Projected sectoral final energy demand

Comparing results for the reference and two policy scenarios (Figure 12), our results suggest significant savings of 502 TWh and 975 TWh in PS 1 and PS 2 respectively in 2030 (or a savings potential of 5%, and 11% in 2030 compared with the reference).

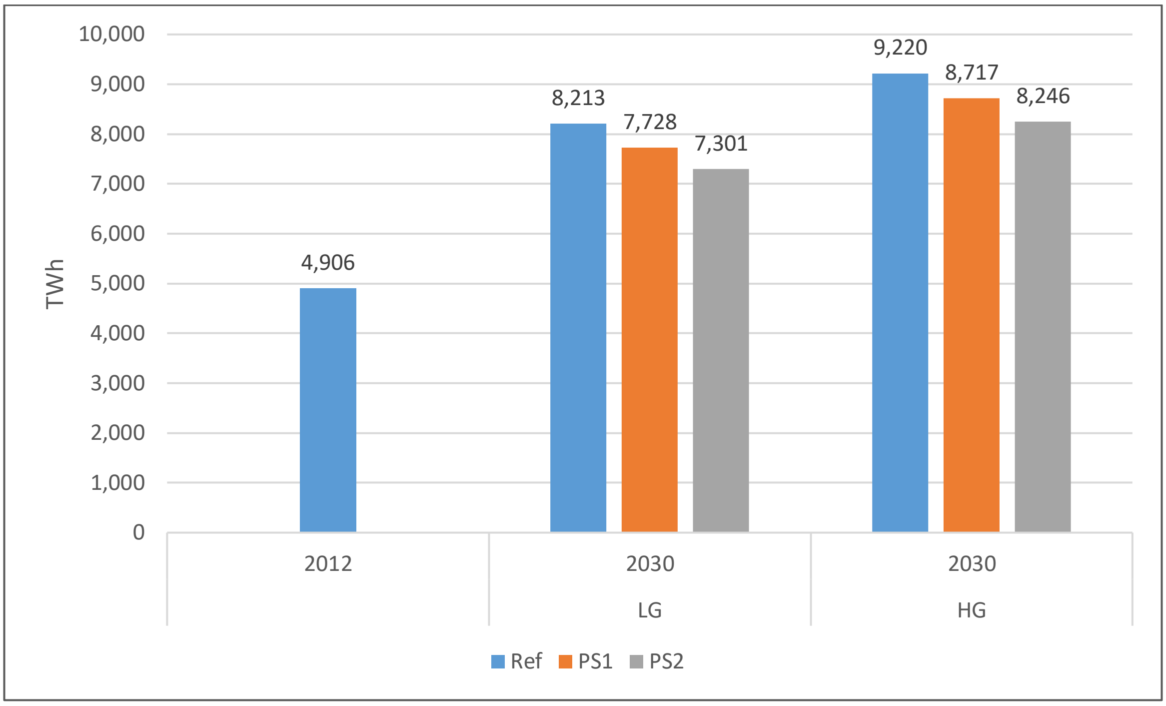

Figure 12: Projected variation in final energy demand

Primary Energy Demand

Total primary energy demand (TPED) grows at a CAGR of 2.7% and 3.8%, respectively, in the LG and HG scenarios by 2030 (6,837 TWh in 2012). This demand is dominated by the use of coal in industries and electricity. As shown in Figure 13, TPED more than doubles by 2030, compared with 2012, mainly driven by the following factors: (a) demand for electricity in residential, commercial, and industrial sectors, and (b) demand for gas from the cooking and transport sectors. The total electricity demand doubles by 2030, compared with the demand in 2012. Share of coal in primary energy demand increases from 20% in 2012 to 22% in 2030 largely driven by the increase in demand for thermal coal in industry.

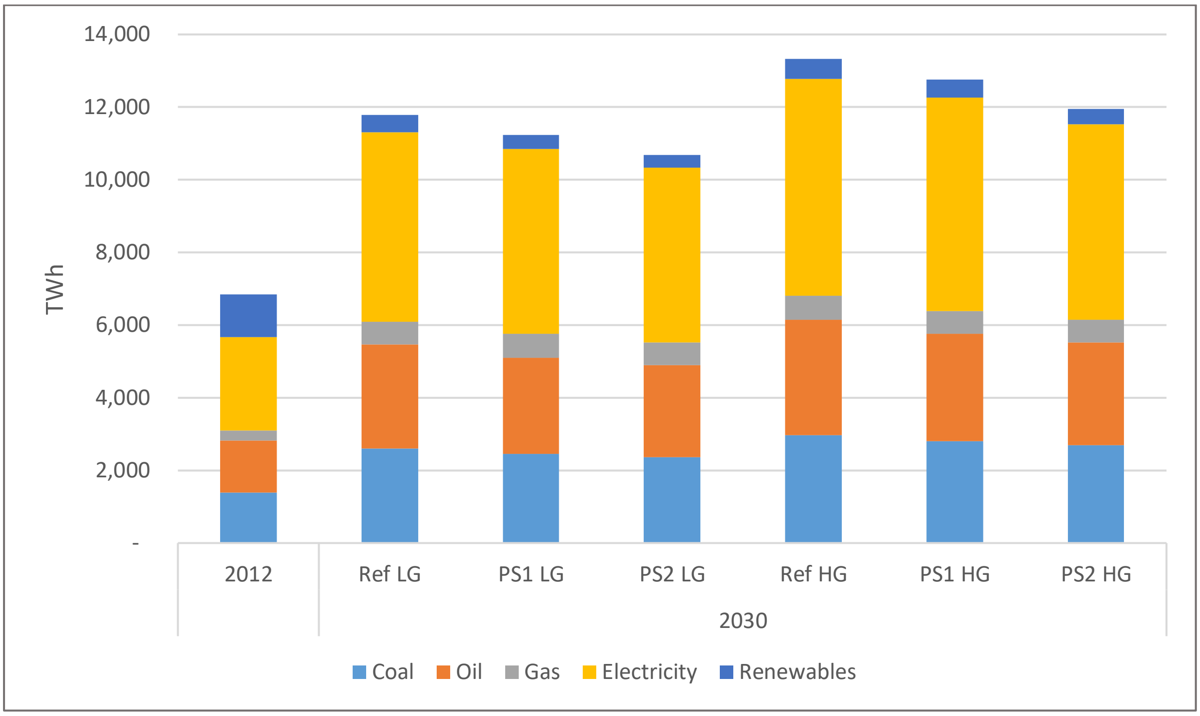

Figure 13: Projected total primary energy demand

Due to various energy-efficiency measures being adopted across the demand sectors, there is a decline in the rate of growth in demand for coal, electricity, and gas. This is despite an absolute increase in the demand due to improved household electrification. The demand for oil is set to increase due to the continued reliance of India's transport sector on oil. Limited deployment of electric vehicles and slower adoption of fuel efficiency norms in freight-based road transport curb the achievement of energy savings potential in this sector.

Electricity generation

In the reference scenarios, there is a 2.4–2.7 times increase of total electricity generation between 2012 and 2030 for the LG and HG scenarios, respectively. In the LG scenario, total electricity generation reaches 2,092 TWh (compared with 2,372 TWh in the HG scenario) from the 2012 value of 884 TWh. Reference-scenario generation mix is heavily dominated by coal. In the HG and LG scenario, coal contributes to almost 57% and 54% of generation, respectively. Penetration of RE-based generation increases substantially in 2030 in both reference growth scenarios, compared with 2012. Total fossil-free electricity share is around 33% for both the scenarios in 2030. Hydro (11%) and nuclear (8%) are other prominent generating options.

In the policy scenarios, total electricity generation is lower than that in the reference ones, due to energy efficiency measures in demand sectors. Higher penetration of RE-based generation is seen in these scenarios primarily due to future cost-reduction potentials. In the high-growth scenarios, total fossil-free electricity share is approximately 41% and 42% in the PS 1 and PS 2 cases respectively in 2030. On the other hand, for the low-growth scenario, fossil-free shares are 44% and 41% respectively for PS 1 and PS 2 cases in 2030.

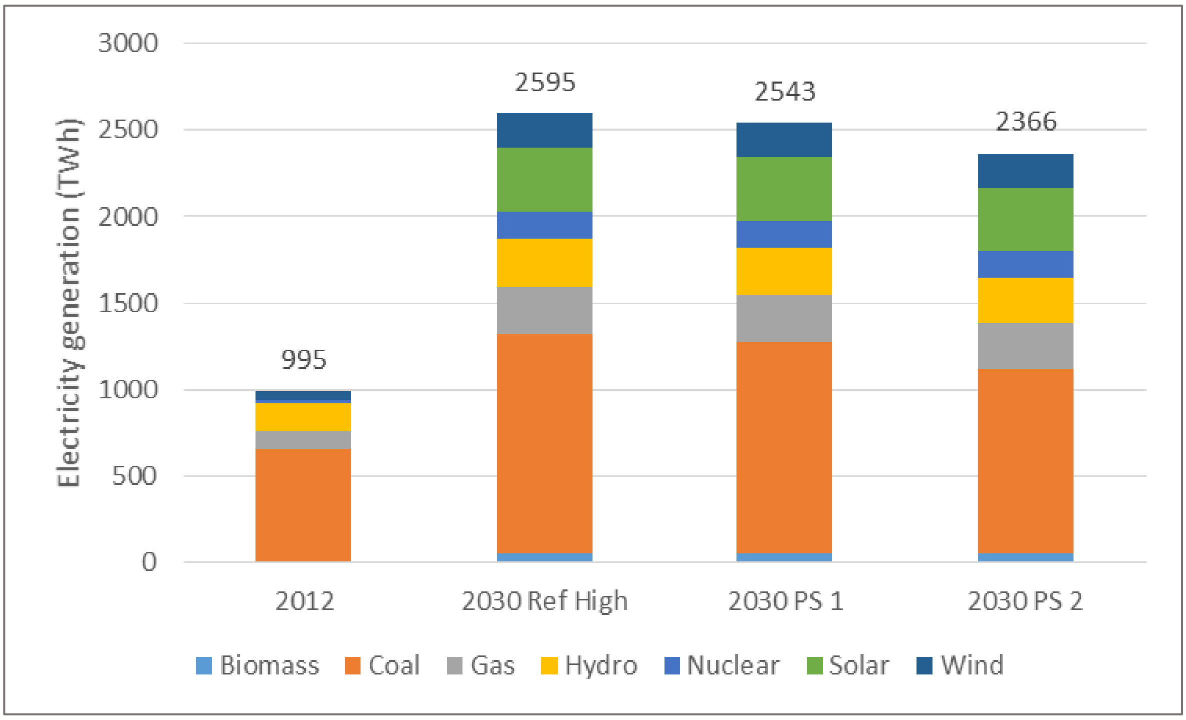

Figure 14: Projected electricity generation

Decoupling of economic growth and energy demand

India exhibited strong economic growth—at an average of 8% p.a.—between 2005 and 2012, led by growth in the services sector. During this period, energy demand grew at a much slower pace of about 3% annually; this indicates a decoupling trend of economic growth and energy demand. As detailed in the previous section, our projections suggest that India's GDP is expected to grow at an annual average of 6.8% between 2017 and 2030 (SIM2). Concurrently, the energy demand is expected to grow at a rate of 5.5% p.a.

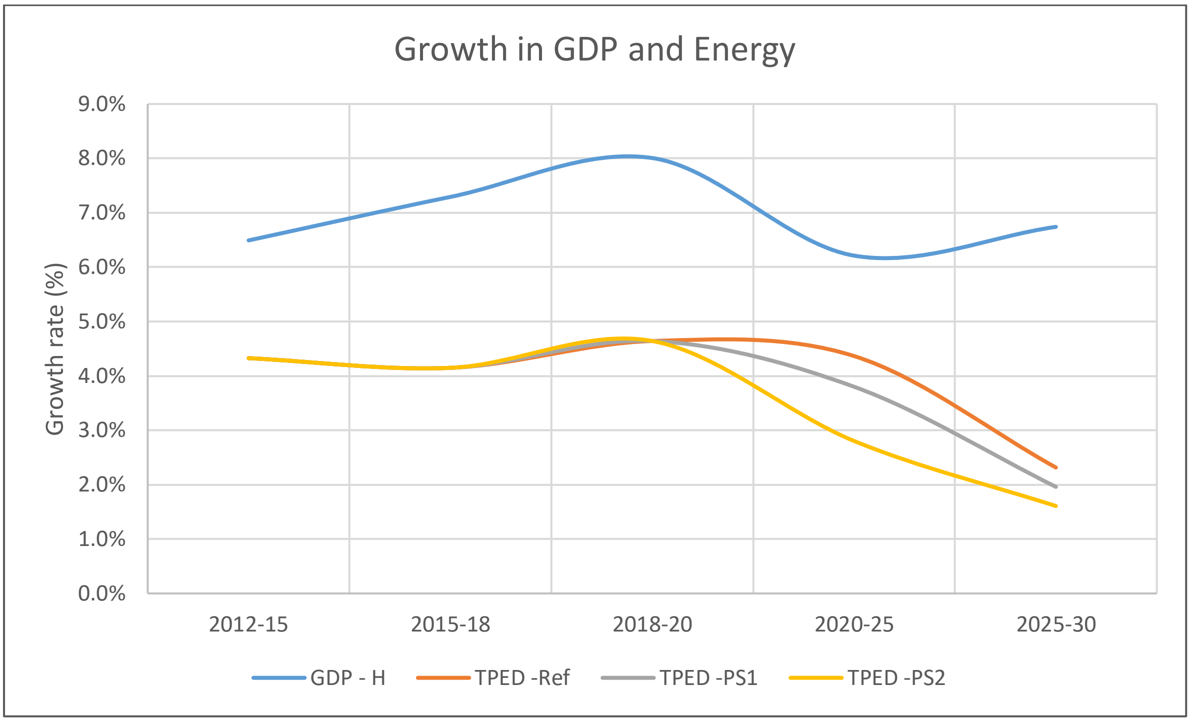

Figure 15: Decoupling of India's GDP and energy demand

As shown in Figure 15, growth in energy demand is expected to decline in the latter half of the decade, compared with economic growth. Thus, our analysis suggests that decoupling trends continue till 2030. This decoupling is mainly attributed to the decrease in energy intensity owing to improvements in energy efficiency due to the implementation of the PAT scheme. The switch to LPG cooking (via the UJWALA scheme) has also further reduced the cooking primary energy demand. Further, we observe that in PS 2, the decoupling effect is stronger, owing to the aggressive implementation of energy efficiency measures.

GHG Emissions

India's total GHG emissions increase from 1834 $MtCO_2e$ in 2012 to 1.5–2 times in 2030 in the low- and high-growth scenarios. The growth in emissions is attributed to increased electricity generation, industrial output, and transport activity. In both economic trajectories, electricity generation and industries continue to be the largest contributers to India's emissions. As seen in Figure 16, India's emissions are likely to grow at an annual rate of 4.3% till 2030 in a HG trajectory. With the implementation of aggressive emission-reduction and energy efficiency measures under PS2, the rate of emission growth is expected to decline to 3.6%. Under a LG trajectory, India's emissions are likely to grow at an annual rate of 3.5%, which can be limited to 2.7% under PS2. This sustained growth in emissions indicates the need for more robust measures to abate emissions from key sectors like electricity generation, industrial process emissions, and transport.

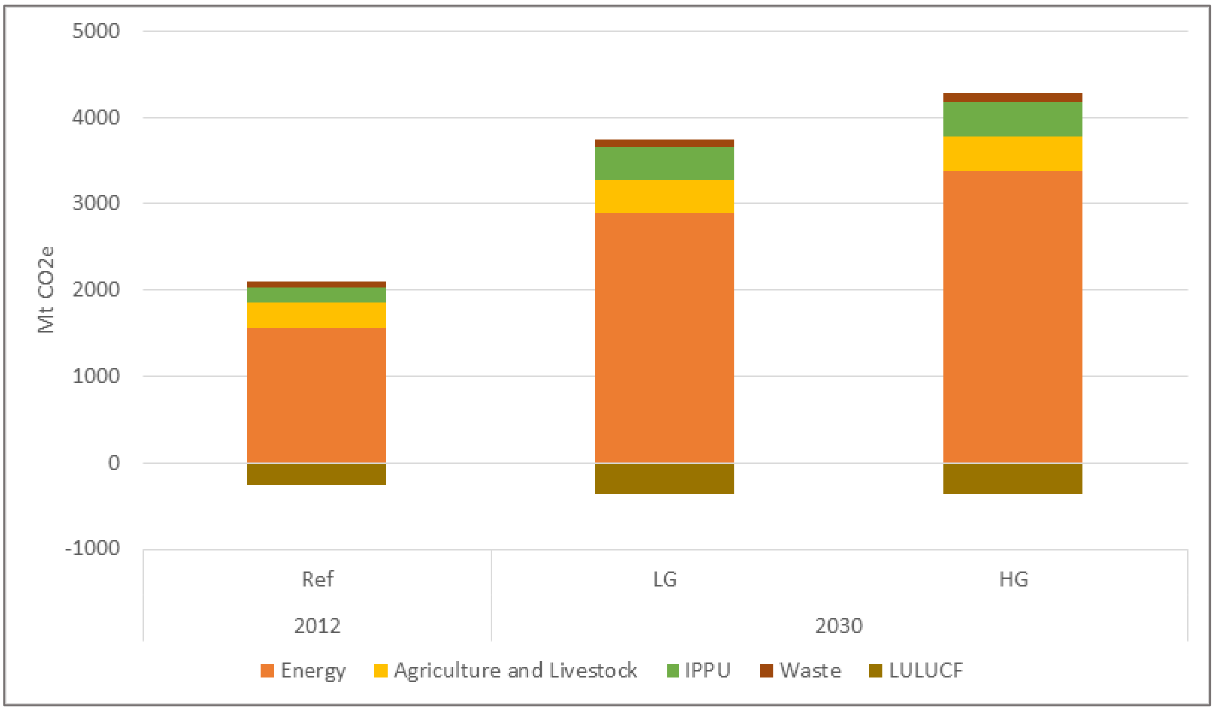

Figure 16: GHG emissions

Emission intensity of GDP

Emission intensity of GDP provides an estimate of the total emissions generated to produce a unit of GDP. It is used to assess the sustainability of an energy system or economy. As discussed previously, India has committed to reduce its emission intensity of GDP by 33%–35% in 2030, compared with 2005 levels, in the Paris Agreement of 2015.

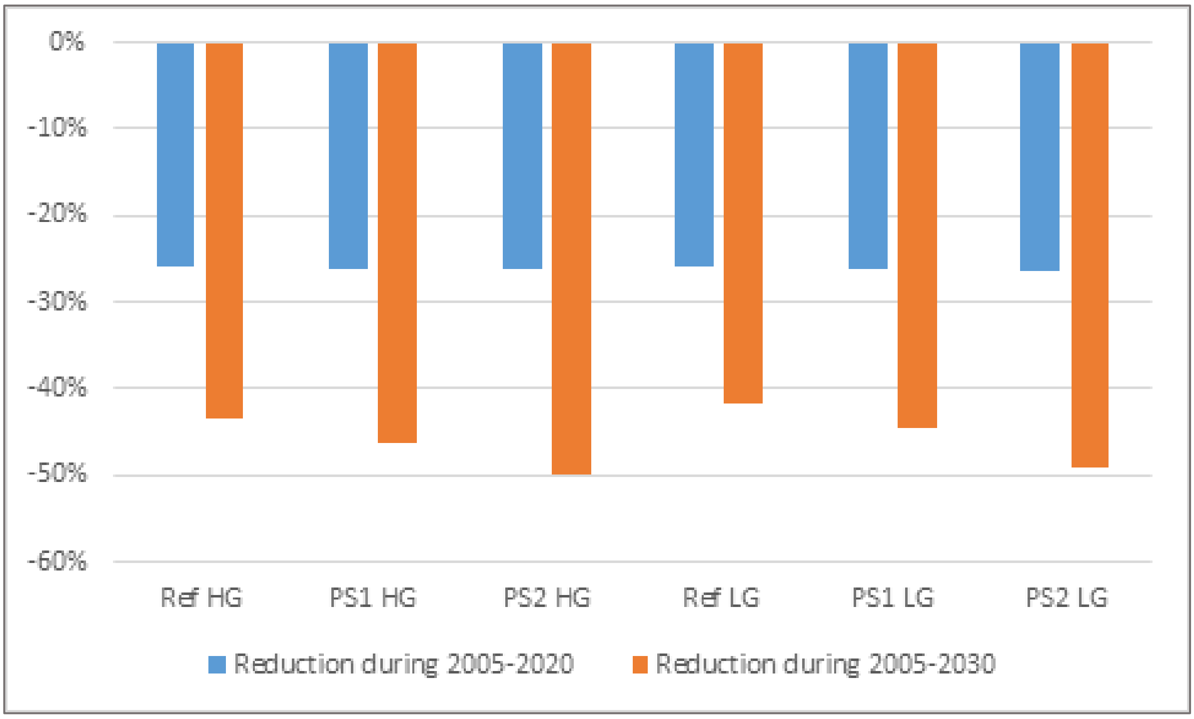

Figure 17: Reduction in emission intensity of GDP

Based on our analysis, India is likely to surpass these targets and achieve an overall reduction of 43% in emissions intensity of GDP (reference scenario). With aggressive implementation of energy efficiency and emission-reduction measures, we can achieve up to 50% reduction in 2030, compared with 2005 levels (PS 2 scenario).

Decoupling of GDP, TPED, and Emissions

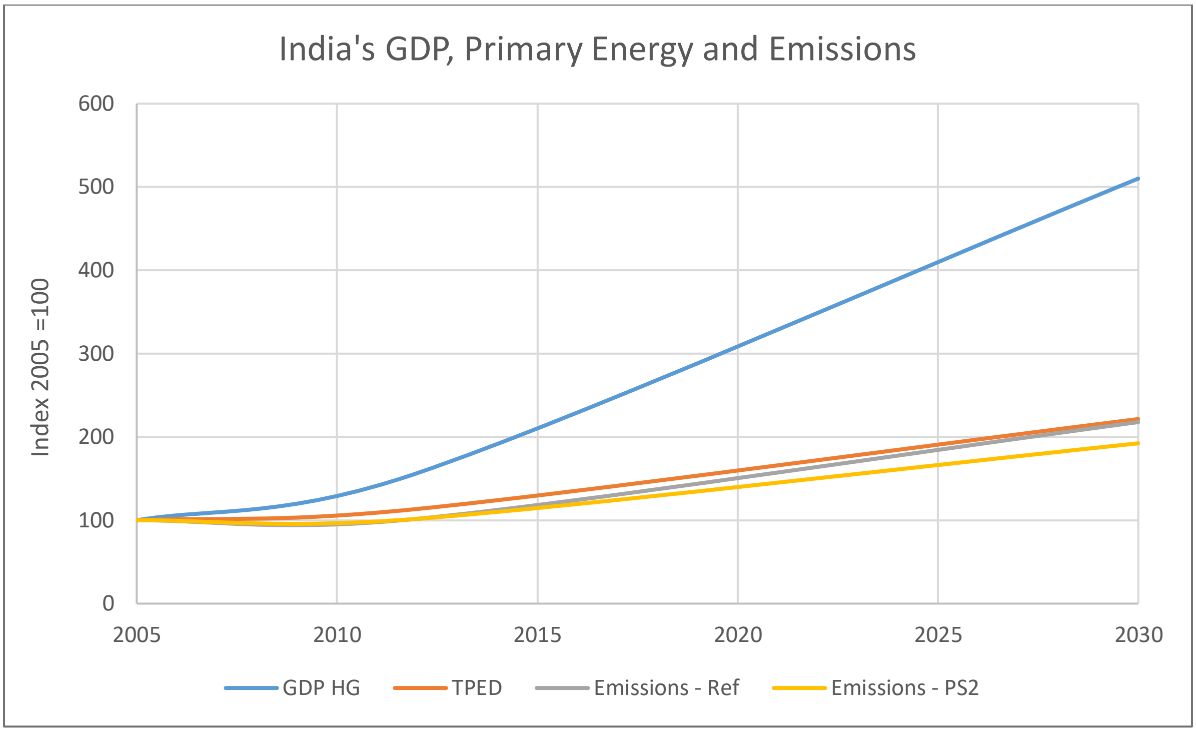

Figure 18: Decoupling of GDP, TPED and emissions in high growth scenario

As shown in Figure 18, GDP and energy demand indicate a distinct trend of decoupling, particularly in the period after 2020. However, energy and emission trends are strongly correlated up to 2030, even in PS 2 (which aggressively implements energy efficiency and emission-reduction measures). Hence, despite the concerted effort to improve efficiency, there is a substantial need to decarbonise India's energy system. For decarbonisation, the system requires an accelerated deployment of clean-energy technologies across various sectors, particularly in transport and industries. The decoupling of energy and emissions growth is imperative to achieve India's goals of energy security and environmental sustainability. Additionally, this will play a key role in demonstrating the success of India's climate policies.

5. Conclusions and Policy Recommendations

This study has aimed to simulate India's long-term economic growth trajectories and assess the implications on energy and emissions till 2030. To this end, we have used a multi-sector general equilibrium framework and linked the results to a bottom-up energy model for emission estimations.

From a methodological perspective, the main contribution of this study is the development of a multi-period CGE model for India with the following features—base year 2012–13, 51 commodity sectors, 66 activity sectors, and 20 household decile classes. Our framework comprises an investment-driven model where investment is fixed and savings endogenously adjust to achieve equilibrium. Investment is the main exogenous lever because it provides a useful framework to evaluate the impact of growth on key sectors and emissions.

Our modelling results suggest that India will continue as a service sector–led economy till 2030. However, projected subdued industry growth suggests that service-sector growth in the medium term could be at risk in a situation of prolonged weakness in industry (also see IMF, 2019). Further, the simulated moderate pace of economic growth has a downside effect on household income and consumption growth.

Our simulations also suggest that high growth in the service sector, besides leading to lopsided development, cannot alone guarantee the USD 5 trillion growth target. Sustained high investments across the economy (overall average 9.3% p.a.) and a faster pace of productivity growth (at a trend rate of 1.2% p.a.) are required to expand economic growth from the current average 7% p.a. to 9% p.a.—to achieve USD 5 trillion in 2025 and meet the *Make in India* targets. Hence, we suggest that an inclusive growth trajectory that prioritises structural reforms be pursued for achieving India's development agenda.

While investments are a key lever for policy planners, it is important to note that investments alone cannot drive economic growth. As the current economic slowdown reveals, demand-side measures like consumption incentives are equally important in stimulating growth. Importantly, from a socioeconomic perspective, we find that inequality remains a major concern in all simulations, and hence recommend that policymakers address this issue in long-term growth planning.

Finally, our projections show that India's emission intensity of GDP in 2030 declines by 50%–43% over 2005 levels, largely due to energy efficiency improvements across demand sectors like industry, buildings, and transport. Thus, India is on track to meet the 2030 NDC targets. The country's structural growth trajectory will also form a key part in achieving these targets. If India chooses, for instance, to incentivise manufacturing growth through a strategic focus on *Make in India*, it is essential that these policies be complemented by an accelerated uptake of more stringent efficiency measures and low-carbon production technologies. Given the scale of development goals to be achieved, it is essential that future climate policies address the decoupling of energy growth and emissions, particularly in energy-intensive sectors. Even in a services-led economy, such measures are crucial in the shift to a sustainable development pathway and for scaling up mitigation targets beyond 2030. Future research aims to improve the representation of energy sectors in our CGE framework, and account for resource constraints, sector-specific emissions, and technology parameters. The aim will be to build an integrated energy-economy model capable of comprehensively assessing a wide range of emission-reduction policies for India.

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7. Annexures

7.1 Capital Stock Assumptions

Table 11: Historical capital stock growth trends

SL No	KLEMS Industry Description	Growth Rate (2010-15)
1	Agriculture, Hunting, Forestry, and Fishing	4.8%
2	Mining and Quarrying	8.8%
3	Food Products, Beverages, and Tobacco	4.9%
4	Textiles, Textile Products, Leather, and Footwear	5.0%
5	Wood and Products of Wood	2.4%
6	Pulp, Paper, Paper Products, Printing, and Publishing	0.7%
7	Coke, Refined Petroleum Products, and Nuclear Fuel	9.2%
8	Chemicals and Chemical Products	5.6%
9	Rubber and Plastic Products	5.1%
10	Other Non-Metallic Mineral Products	3.7%
11	Basic Metals and Fabricated Metal Products	8.0%
12	Machinery	5.9%
13	Electrical and Optical Equipment	3.0%
14	Transport Equipment	9.0%
15	Manufacturing; Recycling	2.3%
16	Electricity, Gas, and Water Supply	7.3%
17	Construction	8.5%
18	Trade	20.7%
19	Hotels and Restaurants	13.6%
20	Transport and Storage	2.7%
21	Post and Telecommunication	11.5%
22	Financial Services	3.5%
23	Business Services	9.4%
24	Public Administration and Defence; Compulsory Social Security	6.9%
25	Education	10.0%
26	Health and Social Work	11.7%
27	Other Services	6.3%
	Overall Economy	7.1%

Source: Historical aggregate capital stock growth rates sourced from RBI-KLEMS Database, 2018

Table 12: Capital stock assumptions

Sectors	Historical (2010-15)	Reference	SIM1	SIM2	SIM3	SIM4
Overall economy	7.1%	6.6%	5.4%	7.0%	7.9%	9.3%
Agriculture	4.8%	4.8%	3.6%	3.9%	6.2%	6.6%
Industry	5.3%	5.9%	5.2%	5.9%	6.0%	7.6%
Services	9.4%	7.7%	5.9%	8.9%	8.4%	8.8%

Source: Authors' compilation; historical capital stock growth rates sourced from RBI-KLEMS Database, 2018

7.2 Productivity Assumptions

Table 13: Historical productivity growth trends

SL No	KLEMS Industry Description	Growth Rate (1980-2015)
1	Agriculture, Hunting, Forestry, and Fishing	0.6%
2	Mining and Quarrying	-1.3%
3	Food Products, Beverages, and Tobacco	0.9%
4	Textiles, Textile Products, Leather, and Footwear	0.6%
5	Wood and Products of Wood	-4.4%
6	Pulp, Paper, Paper Products, Printing, and Publishing	1.3%
7	Coke, Refined Petroleum Products, and Nuclear fuel	-2.9%
8	Chemicals and Chemical Products	3.5%
9	Rubber and Plastic Products	-0.2%
10	Other Non-Metallic Mineral Products	-1.0%
11	Basic Metals and Fabricated Metal Products	-1.8%
12	Machinery	-1.1%
13	Electrical and Optical Equipment	2.0%
14	Transport Equipment	0.5%
15	Manufacturing; Recycling	2.4%
16	Electricity, Gas, and Water Supply	1.4%
17	Construction	-2.3%
18	Trade	0.2%
19	Hotels and Restaurants	0.8%
20	Transport and Storage	2.5%
21	Post and Telecommunication	5.7%
22	Financial Services	3.1%
23	Business Services	2.8%
24	Public Administration and Defence; Compulsory Social Security	3.5%
25	Education	0.8%
26	Health and Social Work	0.1%
27	Other Services	0.7%
	Overall Economy	0.6%

Source: Historical total factor productivity (value added-based) growth rates sourced from RBI-KLEMS Database, 2018

We note that although Table 13 reports negative productivity growth for select sectors, our model considers only positive productivity growth for all sectors. This concurs with our assumption of stimulating long-term economic growth by pushing for growth in investments and productivity improvements.

7.3 Power Sector Assumptions

Table 14: RE cost reduction trajectory from 2016 to 2030 assumed in the IMRT model

Technology	Investment cost in 2016-17 (INR billion/GW)	Reference	Policy Scenario 1 (PS 1)	Policy Scenario 2 (PS 2)
		Percentage reduction of investment cost in 2030 from 2016-17 levels		
Solar PV mono SI (Fixed tilted)	46	-19%	-20%	-23%
Solar PV poly SI (Fixed tilted)	40	-19%	-20%	-23%
CdTe/CIGS	45.5	-19%	-20%	-23%
HIT	46	-10%	-11%	-14%
RTPV mono Silicon	51.25	-19%	-20%	-23%
RTPV poly Silicon	48.75	-28%	-32%	-36%
RTPV CdTe/CIGS	48.5	-28%	-32%	-36%
Solar CSP	221	-20%	-30%	-56%
Wind	62-72	-3%	-9%	-15%
Offshore wind	178-315	-5%	-15%	-22%

Source: IRENA, 2016; JRC, 2014; Gulagi et al., 2017; Sharma et al., 2018; Wiser et al., 2016

7.4 Industries Sector Assumptions

Cement

Table 15: Cement sector - Reference scenario assumptions

Reference		2012	2030
Improvements in Specific Energy Consumption (SEC)	Thermal SEC (kcal/Kg Clinker)	727	704
	Electrical SEC (kWh/t cement)	80	75
Improvement in cement to clinker ratio (Clinker Factor)		0.74	0.68
Use of alternate fuels and raw material (Thermal Substitution Rate)		1%	6%

Table 16: Cement sector - Policy scenario 1 assumptions

Policy Scenario 1		2012	2030
Improvements in Specific Energy Consumption (SEC)	Thermal SEC (kcal/Kg Clinker)	727	703
	Electrical SEC (kWh/t cement)	80	74
Improvement in cement to clinker ratio (Clinker Factor)		0.74	0.68
Use of alternate fuels and raw material (Thermal Substitution Rate)		1%	7%

Table 17: Cement sector - Policy scenario 2 assumptions

Policy Scenario 2		2012	2030
Improvements in Specific Energy Consumption (SEC)	Thermal SEC (kcal/Kg Clinker)	727	697
	Electrical SEC (kWh/t cement)	80	72
Improvement in cement to clinker ratio (Clinker Factor)		0.74	0.65
Use of alternate fuels and raw material (Thermal Substitution Rate)		1%	8%

Aluminium

Table 18: Aluminium sector - Reference scenario assumptions

Reference		2012	2030
Shift to less energy-intensive production process	Point Feed Pre-Baked Anode	70%	80%
	Soderberg	10%	0%
	Secondary Production (Scrap)	20%	20%
Improvements in Specific Energy Consumption (SEC) GJ/t	Point Feed Pre-Baked Anode	66	60
	Soderberg	92	83
	Secondary Production (Scrap)	5	4

Table 19: Aluminium sector - Policy scenario 1 assumptions

Policy Scenario 1		2012	2030
Shift to less energy-intensive production process	Point Feed Pre-Baked Anode	70%	80%
	Soderberg	10%	0%
	Secondary Production (Scrap)	20%	20%
Improvements in Specific Energy Consumption (SEC) GJ/t	Point Feed Pre-Baked Anode	66	58
	Soderberg	92	80
	Secondary Production (Scrap)	5	4

Table 20: Aluminium sector - Policy scenario 2 assumptions

Policy Scenario 2		2012	2030
Shift to less energy-intensive production process	Point Feed Pre-Baked Anode	70%	80%
	Soderberg	10%	0%
	Secondary Production (Scrap)	20%	20%
Improvements in Specific Energy Consumption (SEC) GJ/t	Point Feed Pre-Baked Anode	66	56
	Soderberg	92	78
	Secondary Production (Scrap)	5	4

Iron and Steel

Table 21: Iron and Steel sector - Reference scenario assumptions

Reference		2012	2030
Shift to less energy-intensive production process	BF - BOF/EOF	42%	52%
	DRI - EAF - Gas	9%	10%
	DRI - EAF Coal	25%	20%
	DRI/IF scrap-based	14%	12%
	Corex - BOF	10%	6%
Improvements in Specific Energy Consumption (SEC) GJ/tcs	BF - BOF/EOF	27	24
	DRI - EAF - Gas	25	20
	DRI - EAF Coal	27	24
	DRI/IF scrap-based	13	12
	Corex - BOF	26	24

Table 22: Iron and Steel sector - Policy scenario 1 assumptions

Policy Scenario 1		2012	2030
Shift to less energy-intensive production process	BF - BOF/EOF	42%	42%
	DRI - EAF - Gas	9%	12%
	DRI - EAF Coal	25%	22%
	DRI/IF scrap-based	14%	17%
	Corex - BOF	10%	7%
Improvements in Specific Energy Consumption (SEC) GJ/tcs	BF - BOF/EOF	27	22
	DRI - EAF - Gas	25	18
	DRI - EAF Coal	27	23
	DRI/IF scrap-based	13	11
	Corex - BOF	26	23

Table 23: Iron and Steel sector - Policy scenario 2 assumptions

Policy Scenario 2		2012	2030
Shift to less energy-intensive production process	BF - BOF/EOF	42%	40%
	DRI - EAF - Gas	9%	14%
	DRI - EAF Coal	25%	19%
	DRI/IF scrap-based	14%	21%
	Corex - BOF	10%	6%
Improvements in Specific Energy Consumption (SEC) GJ/tcs	BF - BOF/EOF	27	21
	DRI - EAF - Gas	25	17
	DRI - EAF Coal	27	22
	DRI/IF scrap-based	13	11
	Corex - BOF	26	22

7.5 Buildings Sector Assumptions

Reference

Table 24: Buildings sector - Reference scenario assumptions

Sectors	Interventions	2012	2030
Residential	Efficiency pathway	L:M:H[24] = 98:1:1	L:M:H = 60:30:10
Residential	Penetration of smart building interventions in residential buildings in the new stock	High Rise: 1%; Horizontal development: 0%; Affordable housing: 0%	High Rise: 29%; Horizontal development: 23%; Affordable housing: 0%

[24] L:M:H indicates Low: Medium: High

Commercial	Penetration of smart buildings	10% of existing buildings	17%
Commercial	Technology penetration	High: 0%; Medium: 50%; Low: 50%	High: 30%; Medium: 50%; Low: 20%
Cooking	Efficiency of cooking technology	LPG cooking stove: 50%	LPG cooking stove: 57%

Policy Scenario 1

Table 25: Buildings sector - Policy scenario 1 assumptions

Sectors	Interventions	2012	2030
Residential	Efficiency pathway	L:M:H = 98:1:1	L:M:H = 20:50:30
Residential	Penetration of smart building interventions in residential buildings in the new stock	High Rise: 1%; Horizontal development: 0%; Affordable housing: 0%	High Rise: 43%; Horizontal development: 31%; Affordable housing: 0%
Commercial	Penetration of smart buildings	10% of existing buildings	20%
Commercial	Technology penetration	High: 0%; Medium: 50%; Low: 50%	High: 50%; Medium: 40%; Low: 10%
Cooking	Efficiency of cooking technology	LPG cooking stove: 50%	LPG cooking stove: 61%

Policy Scenario 2

Table 26: Buildings sector - Policy scenario 2 assumptions

Sectors	Interventions	2012	2030
Residential	Efficiency pathway	L:M:H = 98:1:1	L:M:H = 10:40:50
Residential	Penetration of smart building interventions in residential buildings in the new stock	High Rise: 1%; Horizontal development: 0%; Affordable housing: 0%	High Rise: 52%; Horizontal development: 46%; Affordable housing: 0%
Commercial	Penetration of smart buildings	10% of existing buildings	25%

Commercial	Technology penetration	High: 0%; Medium: 50%; Low: 50%	High: 80%; Medium: 20%; Low: 0%
Cooking	Efficiency of cooking technology	LPG cooking stove: 50%	LPG cooking stove: 65%

7.6 Transport Sector Assumptions

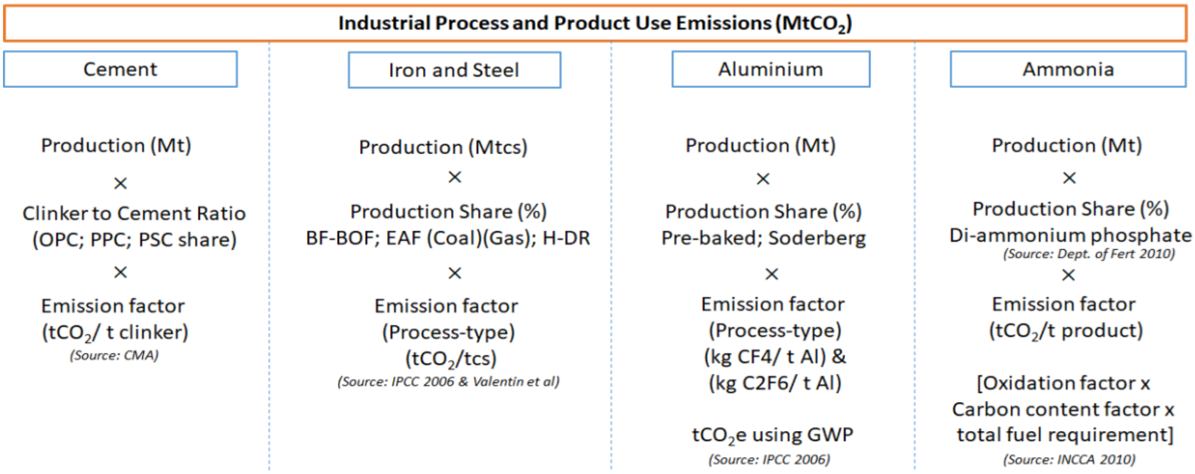
Recent vehicle sales trends, and electrification targets were used to refine scenario assumptions used in the IESS-2047 calculator and validated with relevant transport sector experts.

Table 27: Transport sector scenario assumptions

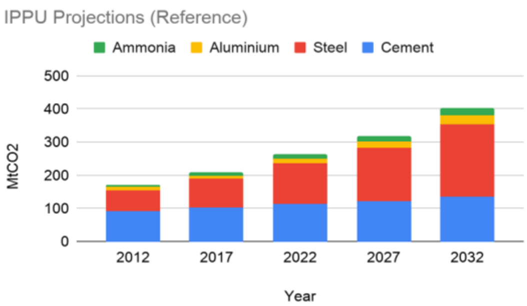
	Reference	Policy Scenario 1	Policy Scenario 2
Efficiency Pathways*	Based on historical trends, targets and aspirations proposed under various policies for passenger (0.92-1.4% improvement annually) and freight modes. Passenger rail - diesel and electric assumes an annual improvement of 4% and 1.4% respectively.		
Public Transport	In keeping with historical trends, public transport share declines to 65% by 2032 from 75% in 2012	Public transport share at 69% in 2032	Public transport share at 69% in 2032
Electrification	In 2032, E2W and E4W account for 0.4% for on-road mobility share; e-taxis - 10% (based on NEMMP annual sales targets)	E2W - 11%; E4W - 1.5%; taxis-12%	E2W - 20%; E4W - 8%; e-taxis - 18%
Share of rail freight and electrification	Declines from 42% to 38% in 2032 (80% electrified)	41% in 2032 (90% electrified)	43% in 2032 (100% electrified)
*Efficiency improvement pathways across scenarios have been considered to be the same and account for regulations and mandates in vehicle manufacturing.			

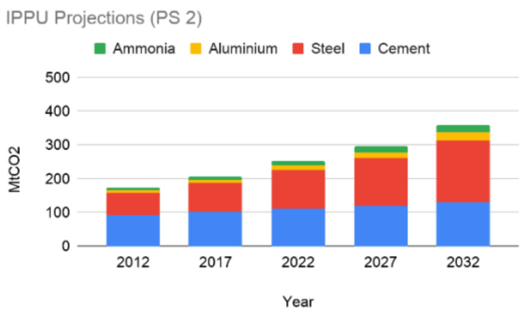
7.7 Non-Energy Sector Emission Estimation Methodology and Results

IPPU emissions: Methodology and results



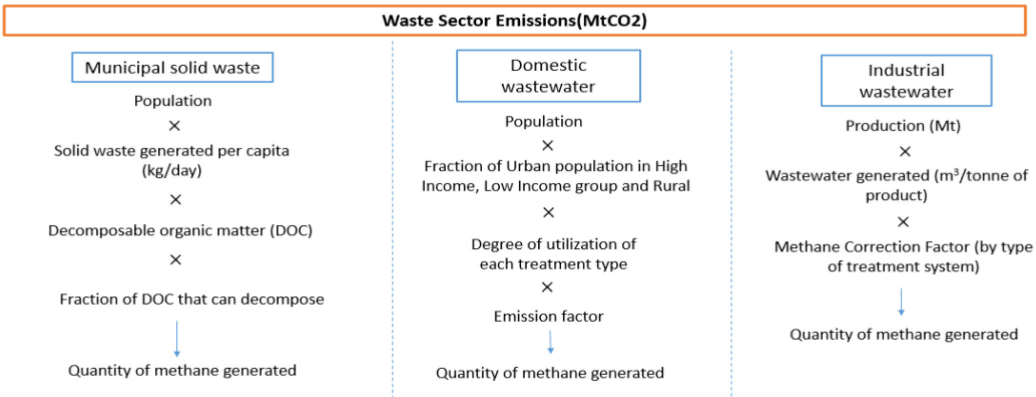
Methodology adopted from guidelines published by IPCC 2006



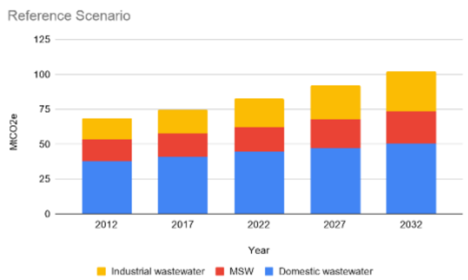


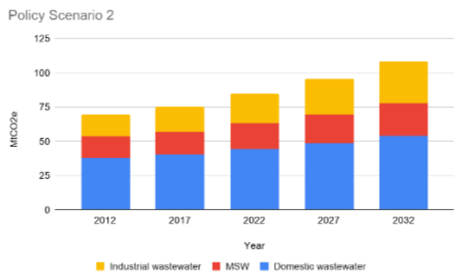
IPPU Emissions (MtCO$_2$)	Scenario	2012	2032
	Reference	172	404
	Policy Scenario 2		359

Waste-sector emissions: Methodology and results



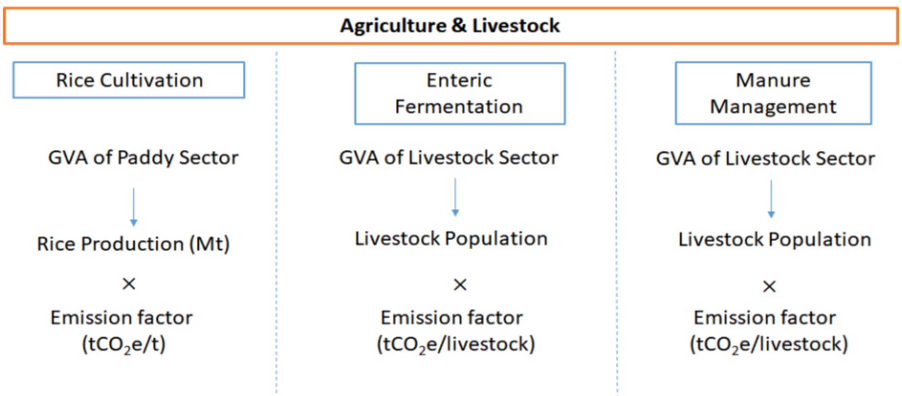
Methodology adopted from Guidelines published by IPCC 2006



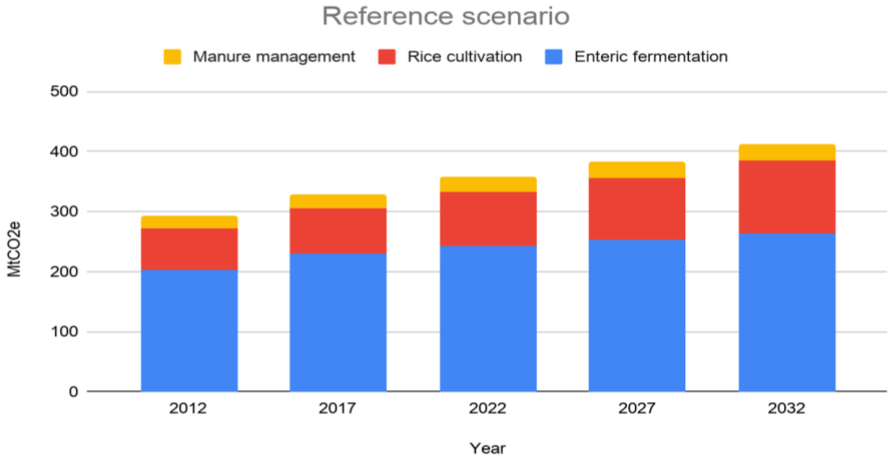


Waste Emissions ($MtCO_2e$)	Scenario	2012	2032
	Reference	69	102
	Policy Scenario 2		108

Agriculture & livestock-sector emissions: Methodology and results



(Source: IPCC 2006 & GHGPI)



Emissions ($MtCO_2e$)	2012	2032
Reference	293	412

LULUCF-sector emissions: Methodology and results

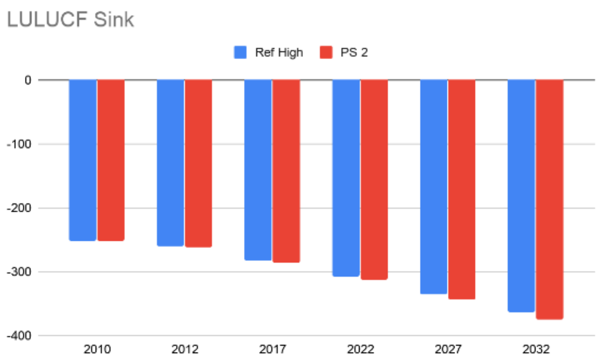
Land Use, Land Use Change & Forests

CAGR based approach to project sink

Historic LULUCF Sink Values

(Source: NC (2000), INCCA 2010, & BUR 2014)

Forest Sink Targets
Green India Mission
NDC: 2.5—3 Billion tonnes of CO_2e (2030)
Ultimate Goal NDC: 33% land area under forest cover (2040)



- Reference Scenario accounts for increase in sink under Green India Mission.
- Increased forest cover in PS2 leads to additional sink of 11 MT CO_2e in 2032.

7.8 Minutes of the Roundtable *Assessing Impacts of India's Long-term Economic Growth Trajectories on Climate Goals* held on 17th March 2020. Authors' responses may be found as footnotes in relevant sections of the report.

The objective of this roundtable was to deliberate on the linkages between low-carbon transitions and economic growth. CSTEP presented its recent work on soft-linking CGE and energy-systems models. The discussions focused on exploring diverse perspectives and methodologies for understanding India's long-term economic-growth trajectories and implications for policymaking.

The roundtable began with introductions by CSTEP and SSEF on project objectives and provided context to the ensuing discussions. This was followed by a brief presentation by CSTEP and a discussion on modelling results. The floor was then opened to an interactive session on specific themes, and participants were invited to contribute their viewpoints. The following key points emerged from all the discussions:

- Participants provided comments and observations on CSTEP's analysis and suggested ways to refine the report's findings for future studies.[25]
- Modelling long-term economic impacts is an important issue to consider while formulating low-carbon pathways.
- Research on the energy-economy-environment nexus is moving away from the narrative on costs and trade-offs with low carbon transitions towards analyzing the convergence of the two. Emerging research questions include exploring the economic impact of changing energy prices and energy efficiency on factor productivity, sectoral implications and linkages with macroeconomic benefits (e.g., net jobs and wages in the economy), and welfare implications (e.g., at the household consumption level).
- It was observed that considering perspectives of human well-being is also important. Future work can focus on detailed sectoral aspects, such as cooling and sustainable mobility.
- Discussants highlighted that from an international perspective, global economic models that represent the Indian region should be compared with bottom-up assessments from India. This can help inform global assessments as India's position is seen to be globally very significant from a climate change mitigation perspective.
- It was suggested that trade-offs between growth and low-carbon transitions may not be as straightforward because not all sectors will benefit equally from growth measures, for example, from higher productivity.
- An interesting point was raised about enhancing the involvement of corporations in achieving India's climate ambitions. This is particularly important given the role of the

[25]Broadly, it was recommended that future research include insights on trade-offs between a manufacturing vs service sector-driven economy; explain linkages between investment and productivity growth trends; implications of structural change on welfare; feasibility of doubling factor productivity and sector-specific variations; future work could consider a feedback loop from the IESS-TIMES framework to the CGE model, which would enable an assessment of energy efficiency measures.

industry sector in our modelling assessments (from both a growth and energy efficiency implementation perspective).

- Responses indicated that most corporations, particularly at the MSME level, may not have access to key information about low-carbon pathways and impacts on industries. Most industries also may not consider timescales up to 2030/2050. Analytical models in the EU have been successful in informing low-carbon and net-zero transition plans. There is potential for learnings there on how Indian researchers can tailor their research findings and involve industries in such analyses.

The roundtable ended with a vote of thanks to all participants.

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