NITI Aayog

SCENARIOS TOWARDS VIKSIT BHARAT AND NET ZERO

MACROECONOMIC IMPLICATIONS

(VOL. 2)

NITI Aayog
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सत्यमेव जयते

Foreword

India enters the coming decades amid heightened global uncertainty, shaped by rising protectionism, policy fragmentation, climate risks, geopolitical tensions, and shifting global supply chains. Yet India's economic performance stands out. As the fastest growing major economy, supported by strong macroeconomic fundamentals, sustained public investment, expanding digital infrastructure, and ongoing structural reforms, India is well positioned to serve as a key engine of global growth over the next two to three decades.

Under the visionary leadership of the Hon'ble Prime Minister, this ambition has been articulated through the vision of Viksit Bharat @2047, which seeks to transform India into a developed society within a generation while expanding its economic size to nearly USD 30 trillion by mid century. Achieving this goal while ensuring inclusion, resilience, and environmental sustainability presents an unprecedented development challenge. With per capita emissions well below the global average and limited historical emissions, India must pursue growth within a constrained global carbon budget, even as it undertakes deep technological and structural transitions in energy and industry. India's early progress on climate action demonstrates that development and sustainability can advance together, offering lessons of global relevance.

This report, *"Pathways to Net Zero - Macroeconomic Implications"*, responds to that need through an economy-wide assessment of the macroeconomic implications of India's Net Zero transition. Using Computable General Equilibrium modelling, it examines interactions across growth, investment, trade, employment, and public finances, with particular attention to financing structures, productivity effects, and distributional impacts.

Three conclusions stand out. India's long-term growth remains resilient under Net Zero pathways, with GDP projected to approach USD 30 trillion by 2047. The transition is investment intensive, and financing choices are critical, as pathways supported by foreign capital inflows and productivity gains significantly reduce transitional macroeconomic pressures. Impacts also vary across sectors and regions, reinforcing the need for targeted policies and strong coordination across levels of government.

स्वच्छ भारत
एक कदम स्वच्छता की ओर

Taken together, the analysis indicates that India's Net Zero transition need not constrain development. If managed effectively, it can strengthen energy security, reduce external vulnerabilities, support industrial upgrading, and generate new sources of employment and competitiveness. Delivering these outcomes will require frontloaded infrastructure investment, credible and stable policy signals, strong institutions, and sustained international cooperation consistent with the principle of common but differentiated responsibilities.

I hope this report informs policy choices as India navigates this critical transition. It reflects the collective work of the Inter Ministerial Working Group, chaired by Dr Arvind Virmani, Hon'ble Member, NITI Aayog, and draws on analytical inputs from our knowledge partners, including the World Bank, the National Council of Applied Economic Research (NCAER), and the World Resources Institute (WRI). I also extend my appreciation to the Green Transition, Energy and Climate Change vertical at NITI Aayog for their dedicated efforts and support in preparing this report.

(Suman Bery)

Place- New Delhi
Dated- 05th February, 2026

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MESSAGE

India today stands at a defining juncture in its development journey. Having emerged as lower middle income country and the world's fourth-largest economy with a GDP of USD 4.18 trillion, the country has demonstrated that sustained growth can be achieved through macroeconomic stability, a policy & institutional reform, and innovation-led governance. Under the visionary leadership of the Hon'ble Prime Minister, the past decade has seen the implementation of policy and institutional reforms such as the Goods and Services Tax, the Insolvency and Bankruptcy Code, the Real Estate (Regulation and Development) Act., and institutional reforms such as creation of digital public infrastructure based on Aadhaar and UPI. These have strengthened formalisation, improved market efficiency, and enabled wider private-sector participation. Public capital expenditure, now exceeding 4.3 percent of GDP, has crowded in private investment and played a catalytic role in laying the foundation for a resilient and low-carbon economy.

As India advances toward the objective of becoming a developed economy by 2047 (Viksit Bharat @2047), it confronts a macroeconomic challenge: managing the transition to net zero emissions by 2070 without compromising growth, stability, or inclusion. Climate change is not just an environmental concern, but a macroeconomic risk, with implications for agricultural productivity, infrastructure durability, public health, fiscal sustainability, and external balances. The central policy question is how to integrate economic development and low-carbon transition in a manner that preserves macroeconomic credibility under constrained global carbon space, evolving trade regimes, and tightening global financial conditions.

This report, *Pathways to Net Zero: Macroeconomic Implications of Net Zero,* is the output of the Inter-Ministerial Working Group constituted by NITI Aayog to assess the economy-wide consequences of India's net zero transition. Its mandate was to rigorously examine how net zero pathways interact with long-term growth, investment patterns, employment outcomes, trade competitiveness, and fiscal sustainability, and to identify the conditions under which the transition can remain macroeconomically stable and development-enhancing. The analysis draws on extensive inter-ministerial collaboration and engagement with leading economic institutions and in-house modelling team to provide an India-specific, economy-wide assessment, to inform policy choices over the coming decades.

The modelling framework evaluates a Current Policy Scenario alongside multiple Net Zero Scenarios consistent with achieving developed-economy status by 2047 and net zero emissions by 2070. Across scenarios, India's long-term growth remains broadly resilient, with net zero imposing limited impacts on aggregate GDP. However, the transition is fundamentally

investment intensive. Capital requirements rise sharply under all pathways, with net zero driving a large-scale reallocation of investment toward renewables, clean manufacturing, construction, and emerging low carbon technologies, while fossil fuel investments decline steadily.

The structure of financing emerges as a critical macroeconomic determinant. Pathways supported by foreign capital inflows show significantly positive GDP impacts, avoid crowding out private consumption, and sustain higher investment and productivity. By contrast, domestically financed transitions place greater pressure on domestic savings, underscoring the importance of mobilising patient international capital alongside domestic resources. These findings reinforce the central role of blended finance, risk-sharing mechanisms, and credible project pipelines in preserving macroeconomic stability while scaling investment.

The net zero transition will also reshape India's economic structure. Industry's share of GDP rises, driven by clean energy, manufacturing, and construction, while agriculture and fossil fuel-based activities gradually contract. Employment impacts remain modest in aggregate, but labour reallocation across sectors is significant. Renewables, infrastructure, transport, and trade emerge as key job creators, while coal-dependent regions face concentrated transition risks. Managing these shifts will require targeted re-skilling, regional transition finance, and proactive labour market policies to ensure an inclusive transition.

From a fiscal perspective, the transition entails short-term pressures but long-term gains. Falling fossil fuel linked revenues and rise in upfront public investment requirements widen fiscal deficits in the near term. However, these pressures ease in later decades as growth strengthens, new revenue sources emerge, and fossil fuel import dependence falls sharply. Lower import bills, particularly for energy, strengthen India's current account balance and enhance long-term economic resilience, even as critical mineral imports rise.

In conclusion, India's net zero transition will allow growth to remain resilient, while necessitating a significant scale-up of investment. By aligning climate ambition with structural reform, infrastructure investment, innovation, and institutional strengthening, India can unlock new sources of competitiveness, generate productive employment, enhance energy security, and sustain high growth. Success will depend on coordinated action across governments, regulators, industry, financial institutions, and international partners.

I would like to acknowledge the dedication of the Inter-Ministerial Working Group, the in-house modelling team, World Bank and NCAER, and all contributing institutions for their thorough analysis and collaborative efforts. It is my hope that this report will provide policymakers and stakeholders with practical insights to steer sustained, fast, inclusive growth to a Net Zero and Viksit Bharat.

New Delhi

February, 2026   **(Arvind Virmani)**

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FOREWORD

The Hon'ble Prime Minister has set an ambitious goal to make India become a developed $30 trillion economy by 2047, - a Viksit Bharat. Historically, industrialization powered by fossil fuels has been the backbone of rapid economic growth for emerging economies. However, India aims to lift hundreds of millions of people to higher income standards while also achieving Net-Zero emissions by 2070. This is notwithstanding the fact India's per capita emissions are much lower than that of the developed world. The two intertwined goals require India to design a new paradigm of growth, which no other country has attempted in the past at this scale.

Achieving Net Zero requires the large deployment of clean energy technologies, such as solar, wind, electric vehicles, battery energy storage systems, green hydrogen, carbon capture utilization and storage, etc. Many of these technologies are still evolving and not mature. Therefore, the key question is: How does achieving Net Zero intersect with India's aspirations of becoming a developed nation?

This report addresses this question based on a comprehensive macroeconomic model. The primary objective is development and achieving the Viksit Bharat goals. The results suggest that Net Zero pathways do not prevent India from achieving the Viksit Bharat goals. All the scenarios explored have only a marginal impact on GDP. Higher mobilization of international financing further helps as it frees up domestic capital for use in other sectors. Our trade balance becomes more resilient with the reduction in fossil fuel imports. We will have to pay particular emphasis on skilling and education and increased investment in R&D while expanding our manufacturing capacities and tapping export markets to take advantage of emerging opportunities

I extend my sincere appreciation to the members of the Working Group chaired by Dr. Arvind Virmani, Member, NITI Aayog for their excellent work in this report. I thank our knowledge partners, National Council for Applied Economic Research (NCAER), the World Bank, and WRI for their research and insights. I also congratulate my NITI colleagues, Dr. Anshu Bharadwaj, Shri Venugopal Mothkoor and Ms. Divya Midha for their outstanding efforts in the report. This report lays down clearly the macro-economic picture of achieving the Net Zero goals while attaining a developed country status.

Dated: 4th February, 2026

[B.V.R. Subrahmanyam]

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Foreword

India stands at a defining juncture in its development journey. Over the past decade, the country has emerged as one of the world's principal engines of growth, underpinned by sustained macroeconomic stability, large-scale public investment, and deep structural reforms. At the same time, climate change has moved from being a distant environmental concern to a first-order macroeconomic risk—affecting agricultural productivity, public health, infrastructure resilience, and long-term growth potential. Reconciling the imperatives of rapid development with environmental sustainability is therefore no longer optional; it is central to India's economic strategy.

India has articulated an ambitious and credible vision: to become a developed economy by 2047 and to achieve net-zero greenhouse gas emissions by 2070. This dual objective is unprecedented in scale and complexity. Unlike earlier industrialisers, India must expand incomes, employment, and infrastructure for a large and youthful population while simultaneously bending its emissions trajectory downward. The success of this endeavour will shape not only India's future but also the global pathway to climate stability.

Against this backdrop, *India's Net Zero Pathway: Macroeconomic Impacts of India's Net Zero Transition* provides a rigorous, evidence-based assessment of how India's development and climate objectives interact at the macroeconomic level. The report brings together energy system modelling and economy-wide computable general equilibrium frameworks to examine the implications of alternative net-zero pathways for growth, investment, employment, trade, household welfare, public finances, and regional development. By analysing different financing structures and policy designs, it moves beyond abstract commitments to address the practical question of how the transition can be managed in a manner that is economically resilient and socially inclusive.

A central message of this report is cautiously optimistic: India's long-term growth prospects remain robust even under net-zero pathways. With appropriate policy choices, the transition need not come at the cost of development. On the contrary, investments in clean energy, resilient infrastructure, and emerging low-carbon technologies can become powerful drivers of productivity, job creation, and energy security. At the same time, the analysis underscores that the transition is inherently investment-intensive and that financing design, sequencing, and institutional capacity will be decisive in shaping outcomes.

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List of Abbreviations

AI	Artificial Intelligence
APMC	Agricultural Produce Marketing Committee
APV	Agrivoltaics
ASSET	Accelerating Sustainable State Energy Transition
BCM	Billion cubic meters
BIS	Bureau of Indian Standards
BOT	Balance of Trade
BSE	Bombay Stock Exchange
CAB	Current Account Balance
CACP	Commission for Agricultural Costs and Prices
CAD	Current Account Deficit
CBAM	Carbon Border Adjustment Mechanism
CCUS	Carbon Capture, Utilization, and Storage
CEA	Central Electricity Authority
CGE	Computable General Equilibrium
CPS	Current Policy Scenario
DBT	Direct Benefit Transfer
DFC	Dedicated Freight Corridor
DISCOM	Distribution Company
DoT	Department of Telecommunications
DRC	Democratic Republic of Congo
ECSBC	Energy Conservation & Sustainable Building Code
ENS	Eco-Niwas Samhita
EV	Electric Vehicle
FAME	Faster Adoption and Manufacturing of Electric Vehicles
FAR	Floor Area Ratio

FD	Fiscal Deficit
FDI	Foreign Direct Investment
FTAs	Free Trade Agreements
FY	Fiscal Year
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GSDP	Gross State Domestic Product
GST	Goods and Services Tax
GVC	Global Value Chain
GW	Gigawatt
IBC	Insolvency and Bankruptcy Code
ICED	India Climate & Energy Dashboard
IEA	International Energy Agency
IISD	International Institute for Sustainable Development
IMF	International Monetary Fund
IMWG	Inter-Ministerial Working Group
INR	Indian Rupee
IRENA	International Renewable Energy Agency
JAM	Jan Dhan–Aadhaar–Mobile
LPG	Liquefied Petroleum Gas
LTGM	Long-Term Growth Model
MHFW	Ministry of Health and Family Welfare
MOAFW	Ministry of Agriculture and Farmers Welfare
MoHUA	Ministry of Housing and Urban Affairs
MoRTH	Ministry of Road Transport & Highways
MOSPI	Ministry of Statistics and Programme Implementation
MSP	Minimum Support Price
MT	Million ton
Mtoe	Million tons of oil equivalent
MW	Megawatt
NDC	Nationally Determined Contribution
NEER	Nominal Effective Exchange Rate
NMP	National Monetisation Pipeline

NPCI	National Payments Corporation of India
NSQF	National Skill Qualification Framework
NZS	Net Zero Scenario
NZdom	Net Zero Domestic Financing
NZdom+	Net Zero Domestic Financing with Productive Investment
NZdomSub	Net Zero Domestic Financing with Subsidy
NZfor	Net Zero Foreign Financing
NZfor+	Net Zero Foreign Financing with Productive Investment
NZforRD	Net Zero Foreign Financing with Revenue Redistribution
NZforSub	Net Zero Foreign Financing with Subsidy
PGE	Platinum-Group Elements
PIB	Press Information Bureau
PLI	Production Linked Incentive
PM-eBus Sewa	Prime Minister e-Bus Service Sewa
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan
PPAC	Petroleum Planning and Analysis Cell
PSU	Public Sector Undertaking
PV	Photovoltaic
R&D	Research & Development
RDSS	Revamped Distribution Sector Scheme
RE	Renewable Energy
REE	Rare Earth Elements
REER	Real Effective Exchange Rate
RERA	Real Estate (Regulation and Development) Act
SAF	Sustainable Aviation Fuel
SPCB	State Pollution Control Board
T&D	Transmission and Distribution
TFP	Total Factor Productivity
TIMES	The Integrated MARKAL-EFOM System
TW	Terawatt
TWh	Terawatt-hour
UDAN	Ude Desh ka Aam Nagrik
ULB	Urban Local Body

UN DESA	United Nations Department of Economic and Social Affairs
UNCTAD	United Nations Conference on Trade and Development
UNESCO	United Nations Educational, Scientific and Cultural Organization
USD	United States Dollar
UT	Union Territory
WHO	World Health Organization
WTO	World Trade Organization

Executive Summary

India's Economic Transformation: Foundations of a Resilient and Reform-Driven Growth Story to become Viksit Bharat@2047: India's economy has undergone a remarkable transformation, crossing a GDP of USD 4.18 trillion, to become the world's fourth-largest economy driven by macroeconomic stability, institutional reforms, and the rise of digital public infrastructure. Structural reforms such as Goods and Services Tax (GST), Insolvency and Bankruptcy Code (IBC), Real Estate Regulatory Authority (RERA), Aadhaar, and Unified Payments Interface (UPI) have strengthened transparency, formalisation, and private-sector participation, positioning India as the world's fastest-growing major economy. Between 2015 and 2025, the country contributed nearly 15% of global GDP growth, supported by strong domestic demand and sustained policy reform.

Growth remains service-led accounting for 55% of GVA, while employing 30% of the workforce, compared to agriculture's 15% GVA share and 46% employment, underscoring the opportunity to pursue more job-rich growth through manufacturing and industrial development. Public capital expenditure has emerged as a key growth driver, tripling over the last decade to over 4.3% of GDP by FY25-26. Energy and electricity consumption have grown, with non-fossil sources now comprising half of installed power capacity. Fiscal prudence, stable debt levels, and targeted infrastructure investments have built a foundation for the next phase of low carbon, inclusive, and broad-based growth.

Balancing Growth and Green Ambition: Climate change poses a direct macroeconomic risk, threatening agricultural productivity, physical infrastructure, and public health systems. India's dependence on imported fossil fuels further aggravates these risks and heightens macroeconomic uncertainty. These challenges are compounded by a constrained global carbon budget and evolving trade dynamics including the growing use of carbon-related trade measures which intensify the headwinds facing developing economies.

Navigating this complex landscape requires aligning India's aspiration of becoming Viksit Bharat with a sustained and credible pathway towards achieving Net Zero by 2070. With per-capita emissions of around three tonnes of CO_2 well below the global average, India is charting a development pathway that integrates climate ambition with its national priorities, building on its progress in renewable power, infrastructure development, and energy efficiency through strategic investments.

As India advances towards balancing growth and low-carbon transition, it is essential to understand the macroeconomic implications. A rigorous, economy-wide assessment has therefore been undertaken to examine the interactions between climate action, growth, investment, trade, fiscal balances, and employment, and to identify potential trade-offs and synergies across sectors through a Computable General Equilibrium (CGE) modelling framework. The implications are examined through multiple Net Zero Scenarios differing by financing sources, redistributive mechanisms, and productivity co-benefits.

Key modelling insights

Net Zero transition has limited impact on long-term GDP growth but demands high investment. India's GDP is projected to stay broadly resilient even in Net Zero (NZ) scenarios, reaching USD 30 trillion by 2047- aligned to the Viksit Bharat goal. While the transition demands massive capital mobilisation, scenarios that rely on higher international finance mobilisation limit GDP deviation from Current Policy Scenario to about -0.5% in a scenario. This highlights the importance of financing: mobilizing external capital such as FDI reduces pressure on domestic savings and avoids crowding out private investment.

Growth Structure Shifts from Consumption-Led to Investment-Driven: In Current Policy Scenario, Private consumption's share in GDP is expected to decrease from 58% in 2025 to 52% in 2070, while investment share changes from 32% in 2025 to around 36% by 2050 before stabilising to 34% by 2070, as the economy matures. In Net Zero Scenarios, financing the investment from domestic sources tightens liquidity and crowds out consumption, whereas dominant foreign financing scenarios sustain both investment and demand, signalling a long-term structural rebalancing toward capital-intensive growth.

Industry Expands driven by clean energy and Fossil Manufacturing Declines: The Net Zero transition accelerates structural change, boosting industry's GVA share to 33% by 2050 and stabilising thereafter, driven by clean energy and manufacturing. Fossil-based manufacturing is lower by 5.6% compared to Current Policy Scenario under domestic financing; and higher by 2.5% compared to Current Policy Scenario under dominant foreign financing pathways by mid-century. Manufacturing remains central as India scales domestic clean-tech capacity.

Investment-Intensive Growth Pathways : India's growth trajectory is capital-intensive across all scenarios, with total investment quintupling by 2070 under Current Policy Scenario (~INR 4,200 lakh cr over 2065-70) and rising even further under Net Zero, highlighting the scale of finance that must be mobilised. The Net Zero pathway drives a sharp reallocation of capital to support rapid scale-up of renewables.

Trade Becomes More Resilient with Lower Fossil Fuel Dependence: Imports and exports grow in absolute terms as India moves to high-income status, but remain broadly stable at 23–

26% of GDP. Under Net Zero pathways, exports are lower relative to Current Policy Scenario by 6% in scenarios that rely on higher foreign finance and over 9% under domestically financed pathways by 2050. Imports are lower by 1.6% compared to Current Policy Scenario in dominant foreign financed scenarios, reflecting reduced fossil fuel dependence. Net Zero scenarios that rely on higher foreign finance consistently show larger Current Account Deficits (peaking at around 3.2% of GDP in 2045) compared to domestically-financed Net Zero scenarios (stabilizing at 2.3-2.5%).

Household Consumption Faces Modest Pressure, mitigated by Policy Support: Without complementary policies, household consumption falls slightly under Net Zero Scenario, particularly for lower income groups, due to higher energy prices and investment crowding. Foreign-financed and redistributive policies such as targeted transfers and RE subsidies help preserve consumption and can keep the lowest 40% of population at Current Policy Scenario levels thereby preventing negative impacts on inequality.

Fossil-Fuel Revenue Losses Offset by Import Savings and Green Transition: Fossil-fuel revenues fall from 2.3% of GDP at present to 0.2% in Net Zero Scenario by 2070, while the fuel import bill drops from 4% to 0.2% of GDP under the Net Zero Scenario by 2070. Although critical mineral imports rise, total import savings reach 0.5% of GDP by 2070, strengthening fiscal and external resilience.

Job Creation Shifts to Renewables, Construction, and Transport: The Net Zero transition reallocates labour from fossil fuels toward renewable electricity, clean-tech manufacturing, and infrastructure-intensive sectors such as construction, transport, and trade. Overall employment effects remain modest, with employment rates deviating by less than ±1 % vs the Current Policy Scenario by mid-century. Net Zero pathways show the shift from agriculture to services while strengthening manufacturing and raising demand for skilled labour. Wage impacts are limited in the near term but diverge over time, with dominant foreign-financed pathways supporting higher real wages, especially in manufacturing.

Policy Suggestions

I.   Reaffirm India's Civilisational Model of Sustainable Development

India's development model has long been grounded in balance with nature and resource efficiency. Civilisational practices such as climate-responsive architecture, sustainable diets, shared living arrangements, and frugal resource use already embody low-carbon aspects. Institutionalising these principles through Mission LiFE, circular economy practices, and energy-efficient design can scale a development pathway where well-being and resilience, rather than just conventional indicators of growth, define progress.

II. Build Low-Carbon Competitiveness in a Fragmented Global Economy

With global trade shifting from efficiency to resilience, India must diversify exports and enable low carbon transition in industries to stay competitive under new carbon-linked regulations like CBAM. Aligning Monitoring, Reporting, and Verification (MRV), carbon accounting and interoperability of sustainability certifications with key partners in future FTAs will safeguard market access and attract investment.

III. Frontload Infrastructure Investment for Net Zero Growth

Increased upfront investment will be needed to achieving Viksit Bharat goals, especially through a pathway consistent with Net Zero goals. India's growth path is investment-intensive under all scenarios: in Current Policy Scenario, investment quintuples by 2070, and under Net Zero Scenario the scale of required capital is even higher, making India's development a uniformly high-investment story that hinges on mobilising unprecedented levels of finance. Targeted public investment in electricity grids, urban infrastructure, EV charging, multimodal logistics, etc. will be critical to crowd in private capital, ensuring that low-carbon transition reinforces, rather than constrains, India's growth trajectory.

A blended financing approach - combining domestic flows with patient foreign capital through instruments like green bonds, risk guarantees, co-investment platforms, etc. - can scale investment while avoiding crowding out of productive private investment. Building transparent, de-risked pipelines of bankable projects will be essential to sustain investor confidence and preserve macroeconomic and fiscal stability.

IV. Make Green Jobs a National Employment Mission

The Net Zero transition can be a net job creator if supported by international capital, targeted reskilling, and flexible labour reforms. Expanding labour-intensive manufacturing for renewable energy services like solar O&M, battery assembly, efficient building retrofits, etc.- through a "Green and Digital Skills Stack," and preparing the workforce for AI & automation will ensure future-readiness.

V.   Strengthen R&D and Innovation for Green Technologies

India must raise R&D investment to match global benchmarks - currently 0.65% of GDP, with private industry contributing just 37% versus 68% in advanced economies. By comparison, the US invests ~3% of GDP in R&D, South Korea ~5.2%, and Japan ~3.4%. Expanding private R&D, fostering industrial innovation clusters, and supporting early-stage commercialisation can accelerate adoption of technologies like storage, electric mobility, climate-smart agriculture, Carbon Capture, Utilization, and Storage (CCUS), Small Modular Reactors (SMR), etc.

VI. Strengthening Institutions to Unlock Low-Carbon Growth

Robust, accountable institutions are critical to India's Net Zero transition. Strengthening core bodies - particularly DISCOMs and the Bureau of Energy Efficiency, will be critical to drive energy transition planning at sub-national level. The regulatory burden can be reduced by overhauling and standardising processes, and by facilitating a single-window approval mechanism with adequate safeguards.

1

INTRODUCTION

Introduction

1

India stands out as a bright spot in a turbulent global economy, growing faster and more resiliently than most peers

From 1993 to 2025, India's economy has grown from under USD 300 billion to nearly USD 4.13 trillion, at a compound annual growth rate (CAGR) of about 8% in nominal terms (IMF, 2025). This growth is particularly striking given that the Indian rupee depreciated by around 3% per year over the same period (Economic Survey 2024). Furthermore, India managed to preserve macroeconomic stability without a steep rise in external borrowing; its external debt-to-GDP ratio was just 18.7% in March 2024, among the lowest for major emerging economies (Economic Survey 2024).

India's growth has lifted incomes and improved the quality of life for millions

India's per capita income rose from USD 302 in 1993 to around USD 1,554 in 2024 and an estimated USD 2,730 in 2025 (IMF; World Bank, 2025), an eightfold increase that translated into enhanced consumption capacity, stronger savings, and upward social mobility. The benefits of growth have also been inclusive: between 2015 and 2022, more than 250 million Indians exited multidimensional poverty, with the MPI headcount ratio falling from 29% to 11% (NITI Aayog 2024; UNDP, 2025). Few other emerging markets have achieved poverty reduction on such a scale and pace.

Since 2014, India has pursued a new model of growth, focused on building public goods and trust to unlock private potential

While the 2004–2014 period demonstrated growth, the post-2014 decade has been defined by institutional and structural reforms that have reshaped India's growth model. This phase saw the country pivot from being primarily a provider of services to a builder of platforms, enabling private enterprise to scale. Key reforms included:

▸ **Building public goods:** Aadhaar for digital identity, UPI for payments, Gati Shakti for logistics, and expanding data infrastructure.

▸ **Trust-based governance:** The Goods and Services Tax (GST) created a unified domestic market, the Insolvency and Bankruptcy Code (IBC) transformed corporate

resolution, the Real Estate (Regulation and Development) Act (RERA) brought transparency to real estate. In parallel, welfare delivery was digitised, making public services faster, more transparent, and more accessible.

⯈ **Private sector as partner:** Recognising private enterprise as a co-partner in development, not merely a revenue source

⯈ **Boosting agricultural productivity and rural incomes:** Through infrastructure, irrigation and e-markets.

Together, these shifts positioned India's growth on stronger institutional foundations, underpinned by digital innovation, productivity gains, and partnership between State and private actors.

Climate change has become a direct macroeconomic risk for India

Sustaining India's growth is no longer just about fiscal prudence or trade liberalisation. Climate change has emerged as a direct macroeconomic risk. For India, it is not a distant possibility but a present reality: extreme weather events, rising sea levels, droughts, and floods already affect agricultural productivity, food and water security, public health, and infrastructure. Air pollution, land degradation, water scarcity and quality compound these risks, reducing growth potential, straining fiscal balances, and deepening poverty and inequality.

Historical emissions and trade barriers magnify India's vulnerability

The developed economies relied on fossil fuels for two centuries, but now press developing nations to decarbonise rapidly through untested pathways. These same countries maintain higher per-capita emissions and, in some cases, continue investing in fossil fuel extraction and use, as seen in the recent U.S. oil approvals[1]. Global climate policymaking largely minimizes the concept of historical responsibility, ignoring the cumulative emissions debt owed to the Global South. India, home to 18% of the world's population, has contributed just 4% of cumulative emissions since 1850, yet bears disproportionate climate impacts.

Carbon tariffs and energy imports reduce India's competitiveness

Between 2000 and 2024, average tariff rates declined significantly, India's from 48.9% to 17.3%, China's from 16.4% to 8.3% (WTO 2024). At the same time, non-tariff measures (NTMs), especially climate-related ones, surged. Over 26,000 trade and investment restrictions were imposed globally between 2020 and 2024 (Global Trade Alert 2024). For example, the EU's Carbon Border Adjustment Mechanism (CBAM) and Deforestation Regulation (EUDR) could affect nearly USD 9.5 billion of Indian exports, around 12.9% of India's total shipments

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1   U.S. oil approvals: Recent U.S. oil approvals refer to government decisions allowing new or expanded oil drilling and infrastructure, reflecting a short-term focus on energy security and price stability, even in the light of long-term climate concerns.

to the EU (Economic Survey 2024–25). These measures, while framed as environmental safeguards, act as protectionist tools that hinder export-led growth in emerging economies.

Energy dependence adds another layer of vulnerability. While the country has made strong progress in energy efficiency and diversification of supply sources, a significant share of its energy needs is still met through imports, exposing the economy to fluctuations in global fuel prices and supply disruptions.

India's aspirations are shifting, from poverty alleviation to developed-nation status

Unlike China, which rose during a wave of globalisation, India's rise is unfolding amid "slowbalisation", characterised by fragmented supply chains, shifting tariffs, and rising geopolitical risks. In this uncertain environment, India's aspirations are evolving. Under the banner of 'Viksit Bharat @2047', the nation seeks to enhance its goal from poverty alleviation to full-fledged developed-country status by its centenary of independence. This is not just an economic ambition but a societal one: to achieve prosperity in a democratic, federal, and culturally diverse context while staying within ecological limits.

⏩ India is embarking on a development journey with no historical precedent, seeking to become a developed, high-income economy by 2047 (Viksit Bharat), the centenary of its independence, while also achieving Net Zero emissions by 2070.

⏩ Unlike past industrial revolutions that relied heavily on fossil fuels, India aims to lift hundreds of millions into higher-income and better-quality livelihoods while simultaneously bending its emissions trajectory downward.

⏩ With per-capita emissions of about 3 tonnes of CO_2, less than half the world average and a fraction of advanced-economy levels, and a cumulative share of roughly four percent of global emissions since 1850, the transition reflects both constrained carbon space and extraordinary ambition.

⏩ Unlike fossil-fuel-led industrialisation elsewhere, India's energy transition is bounded by acute land and water scarcity. Limited per-capita land availability (0.23 ha) and widespread water stress mean clean energy expansion directly competes with food security, livelihoods, and ecosystems, a constraint not faced by early industrialisers.

⏩ India's Net Zero pathway requires large-scale investment in public goods and frontier technologies, including resilient grids, water systems, CCUS, green hydrogen, offshore wind, SMRs, and long-duration storage, many of which remain commercially unviable without international finance and risk-sharing, reinforcing climate action as a global public good under Common But Differentiated Responsibilities and Respective Capabilities (CBDR–RC).

There are concerns that large-scale investments toward Net Zero could divert resources from development needs such as health, education, and social infrastructure. However, the analysis indicates that climate action need not come at the expense of development priorities. Investments in clean energy, resilient infrastructure, and low-carbon technologies can generate quality jobs, enhance energy security, and improve public welfare, thereby reinforcing rather than competing with the country's broader development objectives.

Toward a Green, Inclusive, and Developed India

Achieving the Viksit Bharat vision will require sustained high real GDP growth (INR terms) of 7-8% annually over the next two decades. But this trajectory is complicated by external shocks, global climate commitments, and fast-evolving technologies. India's development pathway must therefore reconcile two imperatives: sustaining growth and delivering on Net Zero commitments.

To steer this path, NITI Aayog set up an Inter-Ministerial Working Group (IMWG) to analyse the macroeconomic implications of India's Net Zero transition. Its mandate is to model how India can simultaneously achieve high growth, create jobs, maintain fiscal stability, and safeguard trade competitiveness, while advancing towards Net Zero. The IMWG's scope of work includes:

- Examine different GDP growth trajectories and structure of the economy consistent with India's Viksit Bharat and other developmental goals.

- Explore the impact of Net Zero Scenarios on GDP, employment, income distribution, Current Account Deficit, Tax revenues, Trade aspects etc using various analytical tools.

- Examine the impact of various GDP scenarios and population projections on total energy demand.

- Examine the institutional/regulatory frameworks at national and state level required to drive the transition in a coordinated manner.

By integrating fiscal, trade, energy, and employment considerations into a unified framework, the IMWG's work will help shape India's macroeconomic roadmap. It will provide policymakers with the evidence base to ensure that India's journey to Net Zero is not only environmentally responsible, but also economically resilient and socially inclusive.

2

MACROECONOMIC LANDSCAPE OF INDIAN ECONOMY

Macroeconomic Landscape of Indian Economy

2

This chapter examines the macroeconomic landscape of India's development from 2015 to 2025, focusing on growth trends, sectoral composition, labour productivity, public investment, and fiscal health. It also highlights the growing role of energy transition in shaping these dynamics. The chapter also underscores the structural reforms and infrastructure push that have underpinned India's emergence as a global economic engine.

2.1 India's Growth and Global Standing

India, with an average annual real GDP growth rate of approximately 7.8% between 2015 and 2025 in nominal terms[2], **contributed around 15% to global GDP growth during this period**, positioning it firmly among **the top three engines of global economic expansion** alongside China and the United States (IMF 2025; World Economics 2024). This performance stands out not just for its scale but also for its resilience, achieved in a decade marked by geopolitical conflicts, pandemic-related disruptions, and volatile commodity markets. In contrast, many advanced and emerging economies experienced slower, more uneven recoveries. India's sustained expansion thus became a key pillar of global economic resilience and recovery. Notably, this period also marked the beginning of India's energy transition, a shift toward renewable energy and sustainable infrastructure that is reshaping key macroeconomic parameters.

India's economic ascent has fundamentally reshaped its global standing. As of April 2025, India, with a GDP of USD 4.18 trillion, had surpassed Japan to become the world's fourth-largest economy (IMF's World Economic Outlook Report of April 2025). On a purchasing power parity (PPP) basis, it ranks third globally, behind only China and the United States (IMF WEO 2025). These milestones reflect India's expanding domestic market, deepening industrial base, and a structural shift toward innovation and productivity-led growth (see figure 2.1).

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2   10-year Compound Annual Growth Rate (CAGR) of real GDP over FY15–FY25 being 6% and average growth rate excluding COVID years of FY21 and FY22 being 7.1% between FY15–FY25

Share of 10-year growth (2015-2025)
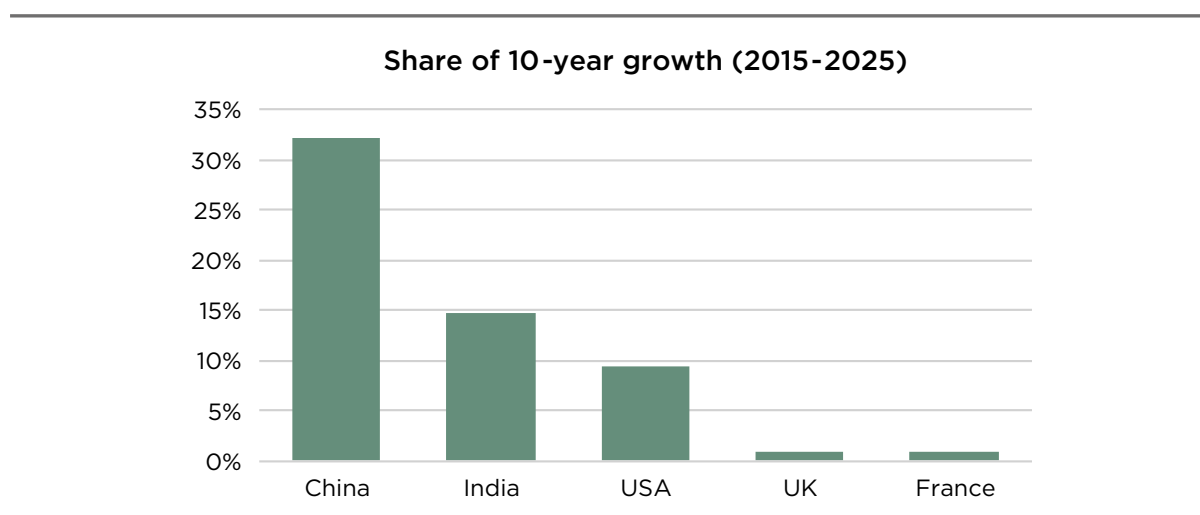
Figure 2.1: Country-wise contribution to global GDP growth

Services-Led Growth

India's economy remained service-led from FY2014-15 to FY2023-24. In FY2014–15, the services sector accounted for 52.4% of India's Gross Value Added (GVA), surpassing both agriculture (16.5%) and industry (31.1%). Almost a decade later, services remain dominant, contributing 54.9% of GVA by FY2024–25, while agriculture's share fell only modestly to 14.4% and industry remained stable (MoSPI, 2025). This reaffirms services-led growth (see figure 2.2).

% Share in GVA (Constant prices)
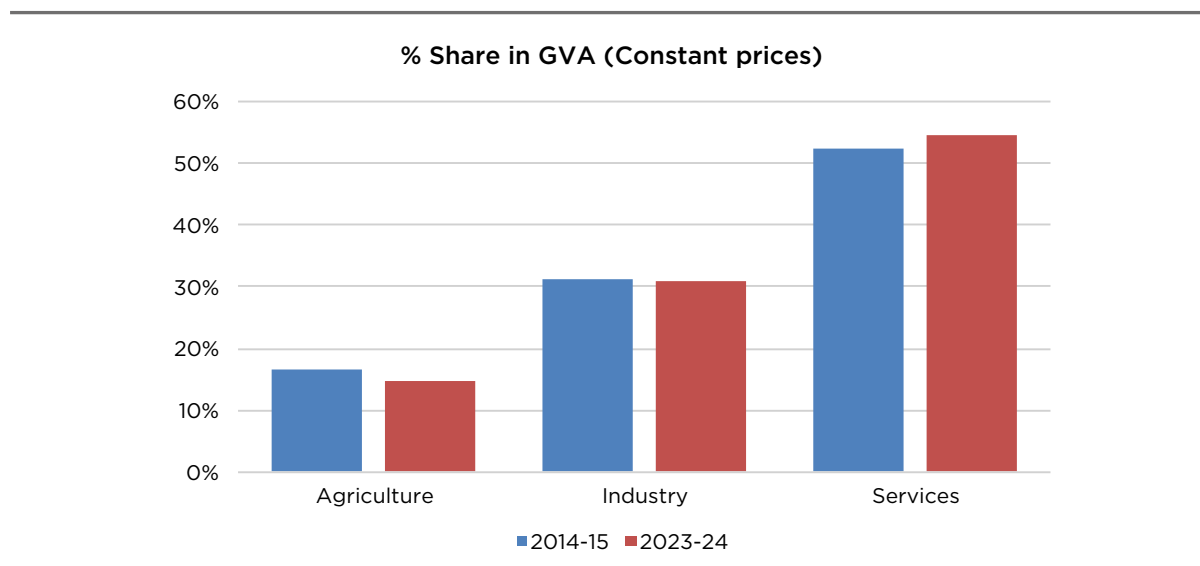
Figure 2.2: Sectoral share in Gross Value Added for India (2014-2024)

Uneven Productivity Across Sectors

India's labour market reveals persistent productivity divergence with wide sectoral output divides. As reported by Periodic Labour Force Survey (PLFS) 2023-24, agriculture employed 46.1% of the workforce but produced only 14.7% of Gross Value Added (GVA). Services generated 54.6% of GVA with just 29.7% of employment, while industry accounted for 30.8% of GVA with 24.1% of jobs (MoSPI 2025). This imbalance means nearly half the workforce remains concentrated in a low-productivity agricultural sector, producing only one-seventh of national output.

Services Far Outpace Agriculture

The productivity differential across sectors is wide and persistent. In 2014–15, agriculture accounted for nearly half of employment but less than 18% of GVA (World Bank; RBI, 2025). By 2023, although agricultural productivity had improved, with GVA per worker rising to about USD 2,029, output per worker in industry and services was much higher, estimated at USD 6,100-8,961. This suggests that a single worker in services produces three to four times the output of a farm worker, an imbalance that continues to shape India's dual economy (World Bank, 2025).

Low Female Labour Force Participation

Only 35 percent of women participated in India's labour force in 2023-24, a level lower than in many emerging economies (PLFS 2023-24). The recent increase in female labor force participation was driven by gains in rural areas, with only modest progress in urban areas. Women in urban areas are less likely to participate in the labour force than women in rural areas across all age groups and levels of education.

2.2 Structural Transformation: India in Global Context

In the international context, India's employment pattern stands out, reflecting a structural transformation in progress. While India's service sector is globally competitive - particularly in export-oriented business and IT services - it has limited capacity to absorb surplus rural labour at scale. A few international perspectives are given below:

▸ **China** underwent dramatic labour reallocation within a generation. In 2005, it employed 44.8% of its workforce in agriculture which contributed about 11.5% of GDP, similar to India's 2023 profile. By 2023, only 22.3% of Chinese workers remained in agriculture, contributing only 6.9% of GVA. Over the same period, industry grew to employ 32% of the workforce and generate 36% of GDP, while services accounted for over half of both output and employment (World Bank 2024; Our World in Data 2024).

- ▸ **Indonesia** followed a similar trajectory: from 44% of employment in agriculture in 2005, it declined to about 29% by 2023, with agriculture contributing just 12.5% to GDP. Services employed around 49% of Indonesian workers and generate over 40% of GDP, demonstrating an effective transition into labour-intensive manufacturing and services (World Bank 2024).

- ▸ **Brazil** represents a largely transformed middle-income economy. In 2023, agriculture employed just 8% of the workforce and contributed around 6% to GDP. Over 70% of Brazil's employment was in services, and nearly 20% in industry (World Bank 2024).

- ▸ **The United States and Germany** exemplify advanced economies, where agriculture employed less than 2% of the workforce and contributed under 1% to GDP. In both countries, services generated over 70–80% of GDP and employment (BLS 2024; Eurostat 2024).

Comparatively, India's sectoral transition is still a work in progress. It continues to show a significantly higher farm employment share than that of some middle-income countries. While its service sector is globally competitive and output-dominant, it has limited capacity to absorb surplus rural labour. Meanwhile, manufacturing's share of GVA (about 18% as of 2023-24) is below that of China (~25%) and Vietnam (~24%). This is a key reason India's productivity growth has yet to match that of its Asian peers.

Interstate Divergence

There is also a large productivity and income gap across states. In 2023, states such as Maharashtra, Gujarat, Karnataka, Tamil Nadu, and Delhi accounted for 26% of India's population and contributed ~44% of its GDP (UIDAI, 2023; RBI, 2023). In contrast, states such as Uttar Pradesh, Bihar, Madhya Pradesh, and Rajasthan accounted for 38% of India's population but only 19% of GDP. As with many developing economies, India exhibits regional differences in development levels; sustained convergence across states would further strengthen overall national growth.

Macroeconomic Implications

This productivity divergence has critical macroeconomic implications. The limited reallocation of labour from agriculture to high-productivity sectors such as manufacturing and modern services dampens aggregate productivity gains and household income growth. While services have expanded its share in output, its employment intensity remains modest. At the same time, industrial employment has been static, reducing the sector's historical role as a conduit for rural-to-urban mobility and formal job creation. There is a need for more job-intensive manufacturing growth.

Structural Reforms and Growth Enablers

The last decade has seen India initiate a **series of bold structural reforms** aimed at accelerating sectoral transformation and boosting competitiveness. The implementation of the Goods and Services Tax (GST) unified India's domestic market and reduced transaction costs. The *Make in India* initiative, combined with the Production Linked Incentive (PLI) scheme, sought to expand domestic manufacturing across critical sectors like electronics, pharmaceuticals, and solar modules, offering fiscal incentives tied to output. The *Skill India* mission was launched to upskill the workforce and better align labour supply with emerging sectoral demand, while *Digital India* expanded digital infrastructure and service delivery across rural and urban India alike. Together, these reforms laid the foundation for deeper industrialisation, broader formalisation, and smoother labour mobility. The impact of these structural efforts is visible in the rapid growth seen in FY25 and H1FY26. India remains the world's fastest growing large economy by all estimates of World Bank, IMF, etc, not only now but for the next few years even in turbulent times. This is a result of the decisive policy shift toward enabling productivity-led, employment-generating growth across sectors.

2.3   Infrastructure-Led Growth Strategy

Infrastructure has emerged as the cornerstone of India's growth strategy over the past decade, fueling connectivity, productivity, and inclusion across sectors. Recognising the high multiplier effect of capital expenditure on output, employment, and private investment, the Government of India substantially increased public infrastructure investment. This push proved critical when the private sector was deleveraging or facing uncertainty, most notably during the pandemic.

Between FY2016–17 and FY2025–26, public capital expenditure more than tripled, rising from INR 4.5 lakh crore (2.9% of GDP) to INR 15.5 lakh crore (4.3% of GDP), highlighting a deliberate shift towards infrastructure-led growth (Union Budget 2025) (See Fig 2.3). Complementing this spending thrust, institutional reforms like the creation of the Infrastructure Finance Secretariat aimed to crowd in private capital and improve project execution.

Effective Central Government Capital Expenditure (% of GDP)
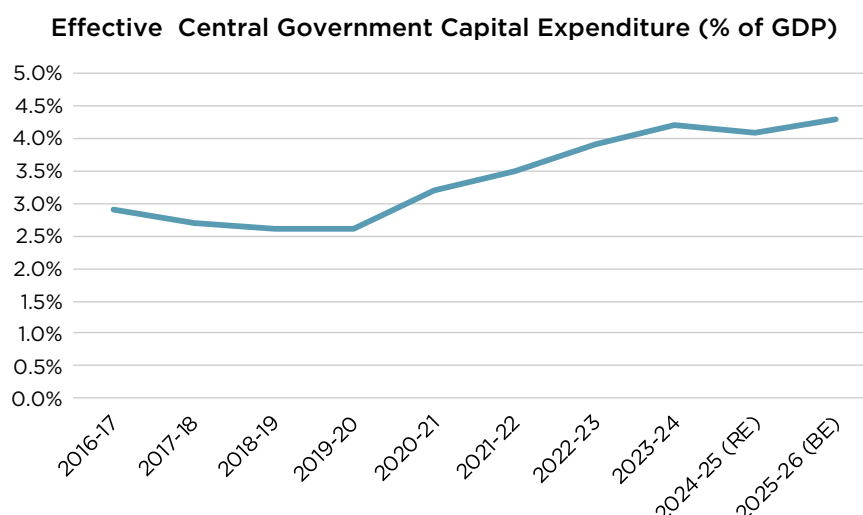
Figure 2.3: Effective Capital Expenditure (% of GDP)

Source: Union Budget 2025, Budget at a Glance

Infrastructure Outcomes: Capacity Creation Across Sectors

This surge in capex translated into tangible capacity creation across physical, digital, and social infrastructure:

▶ **Power generation**: Installed electricity capacity rose from 303 GW (2014–15) to 467.9 GW (2024–25), enhancing grid reliability and access (CEA 2025).

▶ **Renewables boom**: Renewable capacity jumped ~ 6.5 times, from 33 GW (2014–15) to ~ 220 GW (MNRE 2025).

▶ **Roads and highways**:

● National highways expanded by over 60% from 91,287 km to 1,46,204 km

● State highways rose from about 1,00,000 km to 1,79,535 km

● India's total road network reached over 6.3 million km, second only to the US (MoRTH 2025).

▶ **Railways**: Track length increased from 1,26,366 km to 1,32,310 km, with 97% of broad-gauge routes electrified. Introduction of 136 Vande Bharat trainsets enhanced intercity mobility (Indian Railways 2025).

▶ **Airports**: Operational airports rose from 132 to 149, with *Ude Desh ka Aam Nagrik (UDAN)* scheme, expanding regional air connectivity (MoCA 2025).

▶ **Ports**: Major port capacity expanded from 1,359 MTPA to about 1,800 MTPA, supporting India's rising trade throughput (MoPSW 2024).

- **Urban mobility**: Metro rail network expanded from about 250 km in 5 cities to over 930 km in 21 cities, with over 1,500 km under construction (MoHUA 2025).

- **Digital infrastructure:**

  - BharatNet connected 210,000 gram panchayats with 1.5 million km fibre (DoT 2025).

  - Broadband subscribers grew from 61 million to more than 900 million (TRAI 2025).

  - UPI adoption surged from 0 in 2014 to more than 14.3 billion transactions per month in 2025, worth over INR 250 lakh crore annually (NPCI 2025).

- **Financial inclusion and logistics:**

  - Jan Dhan accounts increased from fewer than 15 crore to more than 52 crore.

  - FASTag adoption rose to over 7 crore users, covering 97% of NH tolling.

  - 1,400 km of Dedicated Freight Corridors (DFCs) became operational, significantly reducing freight transit times.

Strategic and Inclusive Infrastructure Build-out

India's infrastructure build-out is not merely quantitative, it is also **strategic, inclusive, and digitally integrated**. These developments have reduced logistics costs, improved access to markets and services, and facilitated business operations. The synergy of transport, energy, and digital connectivity has laid the groundwork for productivity-driven growth, particularly in Tier 2–3 cities and rural areas.

Climate-oriented public investments (e.g., in solar parks, grid upgrades for renewables) have expanded, dovetailing with the broader infrastructure push. Investments in non-fossil energy are not only an environmental milestone but also a macroeconomic one, as the transition strengthens energy security and creates new growth industries, such as solar panel manufacturing and battery storage, contributing to sustainable development. India now ranks 3rd worldwide in solar capacity and 4th in wind capacity, demonstrating global leadership in the clean energy economy.

Fiscal Strategy and Debt Prudence

What makes India's fiscal strategy stand out is its combination of infrastructure ambition with debt prudence. While many advanced and emerging economies saw steep rises in general government debt post-2008 and again after the pandemic, India's General Government debt-to-GDP ratio remained stable, from 82.4% in 2005 to 81.3% in 2024 (IMF Debt Database).

In contrast, Japan's debt rose from 174.6% to 236.7%, the U.S. from 65.6% to 120.8%, China by over 200%, and the U.K. by more than 145% over similar periods (See Fig 2.4).

India's moderation stems from sustained growth, a favourable growth-interest rate differential (Economic Survey 2022–23), and the predominance of rupee-denominated domestic liabilities. External public debt is just 2.8% of GDP, while the weighted average residual maturity of dated securities is nearly 12 years, limiting rollover and currency risks.

General Government Debt (as % of GDP)
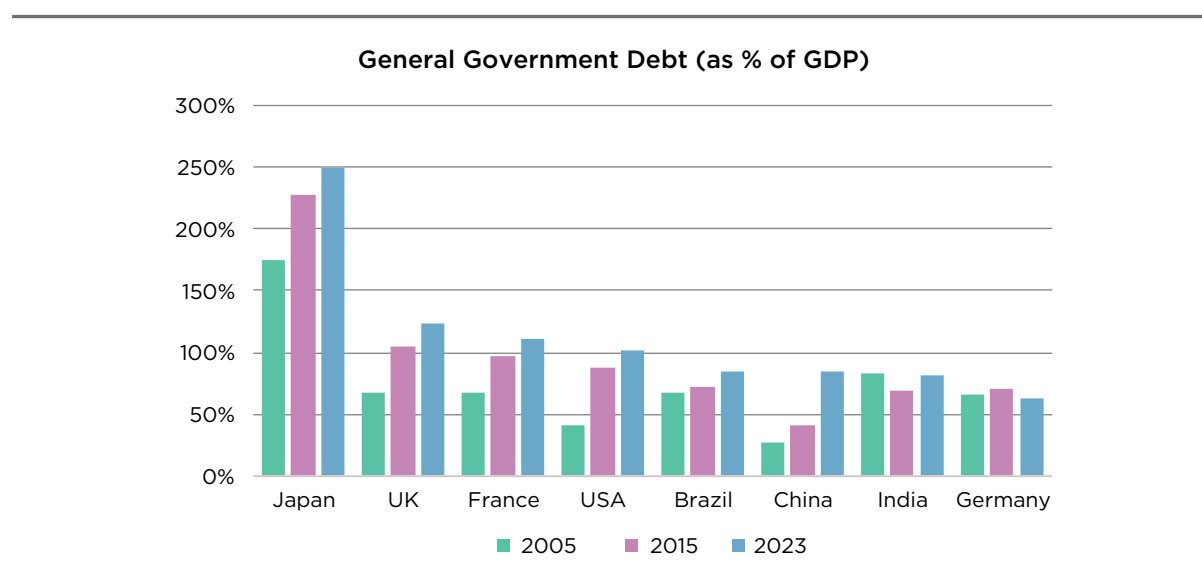
Figure 2.4: General Government Debt (% of GDP)

*Source: IMF, Globa*l Debt Database

Fiscal Consolidation and Quality of Spending

India's fiscal consolidation is not just numerical, it is structurally sound and quality-enhancing. After peaking at 9.2% of GDP in FY2020–21 during the pandemic, India's fiscal deficit has declined steadily to 5.8% in FY2023–24, with a glide path to 4.4% by FY2025–26. More importantly, this consolidation reflects a qualitative shift, away from revenue expenditure toward asset-creating capital outlays. The revenue deficit dropped from 7.3% to 2.9%, while the effective revenue deficit, which excludes capital grants, fell from 5.9% to just 1.1% of GDP, signalling a deeper structural correction (see figure 2.5).

By contrast, the combined gross fiscal deficit of the Centre & states increased from 2.3% in FY2018-19 to 3.2% in FY2023-24, reflecting higher spending by the state governments (RBI 2025).
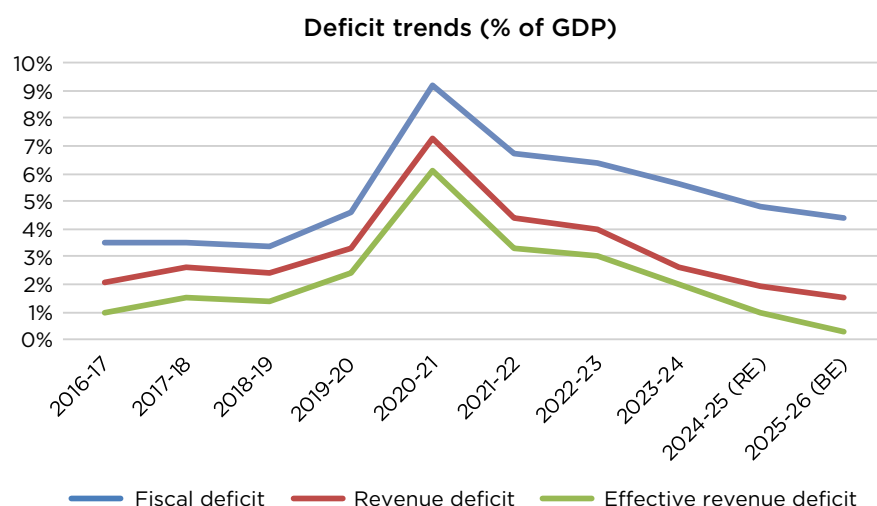
Figure 2.5: Deficit Trends as % of GDP, 2016–2026

Source: Union Budget 2025

Inflation Management and Monetary Stability

Throughout this period, India benefited from a favourable growth-inflation dynamic. Inflation averaged between 4–6%, barring temporary supply-side shocks, while the Reserve Bank of India (RBI) maintained a prudent monetary stance to ensure a growth-friendly interest rate environment. Despite global monetary tightening cycles, **domestic inflation remained contained** due to proactive food price management, energy subsidies during global spikes, and the moderating impact of renewables in the energy mix. This monetary stability, coupled with high nominal GDP growth, sustained a favourable growth-interest rate differential, reinforcing debt sustainability.

Revenue Mobilization and Tax Reform

Robust tax revenue growth has been central to this fiscal turnaround. India's gross tax revenue-to-GDP ratio increased from 11.1% in FY2016–17 to about 12% in FY2024–25. In absolute terms, gross tax collections more than doubled, from INR 16.5 lakh crore in FY2014–15 to over INR 36.5 lakh crore in FY2024–25 (Revised Estimates, RE). This growth reflects post-GST formalisation, better compliance, and digital enforcement mechanisms. Notably, the share of direct taxes rose from about 51% to 56% of gross tax revenue, indicating a more progressive tax structure and expanding formal incomes.

Debt Sustainability and Investment Protection

India's fiscal consolidation did not compromise investment or stability. Compared to global benchmarks, India's overall debt burden remains moderate. Total debt-to-GDP stood at about

171% in 2024, well below the levels seen in China, France, the UK, and the US (IMF Debt Database). Government debt, at 83% of GDP, mirrors China's, but what distinguishes India is its low private debt, at only 98.4% of GDP versus over 150% in most advanced economies (See Fig 2.6). This conservative leveraging by households and firms adds a vital cushion to financial stability, especially in uncertain global conditions.
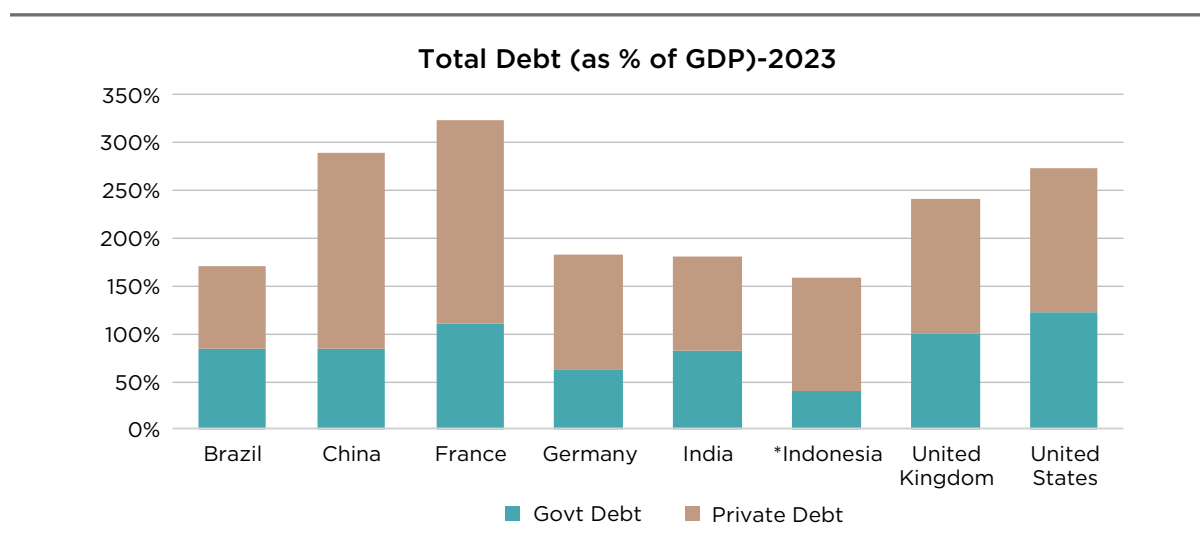
Figure 2.6: Total Debt as % of GDP for key economies (2023)

Source: IMF Global Debt Database

2.4   Integrated Strategy: Infrastructure and Fiscal Management

India's strategy of combining an aggressive infrastructure push with disciplined fiscal management has proved effective. Public investment was deployed as a counter-cyclical tool, not a structural imbalance. Institutional reforms, such as the Fiscal Responsibility and Budget Management (FRBM) Act, GST-led revenue buoyancy, and real-time digital budget management, enabled high-impact spending without compromising debt sustainability.

External Debt and Sustainability

India's external debt is low, long-term, and well-covered. As of FY2023–24, India's total external debt stood at just 18.7% of GDP, among the lowest in its peer group. Short-term debt comprised only 18.5% of total external debt, and the short-term debt-to-forex reserves ratio was just 19%. Importantly, foreign exchange reserves cover 97% of total external debt, underlining external sustainability. Most borrowings are long-term and concessional in nature, limiting rollover and currency risks.

Investment-Led Growth Anchored in Structural Rebalancing

India's strong external macroeconomic position is underpinned by a balanced investment-savings framework that enabled high growth without jeopardising external sustainability. India's growth momentum during FY2015–24 was supported by a healthy investment rate averaging at about 32% of GDP, (MosPI 2025). The quality and composition of investment improved, reflecting India's pivot toward infrastructure, energy transition, and digital connectivity. Significant potential remains, especially compared with China, which recorded an investment rate of 41.5% of GDP over the last two decades (World Development Indicators, World Bank).

Domestic Savings and Composition Shifts

On the savings side, gross domestic savings averaged around 31% of GDP in FY2015–25. The composition of savings has improved significantly:

▸▸ Net Household financial savings rose from INR 6.4 lakh crore (current prices) in 2011-12 to INR 15.5 lakh crore, enabled by financial inclusion (Jan Dhan), digital access (UPI), and mutual fund/SIP expansion (MoSPI, 2024). According to the Economic Survey 2022–23, digitalization and formalization improved the efficiency of financial intermediation, channeling household savings into productive investments. This qualitative improvement in savings means a larger portion of savings is available to fund infrastructure and industry, rather than sitting idle in unproductive assets.

▸▸ Corporate savings improved as deleveraging reduced interest outflows and rising profitability boosted retained earnings (Economic Survey 2023–24).

▸▸ Government dissaving narrowed with the fiscal consolidation path reducing revenue deficits, from 7.3% in FY2020–21 to 2.54% in FY2023–24 (Union Budget 2024–25).

External Balance and Current Account

This internal balance meant that **India's investment needs were largely financed domestically,** with only a modest reliance on foreign borrowings. As a result, the current account deficit (CAD) averaged a sustainable 1.1% of GDP over FY2015 -24, much lower than the 2.5–3% range seen during earlier high-growth periods (RBI BoP Data; Ministry of Finance CAD analysis 2024). In FY2023–24, CAD fell below 1%, reflecting stronger net exports of services, remittances of over USD 125 billion, and improved terms of trade.

Energy Dependence and Transition

Even so, India remains exposed to global energy price fluctuations, it imports 85% of its oil and 50% of its gas, which adds pressure to the trade deficit and inflation (IEEFA 2024). This

made the macroeconomy vulnerable to oil price shocks in the 2010s. The past decade's pivot to renewable energy has gradually mitigated this risk. By mid-2025, non-fossil sources already accounted for roughly half of India's installed power capacity. In the long run, a greener energy mix should improve the current account and cushion the economy from commodity shocks.

FDI as a Growth Driver

India has established itself as a top global investment destination. Between FY2015–16 and FY2024–25, the country received USD 748.8 billion in cumulative gross FDI inflows, more than double the USD 308.4 billion during FY2005–06 to FY2014–15 (DPIIT; Economic Survey). FDI inflows averaged about 2.5% of GDP during FY2015–25, up from about 2.2% in the previous decade. The peak inflow was USD 83.6 billion in FY2021–22 (PIB, 2022), while the average annual inflow over the past decade stood at about USD 68 billion, well above peer economies like Brazil and Indonesia. This sustained performance, even amid global volatility, reflects India's macroeconomic stability, improving ease of doing business, and strong long-term growth prospects.

Foreign Exchange Reserves and Rupee Stability

India's foreign exchange reserves have more than doubled, from about USD 304 billion in FY2013–14 to over USD 646 billion by FY2023–24, making them among the largest globally (Economic Survey 2023-24). This buffer enabled smooth external adjustment even in periods of global volatility. As India reduces energy import dependence via domestic renewables, pressure on reserves and exchange rate volatility may ease further.

Over the past decade, the Indian rupee exhibited far lower volatility compared to the previous one. In FY2023–24, the rupee's coefficient of variation was just 0.58, reflecting macroeconomic credibility and improved external positioning. Despite bouts of global dollar strength, the NEER (Nominal Effective Exchange Rate) remained broadly stable, while the REER (Real Effective Exchange Rate) appreciated modestly, indicating that India retained competitiveness without excessive depreciation.

Capital Markets and Financial Deepening

India's financial markets have transformed over the past decade, emerging as some of the best-performing and most resilient globally. The BSE market capitalization surged to over 136% as share of GDP by December 2024, crossing USD 5 trillion for the first time. The Nifty 50 delivered a 10-year CAGR of 8.8% in USD terms, outperforming most emerging markets and rivaling global benchmarks like the Dow Jones (Economic survey 2024-25). This performance reflects robust corporate profitability, policy reforms, expanding investor participation, and world-class digital financial infrastructure.

Equity market participation broadened significantly through UPI, Jan Dhan, and mutual fund SIPs, enabling financial intermediation to play a stronger role in channeling household savings into productive investments

Conclusion: Resilience and Opportunity

Over the past decade, India has shifted from being seen as a structurally constrained economy to one that is far more **stable and reform-oriented. Strong public investment, prudent fiscal and monetary management, and rising private capital inflows** have together opened space for a new phase of productivity-driven and more inclusive growth. India's decision to lean into the energy transition, supported by deeper financial markets and a sizable domestic savings pool, has also **turned climate policy into a macroeconomic opportunity** rather than just a cost. Taken together, these factors mean that India is now in a position to aim for high growth that is not only more durable, but also more fiscally responsible, competitive in global markets, and less burdensome on the environment.

3

MACROECONOMIC MODELLING: APPROACH AND RESULTS FOR INDIA'S NET ZERO PATHWAYS

Macroeconomic Modelling: Approach and Results for India's Net Zero Pathways

3

This chapter outlines the macroeconomic modelling framework used to assess India's Net Zero transition. It explains the approach, assumptions, and scenario design, and presents the results on GDP, investment, trade, fiscal balances, labour markets, and sectoral shifts under different financing and policy pathways.

Achieving India's development objectives, including a high-income status by 2047 with energy security while reducing emissions to Net Zero by 2070 will require a profound transformation of the economy. The structural changes needed to boost economic growth and achieve low-carbon transition will reshape not only the energy system, but also patterns of production, consumption, trade, and investment, generating both opportunities and adjustment costs. A holistic assessment of these impacts is essential for informing policy choices that balance growth, equity, and sustainability.

Given the complexity of these interactions, this chapter applies Computable General Equilibrium (CGE) models, which capture the behaviour of households, firms, and government, and links them through markets for goods, services, factors (labour and capital), and energy. By reflecting how resources are reallocated across the economy, driven by substitution possibilities between capital, labour, and diverse energy sources, CGE models provide a robust framework for analysing the macroeconomic dimensions of India's development and Net Zero transition. This chapter assesses the macroeconomic, sectoral, and employment implications of India's development pathways using two CGE modelling frameworks: the NCAER model and the World Bank's MANAGE model. The models simulate different development and financing scenarios and trace their effects on GDP growth, employment, income distribution, external balances, trade flows, and fiscal outcomes. By integrating sectoral activity, factor markets, and energy use within a consistent economy-wide framework, the models provide a comprehensive assessment of India's development pathways.

A first projection, referred to as the **Reform Scenario**, is developed using the Long-Term Growth Model (LTGM)[3], a supply-side growth projection tool that links GDP growth to Total

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3   Long Term Growth Model (LTGM) is an Excel-based tool to analyze long-term growth scenarios building on the celebrated Solow-Swan Growth Model.

Factor Productivity (TFP), the human capital index, labour force participation, the incremental capital-output ratio (ICOR), and investment rates. The Reform Scenario is calibrated to align with India's aspiration of achieving a USD 30 trillion economy by 2047, underpinned by ambitious assumptions of higher female labour force participation, substantial improvements in human capital, sustained investment, and accelerated Total factor productivity (TFP)[4].

The GDP trajectory produced through this LTGM exercise provides the macroeconomic baseline against which the impacts of the Net Zero energy transition are assessed using the CGE models.

Practically, the real GDP growth rates from the LTGM are used as an input for the energy system model to estimate energy mix and investment needs in Current Policy Scenario and Net Zero Scenario. Then, the inputs from LTGM and energy models are combined to create long-term growth scenarios in CGE framework. The implications for GDP growth, income and consumption, structural change and employment, and other macroeconomic aggregates such as public debt and the current account deficit are analyzed in the following sections.

3.1 Methodology and assumptions

Energy Model Scenario definition

Starting from the real GDP growth rates generated using Long-Term Growth Model (LTGM), the study developed two energy scenarios using The Integrated MARKAL-EFOM System (TIMES) and India Energy Security Scenarios (IESS) which are discussed below:

⇉ **Current Policy Scenario (CPS):** The Current Policy Scenario represents a level of effort that is realistically achievable based on historical trends and continuation of current policies (as of 2023), thereby projecting ongoing trends in low-carbon technology deployment.

⇉ **Net Zero Scenario (NZS):** The Net Zero Scenario reflects an ambitious pathway aligned with India's commitment to achieve Net Zero GHG emissions by 2070. It incorporates both existing and additional policy measures to accelerate demand electrification, enhance circularity, improve energy efficiency, promote the rapid development of low-carbon technologies/fuels and encourage behavioural shifts.

These scenarios provide inputs to the CGE models, especially:

⇉ Additional investments required to provide the same energy services with lower emissions.

⇉ Changes in the energy and power mix, and in energy expenditures and imports.

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4 The trajectory rests on sustaining an investment rate near 34% of GDP through 2047, increase in female labour-force participation toward high-income benchmarks (about 70%), and human-capital convergence toward developed-economy levels. Total factor productivity (TFP) growth is assumed at 2.18% per year to 2035 (versus about 1.88% in 2010–2019), moderating to 1.88% by 2047.

The details of the scenarios and methodology are available in the Scenarios towards Viksit Bharat and Net Zero: Sectoral Insights (Vol.3-8), Financing Needs (Vol. 9) and Study report on Scenarios towards Viksit Bharat and Net Zero: An overview (Vol. 1) reports.

Investment and Financing

The Scenarios towards Viksit Bharat and Net Zero: Financing Needs (Vol. 9) report estimates investment requirements under the Current Policy Scenario and the Net Zero Scenario. The report projects cumulative investment needs of USD 14.7 trillion under the Current Policy Scenario and USD 22.7 trillion under the Net Zero Scenario by 2070, indicating that the Net Zero Scenario is more capital-intensive. The macroeconomic implications of this higher investment requirement are analysed separately in this report.

Macroeconomic model scenario definition

The MANAGE model[5] (World Bank) explores seven macroeconomic Net Zero Scenarios each combining different sources of financing and complementary policies (See Table 3.1 for summary) while the NCAER model explores only one Net Zero Scenario. Both models (MANAGE and NCAER) have Current Policy Scenario which aligns with Energy Model-Current Policy Scenario (described earlier). The macro-economic scenarios are summarised below:

▸ **Current Policy Scenario:** Current Policy Scenario incorporates long-term macroeconomic assumptions and energy projections, serving as reference cases in both MANAGE and NCAER model.

▸ **Net Zero Scenario:** Net Zero Scenario quantifies the macroeconomic impacts of India's pathway consistent with achieving Net Zero emissions by 2070, while keeping all other growth assumptions unchanged.

MANAGE model Net Zero Scenarios

Net Zero Scenario-1 (NZdom) & Scenario-2 (NZfor)

The two scenarios represent the transition being financed through domestic savings (NZdom) or through foreign capital inflows (NZfor), without additional subsidies or redistribution mechanisms.[6] The two scenarios represent two extreme cases in which funding is either completely through domestic or foreign sources. These are theoretical constructs assumed for the purpose of modelling. Reality will be somewhere between these two extremes.

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5   MANAGE-World Bank is a Computable General Equilibrium (CGE) model developed by a network of CGE modelers to support World Bank teams and clients in conducting macroeconomic analyses across a broad range of topics. It is a single-country, open-economy CGE model featuring multiple sectors, institutions, and factors pf production.

6   These scenarios are conservative as they assume there are no co-benefits from using low-carbon technologies, beyond energy savings and reduced GHG emissions; they ignore benefits from lower air pollution, lower dependency to energy import and associated volatility, or lower congestion in urban areas, all of which could further enhance economic and welfare outcomes.

Policy variants of Scenario-1 and Scenario-2 with Subsidies: Scenario-3 (NZdomSub) and Scenario-4(NZforSub)

The scenarios *NZdomSub* and *NZforSub* represent the same scenarios as *NZdom* and *NZfor*, but adding renewable energy (RE) subsidy financing through domestic and foreign sources, respectively. These subsidies improve the affordability of electricity for consumers and industrial users in the Net Zero Scenario by offsetting the electricity price increases associated with the transition. Under these scenarios, electricity prices in the Net Zero Scenarios were assumed to remain at the levels of Current Policy Scenario.

Scenario-5 with Revenue redistribution (NZforRD)

The scenario *NZforRD* introduces a redistribution mechanism designed to ensure that the poorest households are protected during the transition to a Net Zero economy. In this scenario, financial transfers maintain the income and consumption levels of the bottom 40% of households, ensuring they are not worse off compared to Current Policy Scenario. It promotes social equity, helping ensure the Net Zero transition is fair and inclusive. While additional investments are financed domestically, the transfers are financed through an expansion of the fiscal deficit, supported by additional external borrowing.

Variants of Net Zero Scenario-1 and Scenario-2 with productive investment: Scenario-6 (NZdom+) and Scenario-7(NZfor+)

More efficient and low-carbon technologies also tend to be more productive and deliver co-benefits such as improved air quality (with health and labor productivity gains), greater production reliability (with competitiveness gains), and reduced congestion (leading to higher productivity in cities). However, the extent of these benefits is uncertain and not quantified in the energy scenario. To capture these potential benefits and the uncertainty surrounding them, scenarios are differentiated by whether the additional investments in the Net Zero Scenario also generate such co-benefits, represented as additional output. In scenarios marked with a '+' (e.g., NZdom+), co-benefits are included by asssuming that additional investments in the Net Zero Scenario are productive: they contribute to the capital stock and have a positive output effect (only the positive spin-offs on output are captured and not the actual co-benefits). In contrast, in scenarios without co-benefits (e.g., NZdom), additional investments reduce GHG emissions but do not contribute to capital formation in the model and do not generate economic value[7]. As the reality is somewhere between these two extremes, these two types of scenarios provide the upper and lower bounds of the potential impact of the transition towards Net Zero emissions on GDP and economic growth.

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[7] The reduction in emissions and air pollution is likely to have long-term growth benefits by reducing the negative impact of air pollution on labor productivity. Although the MANAGE-WB model can incorporate such mechanisms, the growth benefits of lower air pollution are not included in the current analysis.

Table 3.1: Summary of Net Zero Scenarios using World Bank and NCAER models

	Benefits from incremental investment in the Net Zero Scenarios		Main source of financing		Complementary measures to facilitate the transition	
	Emission reduction only	Output effect	Domestic	Foreign	RE subsidy	Redistribution
NZdom	✓		✓			
NZdom+	✓	✓	✓			
NZfor	✓			✓		
NZfor+	✓	✓		✓		
NZforSub	✓			✓	✓	
NZdomSub	✓		✓		✓	
NZforRD	✓		✓	✓		✓
NCAER				✓		

3.2   Results

3.2.1 Impact on GDP: Net Zero transition has limited impact on long-term GDP growth but demands high investment.

In the Current Policy Scenario (CPS), India's GDP is projected to grow at an average annual rate of 7.4% during 2026–30, reflecting strong momentum. Growth moderates slightly to ~7% between 2030 and 2045, remaining robust enough to support India's goal of attaining developed-economy status by 2047. Beyond that, growth eases to about 5% in 2046–60 and to 2.8% in 2060–70. Across both models (NCAER and MANAGE), the impact of the Net Zero pathway on GDP growth is marginal. The economy remains resilient in all scenarios, reaching roughly USD 6.8 trillion by 2030 and achieving high-income status in 2047 even under Net Zero. Even with higher penetration of low-carbon technologies under the Net Zero Scenario, the impact on real GDP growth remains limited. Real GDP growth rates are endogenously determined and differ only marginally from the Current Policy Scenario, irrespective of financing assumptions. This finding holds even when accounting for financing uncertainties and the inclusion or exclusion of co-benefits from the low-carbon transition. (See Figure 3.1). **By 2047, India reaches USD 30–31 trillion across all scenarios** (NCAER and MANAGE), meeting the "Viksit Bharat" target.
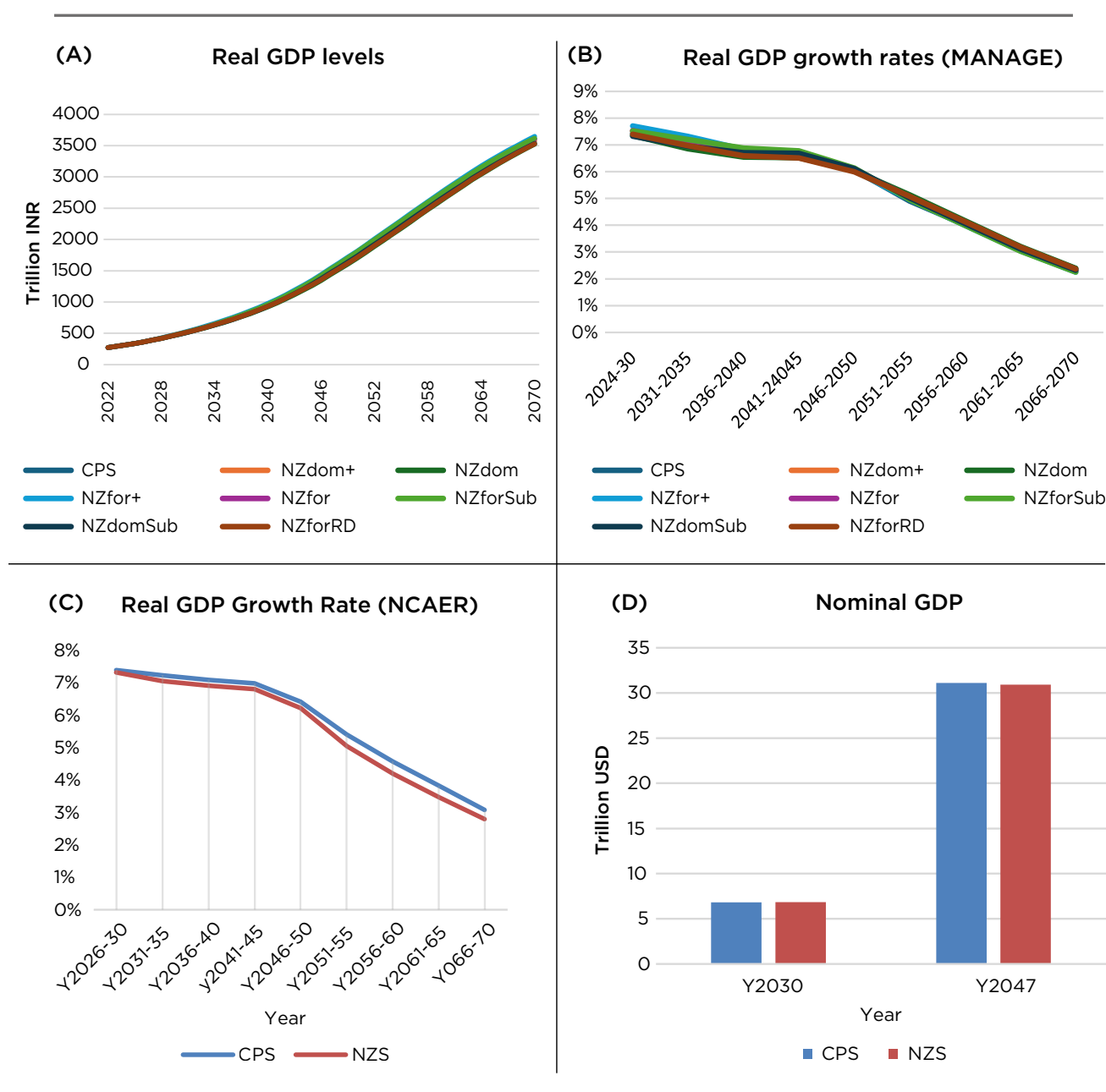
Note: *CPS = Current Policy Scenario; NZS = Net Zero Scenario*

Figure 3.1: Impact of the Net Zero transition on GDP in various scenarios

(A) Real GDP levels (trillion INR) — MANAGE model

(B) Real GDP growth rates (%) — MANAGE model

(C) Real GDP growth rates (%) — NCAER model

(D) Nominal GDP — NCAER model

The incremental investment requirements of Net Zero affect GDP outcomes differently under varying assumptions (See Figure 3.2). When additional investments are productive because of co-benefits, they expand the capital stock, reduce emissions, and enhance output, leading to positive growth effects, especially in foreign-financed pathways. By contrast, if these investments are treated as unproductive (serving only emission reduction without any co-benefit), GDP temporarily dips below Current Policy Scenario before recovering. The size of this dip depends on the financing mix: under domestically financed Net Zero (NZdom), GDP is lower than the Current Policy Scenario projections by up to 4.5% around 2046-50 at its lowest point, while under foreign-financed Net Zero Scenario (NZfor), the decline from Current Policy Scenario is limited to about 0.5%. This highlights the importance of financing structure: mobilizing external capital such as FDI prevents pressure on domestic savings, avoids crowding out private investment, and enlarges the transition budget. However, Foreign financed scenario combined with renewable energy subsidies, can lead to overall positive impact on GDP throughout in comparison to Current Policy Scenario, even if incremental investment is treated as unproductive.
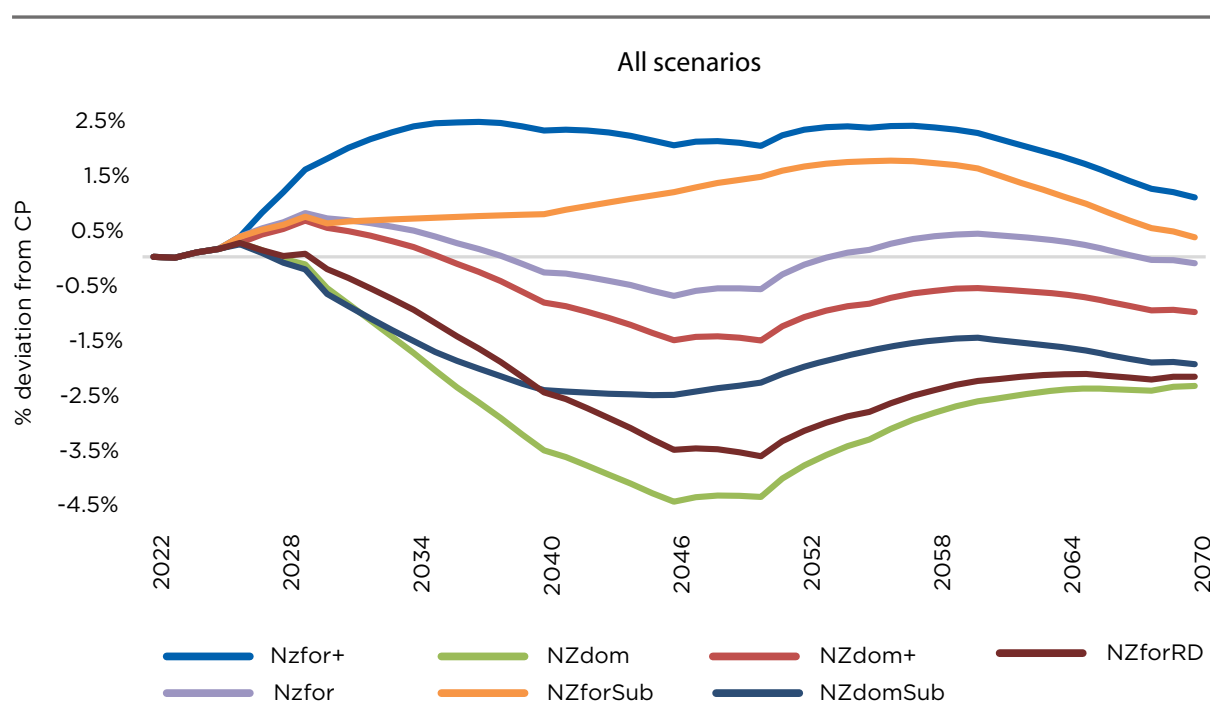
Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

Figure 3.2: Net Zero Scenario GDP outcomes across financing channels (deviation from the Current Policy Scenario in %) – (MANAGE model)

Caveat: These results exclude both negative externalities and positive co-benefits of climate change. The negative impacts include reduced labour productivity or agricultural losses from rising temperatures whereas the positive co-benefits include improvements in air quality and health outcomes, which the model does not capture. The analysis also excludes the costs of

climate adaptation, and therefore reflects transition-related mitigation economic effects rather than the full welfare impacts of climate change and climate action.

While there are concerns that large-scale investments toward Net Zero could divert resources from pressing development needs such as health, education, and social infrastructure, the analysis indicates that climate action need not come at the expense of development priorities. Investments in clean energy, resilient infrastructure, and green technologies can generate quality jobs, enhance energy security, and improve public welfare, thereby reinforcing rather than competing with the country's broader development objectives.

Key Messages

▸ **GDP resilience with high investment needs**: Across all Net Zero Scenarios, GDP growth is projected to remain broadly resilient. However, each pathway demands very high investment and substantial capital mobilisation, particularly to scale up nascent and emerging technologies.

▸ **Difference from Current Policy Scenario**: Net Zero Scenario growth rates diverge slightly from Current Policy Scenario, with GDP reaching USD 30–31 trillion by 2047 in all scenarios, meeting the Viksit Bharat target. Under the assumption of total absence of co-benefit, GDP is lower by 0.5–4.5% below Current Policy Scenario around 2046–50 before recovering.

▸ **Role of financing design**: Foreign financing helps sustain growth by avoiding domestic crowding-out, and when combined with RE subsidies, Net Zero Scenarios even outperform Current Policy Scenario across the entire transition, even without co-benefits. However, the foreign financing implications on Current Account Deficit are discussed subsequently.

3.2.2 Impact on GDP components: In the Net Zero transition, domestic financing reduces investment and consumption, while foreign financing and productive investment support stronger outcomes.

In the Current Policy Scenario, GDP composition (Consumption, Investment and Net Exports) evolves significantly between 2022 and 2070. The share of private consumption declines from about 58% in 2025 to 52% by 2070, while the share of investment rises to sustain growth. This trend is counterbalanced by increases in other components: the share of public consumption increases from about 9% in 2025 to 14% in 2070, while the total investment (public+private) share climbs from roughly 32% in 2025 to a peak of 36% by 2050, reflecting capital deepening, before easing to 34% by 2070 as the economy matures (See Figure 3.3).

GDP components (at constant 2012 prices)
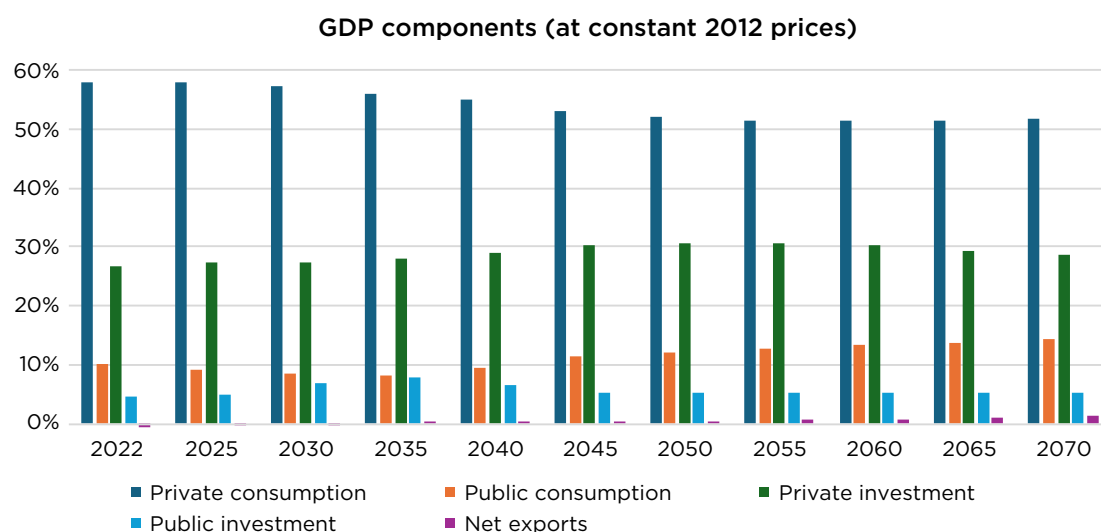
Figure 3.3: GDP components (at constant 2012 prices) in the Current Policy Scenario (MANAGE).

Financing choices drive different macro outcomes. An increase in government borrowing raises the demand for funds in the economy, reducing their availability for private firms. This higher demand puts upward pressure on interest rates, which can crowd out private investment and consumption. By contrast, external financing relaxes the domestic savings constraint, eases interest-rate pressures, and supports higher investment with smaller consumption trade-offs. Domestic financing, whether public or private, will either require an increase in savings to finance new investment by forgoing consumption, or a shift of investment away from other sectors towards Net Zero transition sectors. Foreign financing puts less pressure on the domestic market but increased foreign capital inflows contributing to exchange rate appreciation and impacts Current Account Deficit. Further, foreign exchange flows are also impacted by skewed credit rating methodologies, which often penalise countries on narrow parameters, overlooking strong fundamentals and a consistent record of external debt servicing.

Hence, scenarios relying on domestic financing (NZdom, NZdom+, NZdomsub) generally exert pressure on investment compared to Current Policy Scenario (See Figure 3.4). This effect is most pronounced between 2040 and 2050, when investment under NZdom falls about 5% below Current Policy Scenario. By contrast, scenarios with external financing (NZfor, NZfor+, NZforSub, NZforRD) show an increase in investment. The main driver is the higher real interest rate under domestic borrowing, which constrains access to affordable capital and reduces investment.

In domestically financed net zero scenarios, relative to Current Policy Scenario, consumption is lower driven by higher interest rates nudging household to save more. In the productive investment cases (NZdom+, NZfor+), however, higher household incomes outweigh the drag from higher interest rates, producing a net increase in consumption.

Depending on the scenario, exports are lower by 2% (NZfor+) to 9% (NZdom) relative to Current Policy Scenario, with the largest variation during 2040-2050 period, though pressures ease in later years. These scenarios represent extreme scenarios with others falling within this range. In case of imports, during 2040-50, imports are higher by 4% (NZfor+) compared to lower by 7% (NZdom) relative to Current Policy Scenario. A detailed analysis of these trade dynamics follows in the next section.
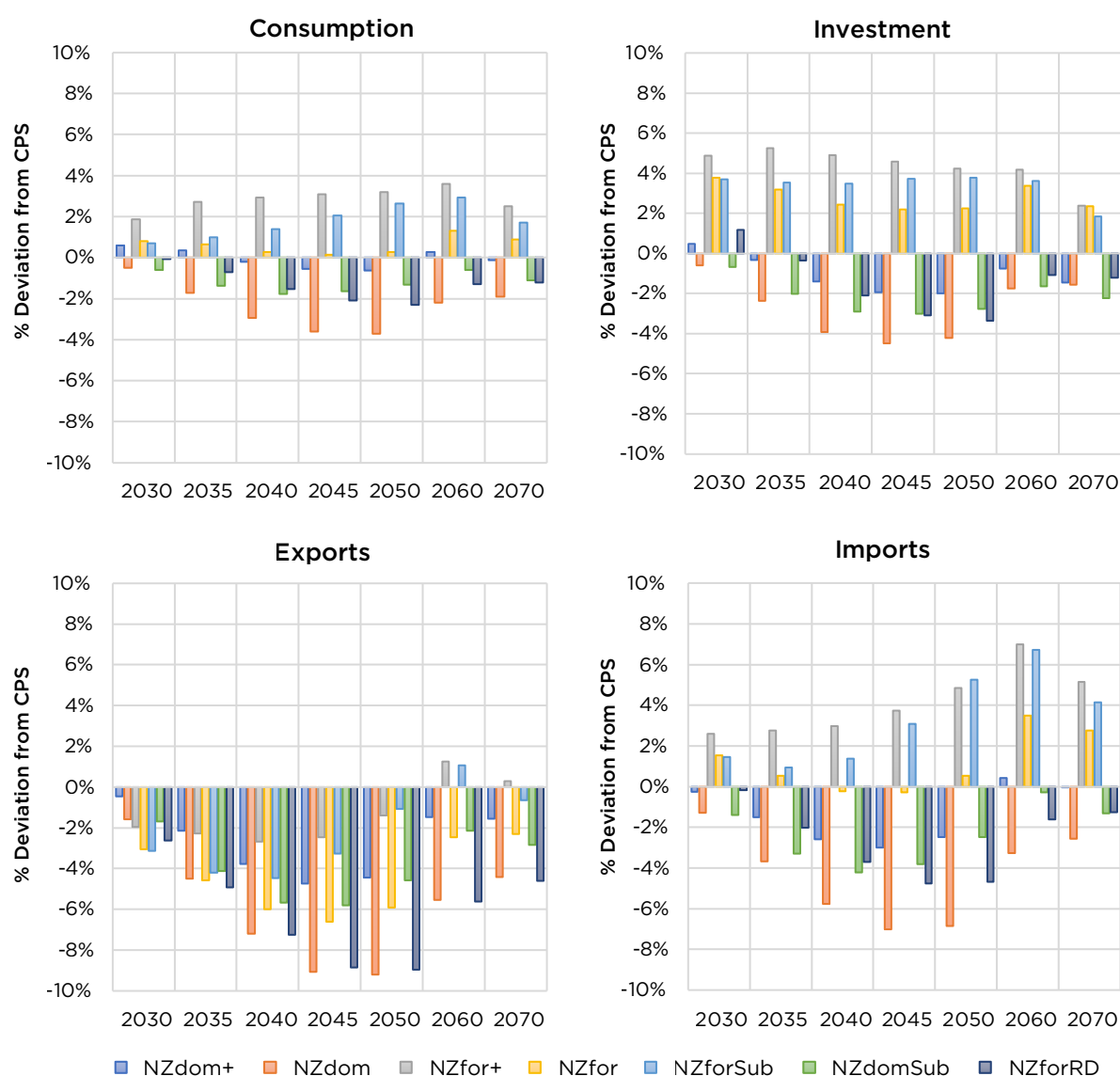
Note: *CPS = Current Policy Scenario; NZS = Net Zero Scenario*

Figure 3.4: GDP components (% deviation from CPS) (MANAGE)

Key Messages

▸ **Shift in composition**: In Current Policy Scenario, the share of private consumption in GDP steadily declines (from 58% in 2025 to 52% by 2070), while public spending and investment gain importance.

▸ **Role of financing**: Under Net Zero Scenarios, outcomes differ across financing pathways. Domestic financing lowers investment and consumption compared to Current Policy Scenario due to higher interest rates, while foreign financing boosts investment by easing pressure on domestic savings.

▸ **Rebalancing under Net Zero**: Across all pathways, GDP components shift from private consumption toward higher investment shares, underscoring the scale of capital mobilisation required for achieving the 2047 high-income objective and the low carbon transition.

3.2.3 Impact on Sectoral output and shares: Net Zero accelerates India's structural shift, expanding industry, especially clean energy and construction, while agriculture and fossil-based manufacturing shares decline.

Under Current Policy Scenario, the share of agriculture in GVA gradually declines, reflecting the ongoing structural shift. Industry's[8] share increases to about 33% by 2050 from 30.2% in 2022 before stabilizing, while services remain the dominant sector, expanding to around 55% by 2050 and continuing to grow as India progresses toward a more advanced economy (Figure 3.5).

Sectoral composition of value added (at constant 2012 prices)
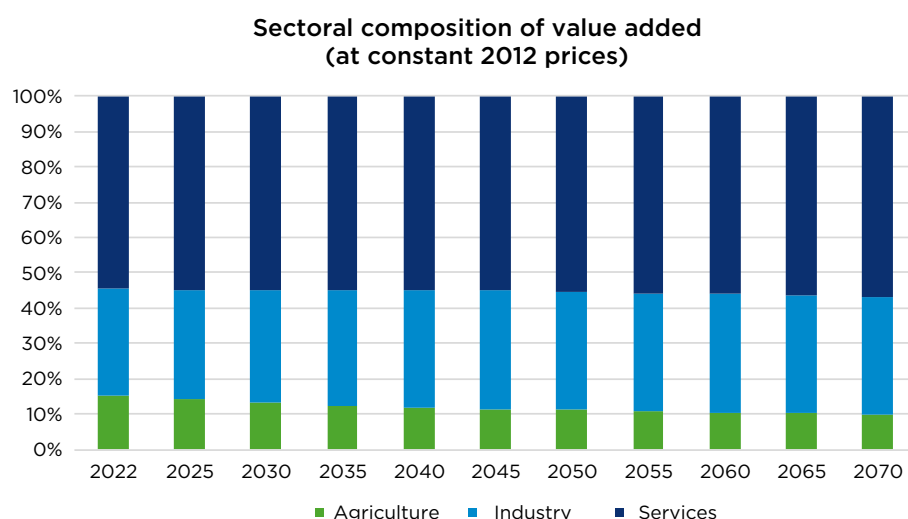
Figure 3.5: GVA sectoral composition in Current Policy Scenario (constant 2012 prices, MANAGE model)

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8   Construction is included in Industry

The Net Zero transition has a marginal impact on the overall economic structure (captured through sectoral GVA), with outcomes primarily driven by financing mechanisms. Two opposing forces operate simultaneously: higher electricity prices in Net Zero Scenario relative to Current Policy Scenario increases production costs, while stronger demand for electricity and low-carbon technologies boosts industrial activity. Financing mechanism and productivity of incremental finance also impact industrial outputs.

In domestically financed Net Zero Scenario (NZdom), higher interest rates amplify cost pressures, resulting in 5.6% lower industrial output in 2045 relative to the Current Policy Scenario (CPS). In contrast, foreign-financed NZ scenario (NZfor, NZfor+) benefit from lower interest rates, but outcomes differ depending on the productivity of incremental finance: industrial output is lower by 1.1% under NZfor relative to Current Policy Scenario, while it is 2.3% higher under NZfor+ relative to Current Policy Scenario by mid-century.

Compared to industry, shifts in services and agriculture are more modest in Net Zero Scenarios compared to Current Policy Scenario reflecting offsetting sub-sectoral dynamics. Within services, some activities contract relative to Current Policy Scenario due to higher electricity prices, most notably the "other services" sub-sector, but these declines are partially offset by growth in air transport and abatement-related services. The agricultural sector shows a similar pattern of internal adjustment: fisheries expand moderately, benefiting from lower petroleum costs, while forestry faces pressure from rising land prices driven by increased demand for land for biofuel production (Annex Figure B1).

Across all sectors, transition costs peak during 2040–2050 and are followed by recovery by 2060–2070, with foreign-financed scenarios consistently outperforming domestic-financed ones. (See Table 3.2).

Table 3.2: Sectoral value added (% deviation from Current Policy Scenario, MANAGE model)[9]

	2030	2035	2040	2045	2050	2060	2070
Agriculture							
NZdom+	0.23	0.06	-0.47	-0.83	-0.94	-0.22	-0.57
NZdom	-0.56	-1.59	-2.76	-3.50	-3.74	-2.62	-2.36
Nzfor+	0.99	1.81	2.11	2.30	2.48	3.03	2.12
Nzfor	0.20	0.18	-0.13	-0.25	-0.15	0.80	0.46
NZforSub	0.16	0.35	0.55	1.01	1.48	2.01	1.04
NZdomSub	-0.61	-1.42	-2.06	-2.19	-2.05	-1.44	-1.85
NZforRD	-0.37	-0.89	-1.71	-2.32	-2.62	-1.84	-1.75

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9   Colours represent the direction and magnitude of deviation relative to the Current Policy Scenario (CPS). Greener shades indicate positive deviations, yellow denotes values close to CPS, and orange to red shades indicate negative deviations, with darker colours reflecting larger absolute changes.

	2030	2035	2040	2045	2050	2060	2070
Industry							
NZdom+	0.60	-0.09	-1.30	-1.96	-1.97	0.15	0.51
NZdom	-0.64	-2.52	-4.49	-5.56	-5.64	-2.85	-1.72
Nzfor+	2.06	2.71	2.42	2.32	2.52	4.09	3.69
Nzfor	0.82	0.31	-0.68	-1.10	-0.90	1.36	1.66
NZforSub	0.66	0.87	1.11	1.79	2.43	3.53	2.93
NZdomSub	-0.84	-1.96	-2.70	-2.65	-2.29	-0.75	-0.57
NZforRD	-0.25	-1.58	-3.34	-4.46	-4.75	-2.31	-1.39
Services							
NZdom+	0.12	-0.39	-1.23	-1.77	-1.87	-0.87	-1.18
NZdom	-0.92	-2.42	-3.87	-4.76	-4.93	-3.27	-2.82
Nzfor+	1.12	1.69	1.64	1.62	1.71	2.16	1.09
Nzfor	0.08	-0.30	-0.92	-1.23	-1.14	-0.02	-0.39
NZforSub	0.02	-0.08	-0.11	0.31	0.93	1.47	0.32
NZdomSub	-0.99	-2.20	-3.05	-3.21	-2.89	-1.84	-2.18
NZforRD	-0.69	-1.66	-2.85	-3.70	-4.01	-2.72	-2.45

The most pronounced sectoral impacts are observed in industry subsectors. By 2045, the share of fossil fuel-based manufacturing, such as petroleum, is lower by about 1.1% compared to Current Policy Scenario. Conversely, this decline is offset by growth in the construction sector and in green energy industries, including electricity generation, distribution, and green hydrogen, which together expand by around 1.5% in NZfor compared to Current Policy Scenario (Annex Figure B1).

These patterns in GVA are mirrored in sectoral output dynamics. Under the domestically financed Net Zero Scenario (NZdom), industrial output is lower by 6.4% and services output is lower by 4.6% in 2045 relative to Current Policy Scenario. In contrast, the foreign-financed Net Zero Scenario (NZfor+) supports sustained sectoral expansion, leading to 2.1% increase in industrial output in 2045, relative to Current Policy Scenario, underscoring the role of financing conditions in shaping transition outcomes (Table 3.3).

Table 3.3: Impact of Net Zero on sectoral output (% deviation from Current Policy Scenario, MANAGE model)[10]

	2025	2030	2035	2040	2045	2050	2060	2070
Agriculture								
Nzdom+	0.07%	0.22%	0.10%	-0.33%	-0.63%	-0.74%	-0.16%	-0.45%
NZdom	0.07%	-0.49%	-1.35%	-2.34%	-2.94%	-3.15%	-2.26%	-2.05%
Nzfor+	0.07%	0.85%	1.57%	1.82%	1.98%	2.13%	2.61%	1.89%
Nzfor	0.07%	0.14%	0.13%	-0.12%	-0.21%	-0.13%	0.67%	0.41%
NZforSub	0.07%	0.10%	0.28%	0.45%	0.82%	1.21%	1.67%	0.91%
NZdomSub	0.07%	-0.54%	-1.21%	-1.74%	-1.85%	-1.76%	-1.27%	-1.60%
NZforRD	0.07%	-0.34%	-0.76%	-1.43%	-1.92%	-2.18%	-1.58%	-1.51%
Industry								
Nzdom+	0.12%	0.66%	-0.37%	-1.75%	-2.63%	-2.73%	-0.58%	-0.34%
NZdom	0.12%	-0.68%	-2.95%	-5.11%	-6.36%	-6.47%	-3.51%	-2.45%
Nzfor+	0.12%	2.43%	2.82%	2.40%	2.08%	2.13%	3.58%	2.99%
Nzfor	0.12%	1.10%	0.27%	-0.85%	-1.46%	-1.34%	0.92%	1.08%
NZforSub	0.12%	0.94%	0.85%	0.94%	1.41%	1.90%	2.90%	2.17%
NZdomSub	0.12%	-0.87%	-2.38%	-3.29%	-3.45%	-3.18%	-1.59%	-1.48%
NZforRD	0.12%	-0.17%	-1.86%	-3.83%	-5.16%	-5.53%	-2.93%	-2.09%
Service								
Nzdom+	0.11%	0.16%	-0.42%	-1.27%	-1.66%	-1.55%	-0.38%	-1.23%
NZdom	0.11%	-0.87%	-2.39%	-3.85%	-4.61%	-4.58%	-2.70%	-2.71%
Nzfor+	0.11%	1.06%	1.53%	1.42%	1.55%	1.90%	2.42%	0.74%
Nzfor	0.11%	0.04%	-0.41%	-1.07%	-1.25%	-0.94%	0.33%	-0.58%
NZforSub	0.11%	-0.03%	-0.14%	-0.08%	0.73%	1.87%	2.30%	0.20%
NZdomSub	0.11%	-0.95%	-2.13%	-2.85%	-2.65%	-1.88%	-0.84%	-2.00%
NZforRD	0.11%	-0.67%	-1.70%	-2.91%	-3.63%	-3.73%	-2.22%	-2.42%

Fossil share energy mix is lower in Net Zero Scenario at 58% (Compared to 75% in Current Policy Scenario) in 2050 and 14% in 2070 (Compared to 54% in Current Policy Scenario) (refer Pathways to Net Zero - Towards Viksit Bharat and Net Zero: An Overview - Vol. 1). This result is also reinforced in CGE model results wherein the fossil output in Net Zero Scenario is lower relative to Current Policy Scenario: Coal output is lower by 94%, gas by

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10   Colours represent the direction and magnitude of deviation relative to the Current Policy Scenario (CPS). Greener shades indicate positive deviations, yellow denotes values close to Current Policy Scenario, and orange to red shades indicate negative deviations, with darker colours reflecting larger absolute changes.

60%, petroleum by 23-24% in 2070 compared to compared to Current Policy Scenario. On the other hand, green hydrogen, biogas and electricity see substantial increase in Net Zero Scenario compared to Current Policy Scenario (See Annex Figure B2)[11].

Key Messages

▶▶ **Current Policy Scenario**: Agriculture's share declines steadily, industry rises modestly, and services remain the dominant driver of output.

▶▶ **Net Zero Scenario**: The transition to Net Zero has marginal impact on economic structure with differential impacts depending on source of financing and productivity of incremental finance, while fossil fuel–based manufacturing declines.

3.2.4 Impact on Investment: The Net Zero transition requires a major reallocation of investment: renewables and green hydrogen expand rapidly, while fossil fuel sectors have reduced shares compared to Current Policy Scenario; manufacturing remains central across all scenarios.

Under Current Policy Scenario, investment requirements rise steadily over time, driven primarily by the service sector, followed by industry and agriculture. By 2066–2070, cumulative five-year investment reaches nearly INR 4200 lakh crore, ~5 times higher compared to the 2031–2035 period. This long-term increase reflects both capital replacement and expansion to support growth as well as the structural transformation of the economy (Figure 3.6).

Sectoral investment

(A)

■ Agriculture ■ Industry ■ Service

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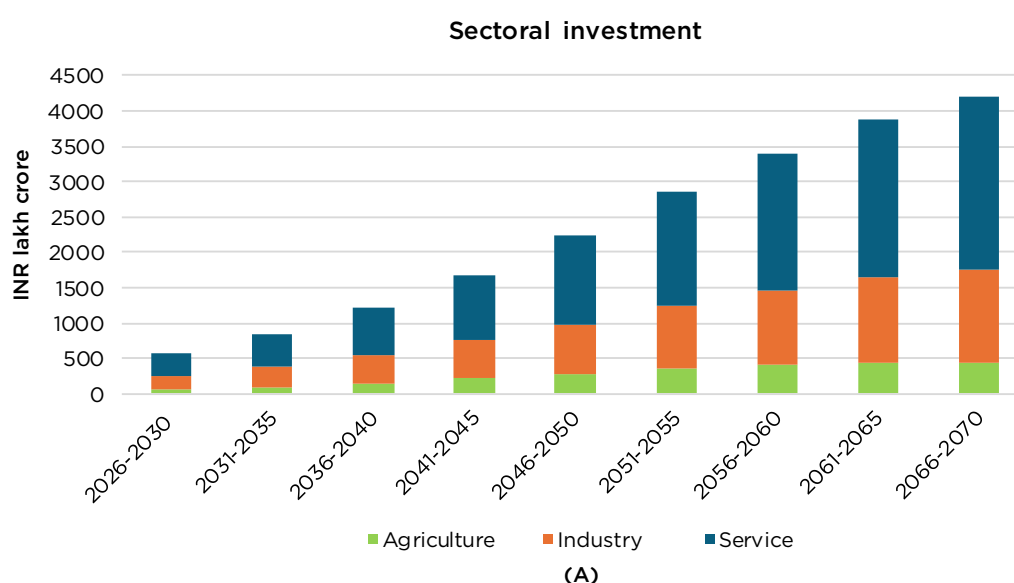
11 There is still use of fossil fuels in 2070 in the Net Zero Scenario as these scenarios are gross positive emissions, largely compensated by negative emissions from CCS and land-use.
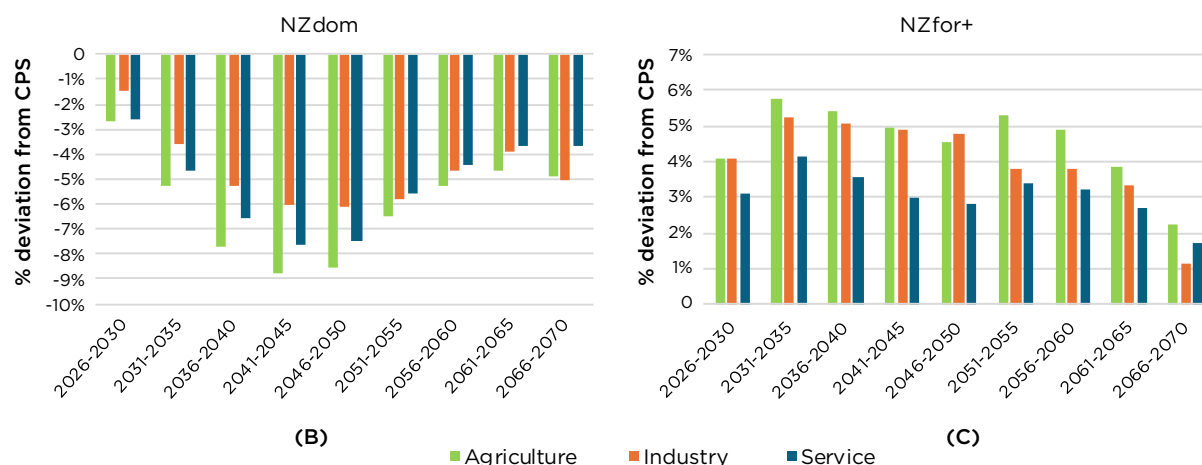
Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

Figure 3.6: Sectoral investment in Current Policy Scenario and Net Zero Scenarios
(% deviation from Current Policy Scenario) (MANAGE model)

(A) Sectoral investment in Current Policy Scenario.

(B, C) Net Zero Scenario investment (% deviation from Current Policy Scenario)

Industry remains the most resilient and largest beneficiary of capital allocation in the Net Zero transition. Under NZdom, capital allocation to all three sectors is lower relative to Current Policy Scenario due to crowding-out effects; however, industry experiences the smallest reduction in 2035-50 (compared to Current Policy Scenario), highlighting its central role in supporting the transition through technology deployment, equipment production, and electrification. In NZfor+, where all additional investment is productive and foreign financed, industry becomes the largest beneficiary of crowding-in, attracting the highest capital inflows during the transition. Agriculture also sees investment growth in this scenario, driven by the expansion of biomass based activities.

Investment patterns during the transition period indicate a rapid scale-up of investments in the renewable energy sector, alongside significantly lower investments in fossil fuels relative to the Current Policy Scenario. Compared to the Current Policy Scenario, electricity generation and distribution attract higher levels of investment under both domestic and foreign financing scenarios through 2070.

Under the domestic Net Zero scenario (NZdom), mining sector investment declines by INR 27 lakh crore during 2026–2050 but more than doubles to INR 52 lakh crore in the post-2050 period relative to the Current Policy Scenario. In contrast, under the Net Zero foreign financing scenario (NZfor+), the decline in mining investment is smaller, as the availability of foreign capital helps avoid crowding-out effects. Similarly, investment in the construction sector is lower under the Net Zero domestic financing scenario compared to the Current Policy Scenario. However, under the Net Zero foreign financing scenario, construction sector investment exceeds the Current Policy Scenario, reflecting the mitigation of crowding-out through increased access to foreign finance. (Figure 3.7).

Sectoral investment CPS (Industry)

Legend:
- Construction
- Machinery and equipment (including electrical)
- Cement and non-metallic metals
- Iron and Steel
- Mining
- Electricity
- Others (Non-ferrous metal, Chemical, textiles, Petroleum)

X-axis categories: 2026-2030, 2031-2035, 2036-2040, 2041-2045, 2046-2050, 2051-2055, 2056-2060, 2061-2065, 2066-2070

Y-axis: INR lakh crore (0, 200, 400, 600, 800, 1000, 1200)

(A)

Figure 3.7: Industry sub-sectoral investment in Current Policy Scenario and Net Zero Scenario (% Deviation from CPS) (MANAGE model).
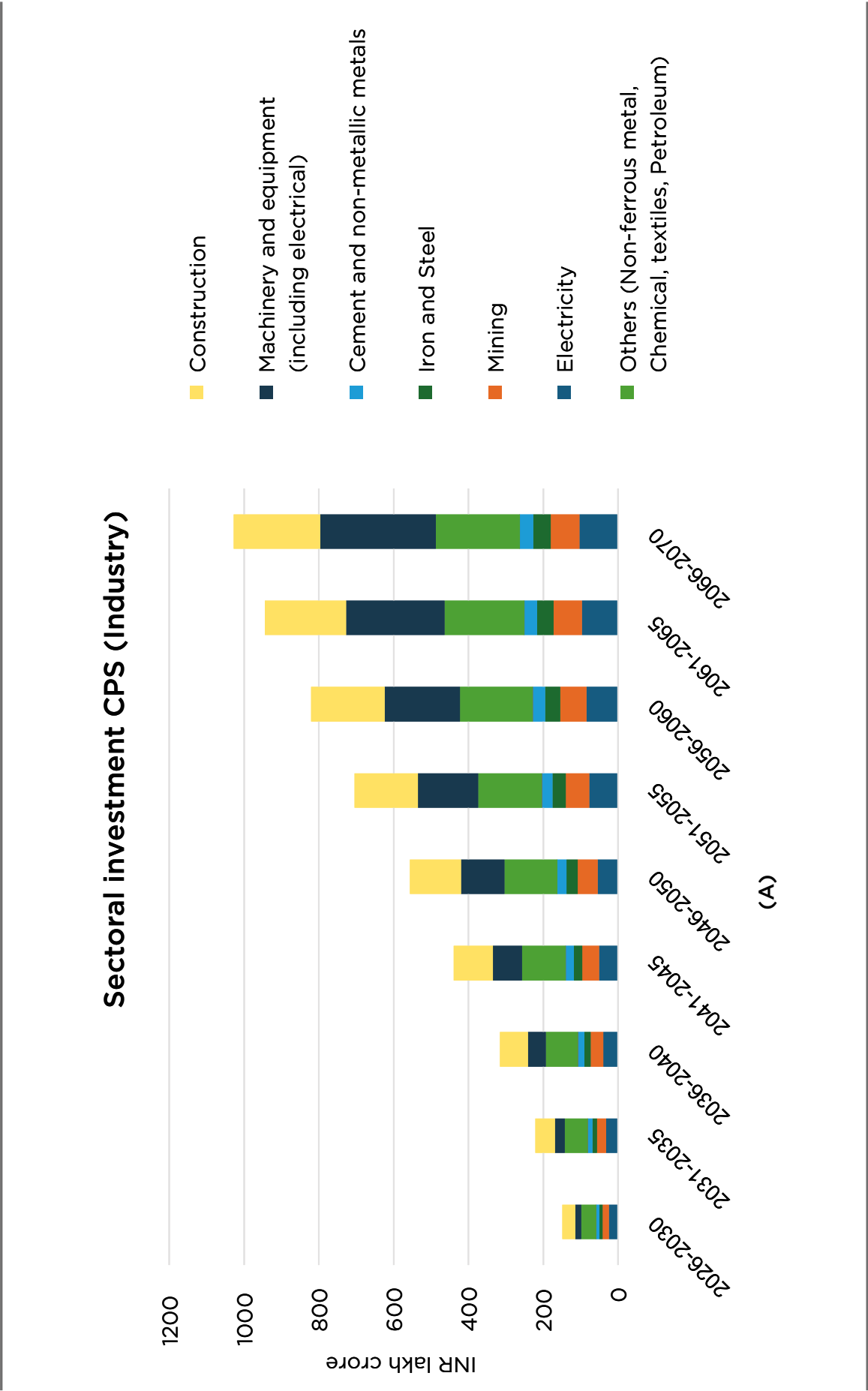
Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

(A) Sectoral investment in Current Policy Scenario.

(B) Net Zero investment (NZdom) (% deviation from Current Policy Scenario)

(C) Net Zero investment (NZfor+) (% deviation from Current Policy Scenario)

According to NITI Aayog's investment requirements and financing gap model, India's Net Zero pathway is increasingly driven by emerging and hard-to-abate technologies, with total investment needs rising from USD 8 trillion till 2050 to USD 22.7 trillion till 2070. By 2070, transmission and distribution (T&D) infrastructure accounts for roughly 18% of required investments, while grid storage, battery storage, and charging infrastructure together make up about 39%. This shift highlights the growing importance of system reliability, grid flexibility, and deep electrification in the later decades of India's transition.

Key Messages

▸▸ **High investment trajectory**: India's growth path is investment-intensive under all scenarios: in Current Policy Scenario, investment quintuples by 2070, and under Net Zero Scenario the scale of required capital is even higher, making India's development a uniformly high-investment story that hinges on mobilising unprecedented levels of finance.

▸▸ **Sectoral shifts under Net Zero Scenario**: Without co-benefits, investment under Net Zero Scenario falls below Current Policy Scenario across most sectors, though industry is least affected till 2050. In productive scenario with higher foreign-financing (NZfor+), industry and agriculture both exceed Current Policy Scenario levels, with industry attracting the largest capital inflows.

▸▸ **Clean energy surge**: Net Zero drives massive investment in emerging sectors, green hydrogen is higher by +160% to +500% versus Current Policy Scenario across successive decades, electricity investment more than doubles during 2046–60, while petroleum investment is lower compared to Current Policy Scenario (about –40% in NZfor+ by 2046–50 comapred to Current Policy Scenario).

3.2.5 Impact on Trade: Trade patterns shift decisively under Net Zero, exports dip modestly, but import savings and structural change drive a more resilient external sector.

India's move to high-income status in Current Policy Scenario is marked by rises in exports and imports. Under the Current Policy Scenario, India's imports and exports in value terms, rise to INR 840 trillion by 2050 and further to INR 3,200 trillion by 2070, while imports increase to INR 1,080 trillion by 2050 and INR 3,920 trillion by 2070 (Figure 3.8).

Legend:
- Services
- Transport-Road, Rail, Water and Air
- Trade
- Construction
- Other industry
- Electrical equipment, electronics, machinery and equipment
- Ferrous metals
- Green Hydrogen
- Fossil Energy-Coal, Oil and Gas
- Agriculture & Allied

(A) Import by Value
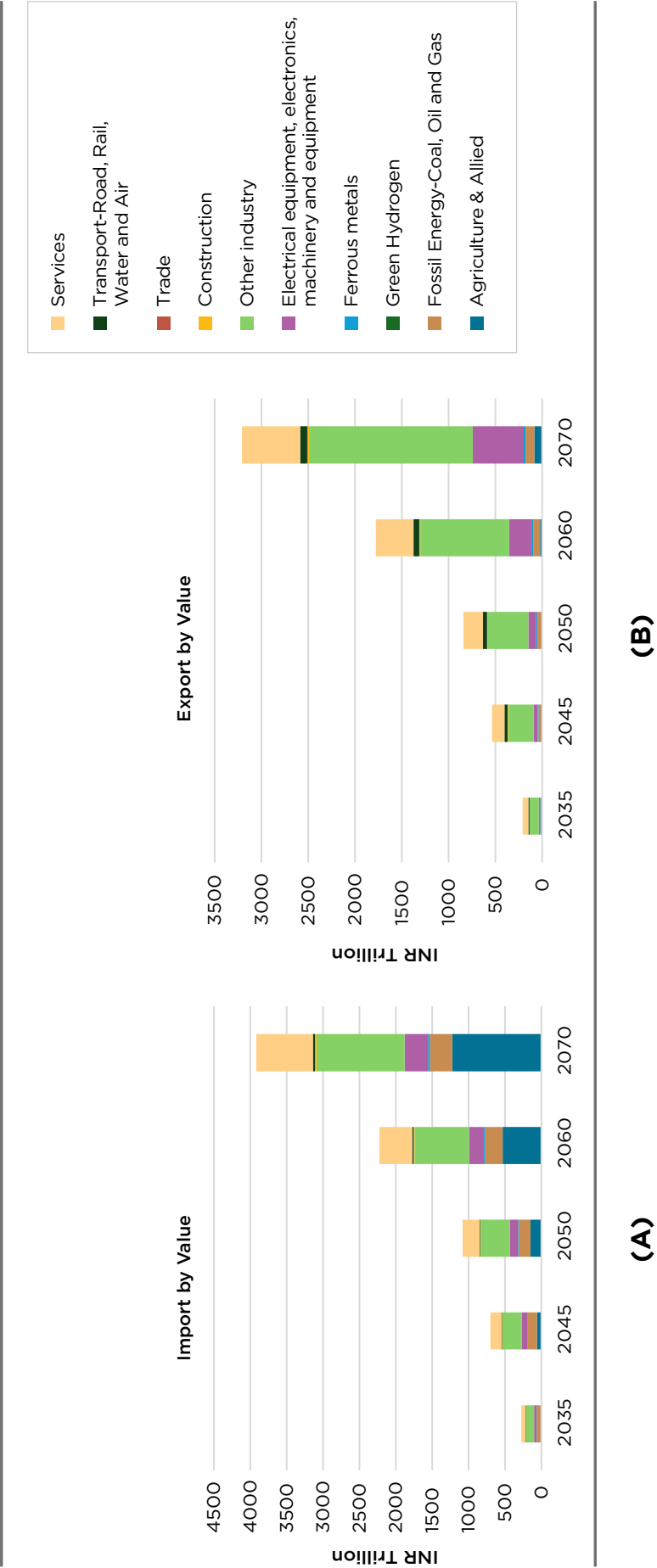
(B) Export by Value

Figure 3.8: Exports and imports by sector in Current Policy Scenario, 2035–2070 (MANAGE model)

(A) Sectoral Imports by value (INR trillion)

(B) Sectoral Exports by value (INR trillion)

With respect to sectoral break-up, in Current Policy Scenario, exports are driven by services and industry. On the import side, agriculture (driven by livestock imports) increase notably (Figure 3.8). These trade dynamics are simulated under the assumption of unchanged trade rules and tariff regimes; any future changes in trade policy could affect the magnitude and composition of the results.

In Current Policy Scenario, the Current Account Deficit (CAD) is assumed to grow to 2.3% of GDP by 2030 and remain at that level thereafter, with the exchange rate adjusting endogenously to maintain this deficit (See Figure 3.9). The adjustment is shaped by an appreciating real exchange rate of 0.9 percent on average annually. Over time, the trade deficit–to–GDP ratio narrows as GDP expands faster than net exports, leading to a decline in the ratio. Offsetting adjustments in the income and transfer accounts ensure that the overall current account deficit remains at its targeted level (Figure 3.9).
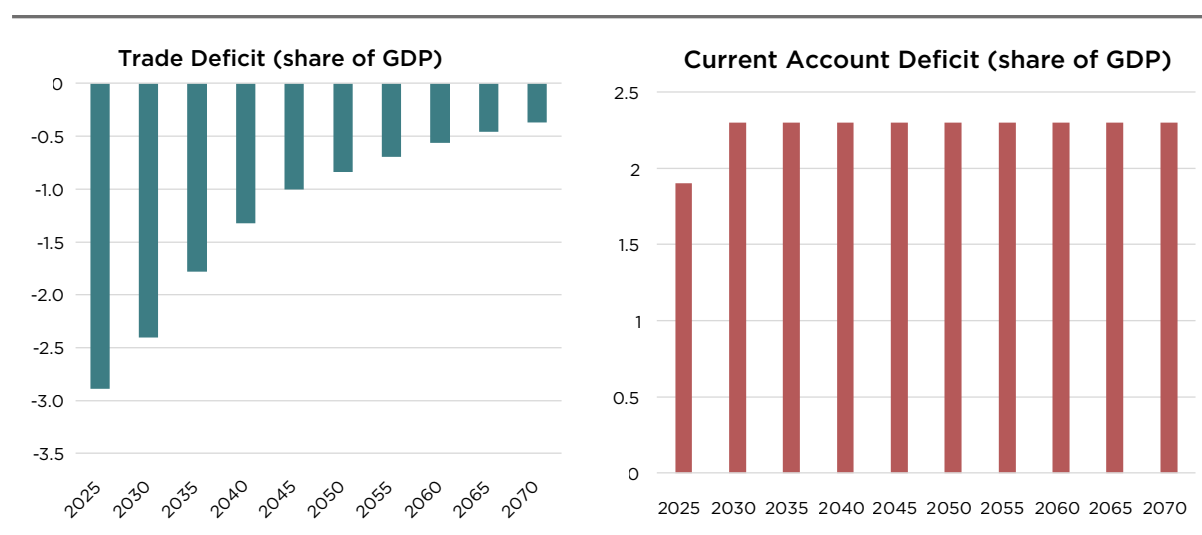
Figure 3.9: Balance of trade and current account deficit in the Current Policy Scenario (MANAGE model).

Across all scenarios, imports and exports increase rapidly in absolute terms. As a share of GDP, however, they remain broadly stable overtime in Current Policy Scenario, with only marginal differences under the Net Zero Scenarios (Figure 3.10). Under Current Policy Scenario, export-to-GDP ratio rises slightly from 23% in 2030 to 24% in 2050, while the Import to GDP remain largely stable at 26% over the same period.
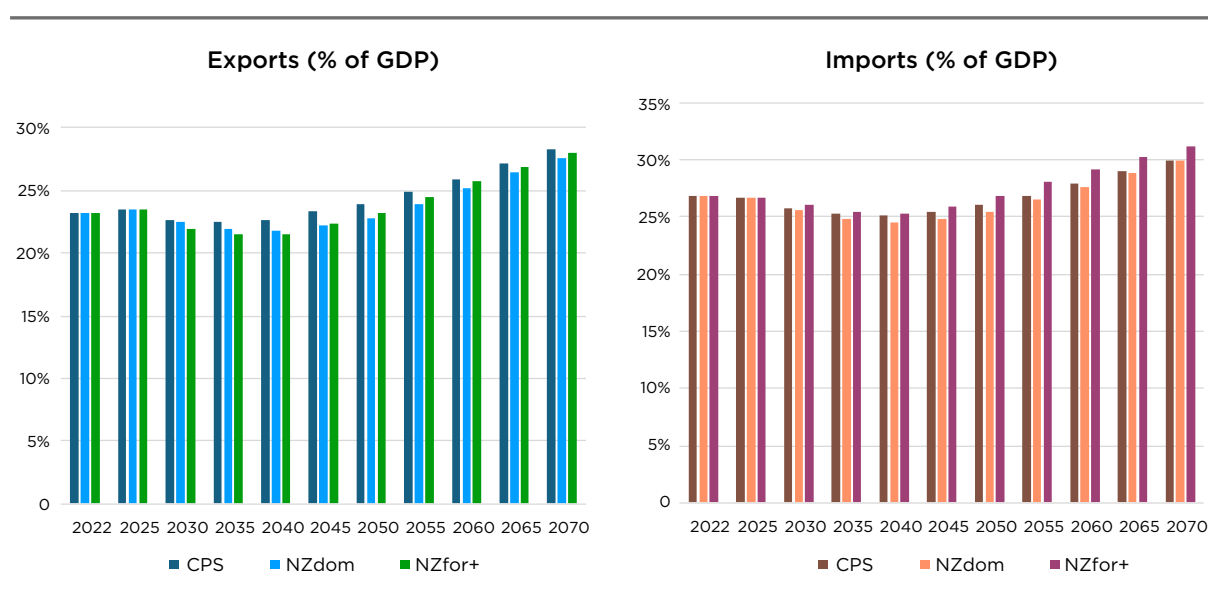
Figure 3.10: Exports and imports as a percentage of GDP (MANAGE model).

Under the Net Zero Scenarios, India's imports are generally lower than Current Policy Scenario, with most scenarios showing reductions of 2-8%, driven primarily by declining fossil fuel dependence (Figure 3.11). Domestically financed scenarios show lower imports as compared to Current policy Scenario, whereas foreign financed variants impact vary depending on the productivity of incremental finance. NZfor shows -1.6% by 2050 and recovers slightlyto +0.7% by 2070 compared to Current Policy Scenario, whereas in NZfor+, imports show +2.4% by 2050 and +3.0% by 2070 compared to Current Policy Scenario (See Figure 3.11).

   i. Fossil fuel-related imports is lower compared to Current Policy Scenario, with reduced imports of oil, coal, ferrous metals, other chemicals and manufactured products (Figure 3.12), reflecting the fundamental shift away from carbon-intensive energy sources.

   ii. However, livestock imports is higher across scenarios compared to Current Policy Scenario as consumption increases with changing dietary patterns. Competition among cropland, grazing, and forests, plus limits on land conversion and rising demand for biomass, drives up land prices, making domestic livestock production costlier and imports more economically viable.

   iii. Similarly, business services imports are higher compared to Current Policy Scenario as higher electricity prices under the Net Zero transition erode the competitiveness of domestic service-sector, prompting a shift toward more cost-effective foreign providers.
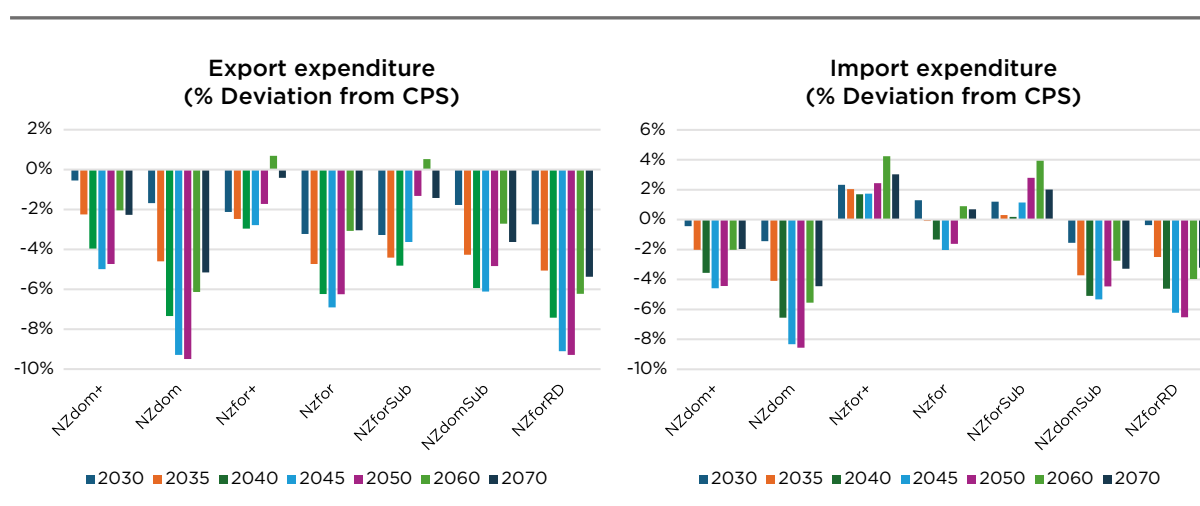
Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

Figure 3.11: Impact of Net Zero Scenarios on India's export revenue and import expenditure relative to Current Policy Scenario, 2030–2070 (MANAGE model)

Similarly, under Net Zero Scenarios, exports are lower across all scenarios relative to Current Policy Scenario, though impacts vary significantly by financing channel and policy design. The domestic financing scenarios show the most impacts, with NZdom showing -9.5% by 2050 and recovering to -5% by 2070 compared to Current Policy Scenario, though this is offset by significant falling fossil fuel imports, implying lower overall trade exposure rather than diminished competitiveness. In contrast, foreign financed variants impact vary depending on the productivity of incremental finance. NZfor shows -6.2% by 2050 and recovers to -3% by 2070 compared to Current Policy Scenario, whereas in NZfor+, exports show -1.7% by 2050 and -0.4% by 2070 compared to Current Policy Scenario, as foreign capital inflows prevent domestic resource crowding out (Figure 3.11). In parallel, falling fossil fuel imports reduce overall trade exposure, underscoring a structural realignment of trade flows rather than a deterioration in performance.
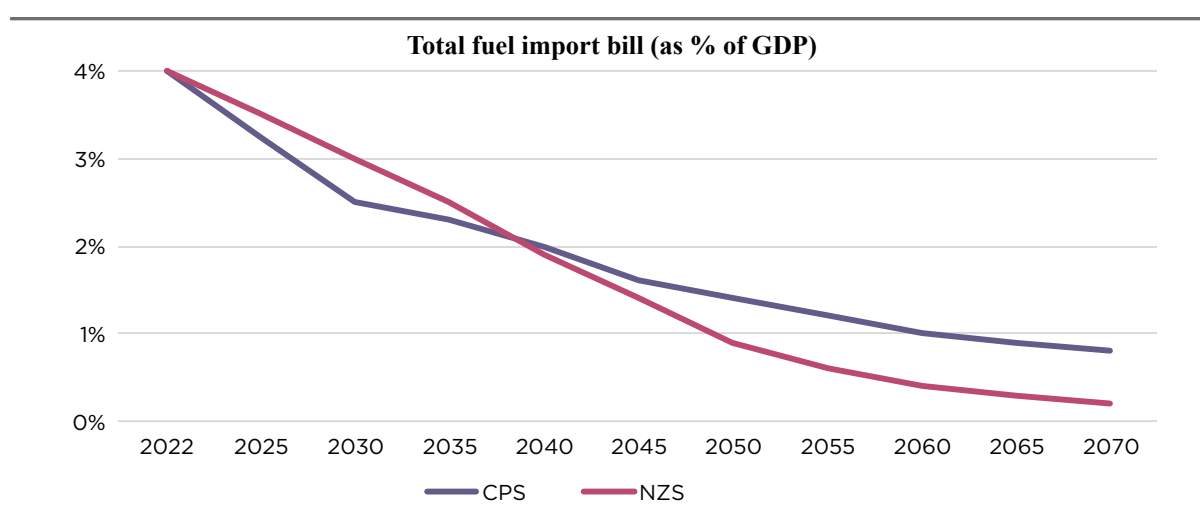
Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

Figure 3.12: Declining fuel imports (NCAER)

i. The overall decline in exports is driven mainly by falling fossil fuel products, partially offest by gains in textiles, cement, and ferrous metals.

ii. Exports of fossil fuels, including petroleum, coal, and related chemical products are projected to fall as domestic supply adjusts. In the model, this outcome reflects world prices treated as exogenous, since the demand and price response from the rest of the world is not modeled. Accordingly, the drop in demand from other countries is attributed to the effect of India's climate policies on supply and domestic prices.

iii. The business services sector has lower export competitiveness, primarily due to higher electricity prices during the Net Zero transition, which raise operational costs. In contrast, notable export gains are expected in industrial goods such as textiles, cement, and ferrous metals, supported by declining domestic coal prices during the transition (Annex Figure B4). This cost advantage reduces production expenses and enhances the global competitiveness of these industries.

The Trade Deficit widens slightly under Net Zero Scenario compared to Current Policy Scenario, but is projected to improve steadily across all pathways. In the near term (2030), the Trade Deficit grows to between 3.5%–4.5% of GDP across different scenarios, with foreign-financed pathways showing the largest deficits. This gradually moderates, narrowing to to 2.5-3.3% of GDP by 2050, and further improving to 1.7-2.3% by 2070 (Figure 3.13).

The Current Account Deficit (CAD) is slightly higher under Net Zero Scenario compared to Current Policy Scenario, with -1% variation in mid-2050s to -.5% in 2070. Foreign-financed scenarios consistently show larger Current Account Deficits (peaking at around 3.2% of GDP in 2045) compared to domestically-financed pathways (stabilizing at 2.3-2.5%). This reflects the role of additional capital inflows, which enable higher investment levels but also necessitate larger external deficits to sustain balance-of-payments equilibrium (Figure 3.13).

[A] Current Account Balance on GDP (%)
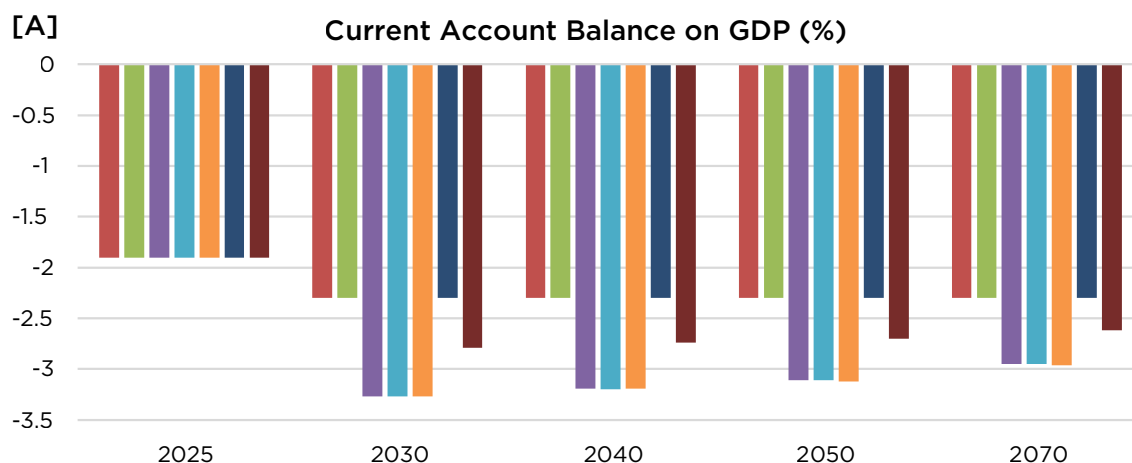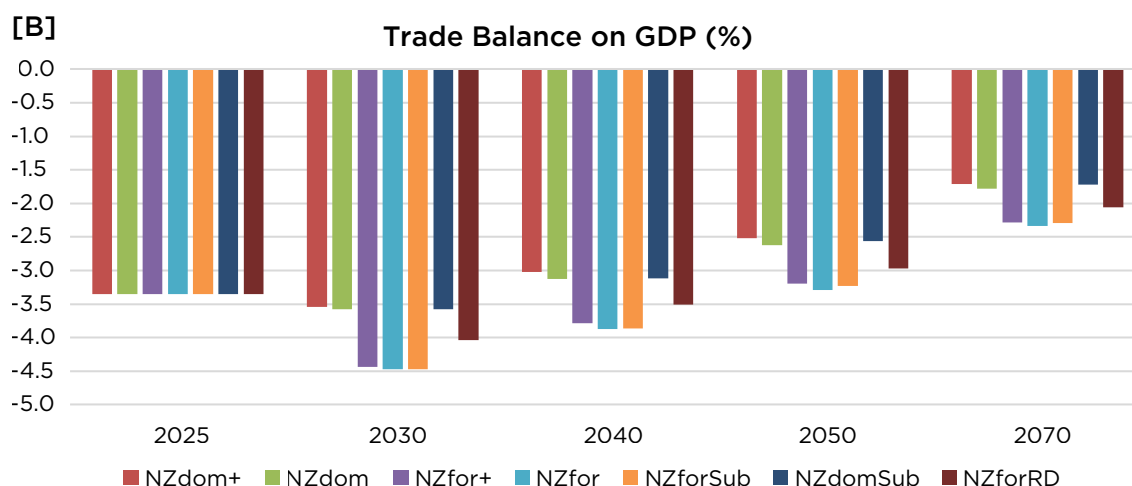
Figure 3.13: Current Account Balance and Trade Balance in Net Zero Scenarios

(A) Current account deficit (% of GDP, MANAGE model).

(B) Balance of Trade (% of GDP, MANAGE model).

Key Messages

▶ **Imports and exports** as a share of GDP, remain broadly stable across scenarios, till 2050 but increase in absolute terms in Current Policy Scenario.

▶ **Under the Net Zero Scenario (NZS), trade outcomes differ by financing mode.** In NZdom, imports show -8.5% by 2050 and -4.5% by 2070 in NZdom, whereas in NZfor+, imports show +2.4% by 2050 and 3% by 2070 compared to Current Policy Scenario. Similarly, exports show -9.5% by 2050 and -5.0% by 2070 in NZdom, whereas in NZfor+ exports show -1.7% by 2050 and -0.4% by 2070 compared to Current Policy Scenario.

▶ **Trade balance**: The Trade Deficit widens in the near term (3.5-4.5% of GDP by 2030) but improves steadily to 1.5–2.5% by 2070 in Current Policy Scenario. While in Net Zero Scenario, Trade Deficit widens under foreign financed scenarios by 0.5-1% compared to Current Policy Scenario, while it remains same under domestic financing scenarios. Current Account Deficit follows a similar pattern, with higher deficits in foreign-financed pathways.

3.2.6 Impact on Household income and consumption: Net Zero puts marginal pressure on household consumption, with poorer groups most affected unless cushioned by redistributive policies.

The financing mechanism also shapes outcomes. Domestic financing raises capital costs, crowds out private investment, dampens output and labor demand, and reduces household

incomes, effects that fall more heavily on poorer households whose consumption is concentrated in necessities. By contrast, foreign financing eases these pressures: external capital inflows prevent crowding out, sustain labor demand and incomes, and moderate consumption losses, especially in rural areas (Figure 3.14).

Redistributive policies can offset these adverse effects. Targeted transfers financed through higher public debt maintain the consumption of the bottom 40 percent at Current Policy Scenario levels, demonstrating that redistribution can mitigate short-term distributional impacts of Net Zero. Similarly, electricity subsidies funded by phasing out fossil fuel subsidies reduce household electricity costs, cushioning welfare losses.
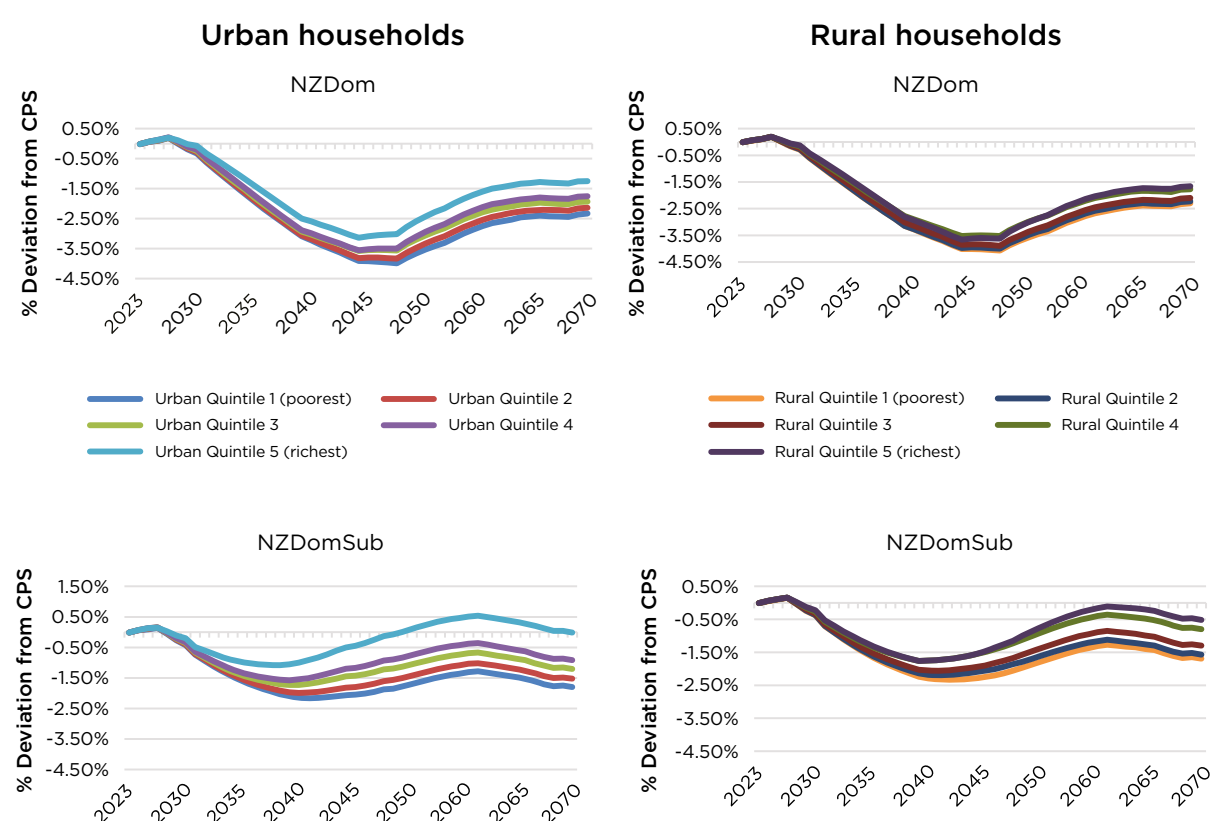
Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

Figure 3.14: Impact of the Net Zero transition on real household consumption (% deviation from Current Policy Scenario, MANAGE model)
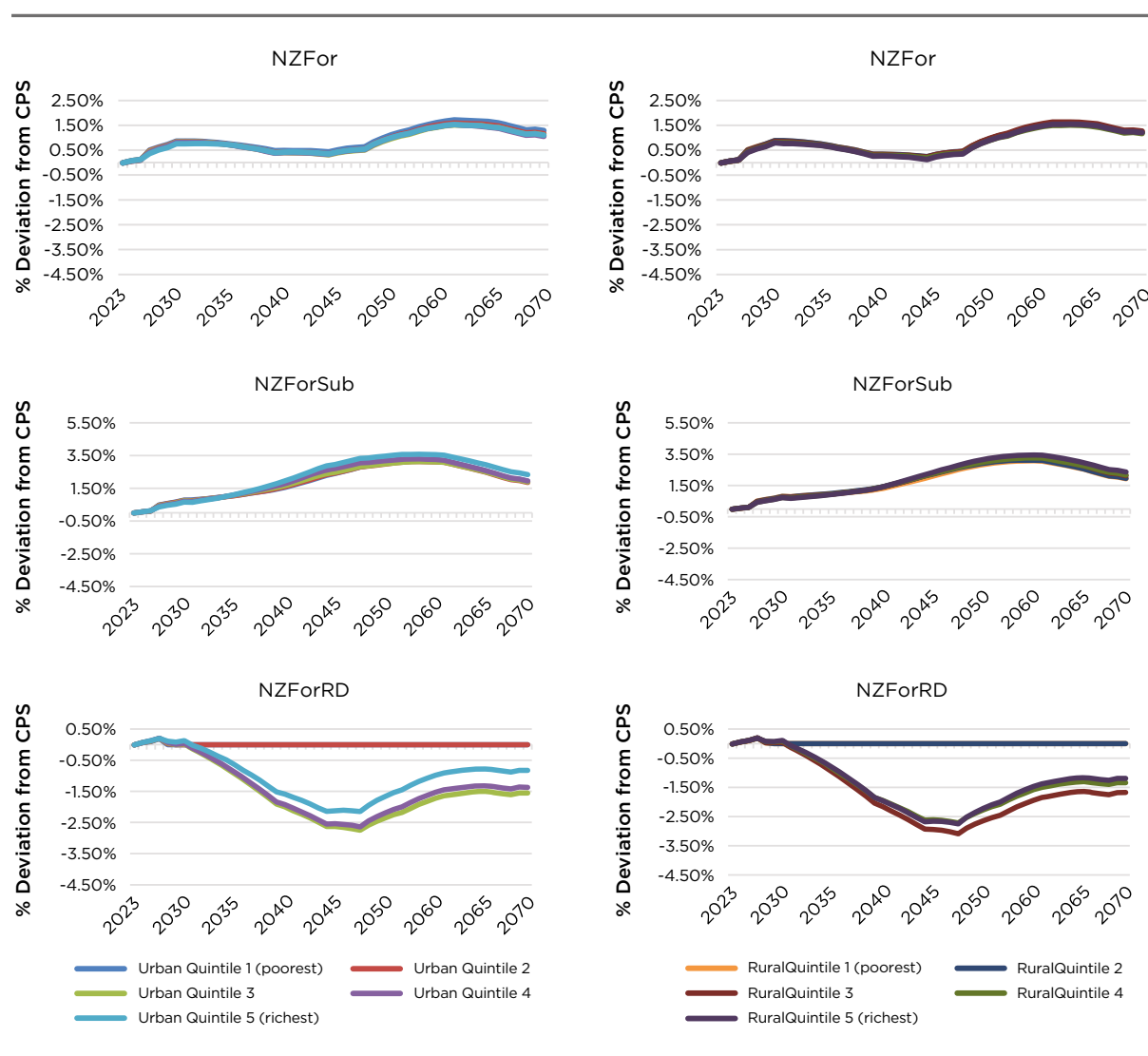
Note: *CPS = Current Policy Scenario; NZS = Net Zero Scenario*

**Figure 3.14: Impact of the Net Zero transition on real household consumption
(% deviation from Current Policy Scenario, MANAGE model)**

Key Messages

▸▸ **Urban-Rural Impacts are different:** Urban–rural income gaps remain unchanged across scenarios, with poorer households more vulnerable to consumption losses.

▸▸ **Financing matters**: Domestic financing deepens household budget pressures, while foreign financing cushions impacts by sustaining incomes and demand.

▸▸ **Policies can protect**: Targeted transfers and electricity subsidies offset losses, keeping the bottom 40 percent at Current Policy Scenario levels.

3.2.7 Impact on Electricity Prices

The Current Policy Scenario and Net Zero Scenario show distinct electricity price trajectories (Figure 3.15). In the Current Policy Scenario, slower pace of demand electrification (increases from 21% in 2025 to 40% by 2070 in Current Policy Scenario vs 60% in Net Zero Scenario) and resultingly lower investment needs in Current Policy Scenario, leads to electricity prices largely remaining stable till 2040 and declining thereafter.

By contrast, the Net Zero Scenario exhibits higher electricity prices in the near to medium term, particularly over 2030–2045, as rapid electrification of transport and industry drives up electricity demand. Meeting this surge requires substantial upfront capital investment in renewable generation, storage, transmission upgrades, and emerging demand-side electrification options such as heat pumps and electric boilers, which can be several times more capital intensive than conventional technologies. These higher upfront costs temporarily push Net Zero Scenario electricity prices above Current Policy Scenario levels during the initial phase of the transition.

After 2045, however, Net Zero Scenario electricity prices begin to fall, from their peaks but continue to remain above Current Policy Scenario due to higher electrification in Net Zero. This decline reflects economies of scale, technology learning effects, and continuing cost reductions in low-carbon technologies. By the 2050s and beyond, electricity becomes more affordable under Net Zero Scenario, supporting long-term competitiveness, consumer welfare, and sustained economic growth.
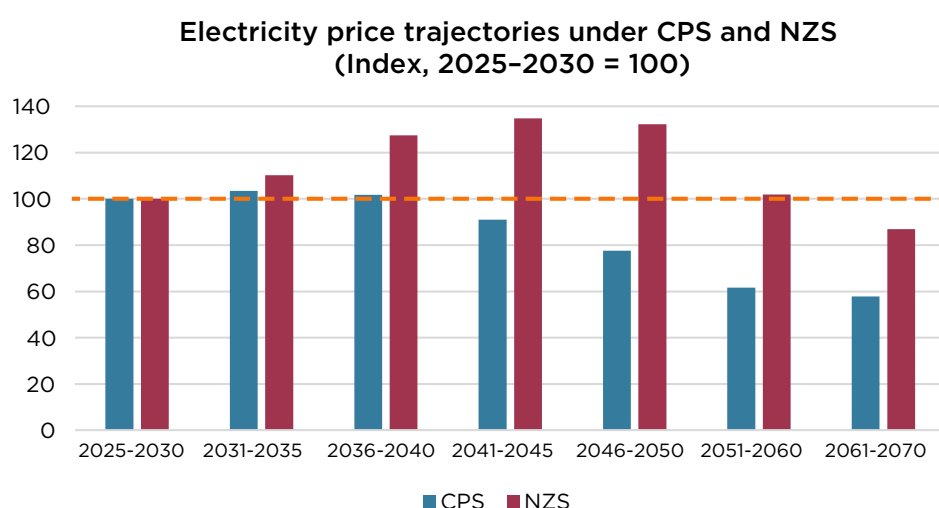
Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

Figure 3.15: Electricity price trajectories under Current Policy Scenario and Net Zero Scenario

3.2.8 Impact on labour market: Under Net Zero, jobs will shift from fossil fuel sectors into renewable electricity, while construction, transport, and trade emerge as major sources of new employment.

In all scenarios, employment shifts steadily from agriculture toward industry and services, mirroring the structural transformation of the economy. By 2050, in the Current Policy Scenario, the agricultural share of total jobs falls from about 46% in 2024 to 34%, while services gains a modest share and industry continues to expand as the main source of employment. This sectoral transition is accompanied by a rising demand for higher-skilled labour, reflecting the growing weight of skill-intensive services and more technologically advanced industries. At the same time, labour force participation increases, with the overall employment rate rising from about 55% in 2025 to 64% in 2050 and 70% in 2070, reflecting higher employment rate over time as the economy develops (Figure 3.16).

The impacts on the overall employment rate are shown to be relatively modest. Scenarios such as NZforSub and NZfor+ result in a slight higher employment rate by +0.7-0.8% compared to Current Policy Scenario by 2050. Conversely, the NZDom and NZforRD scenarios show a slightly lower employment rate (-0.3 to -0.5%) compared to Current Policy Scenario by 2050.
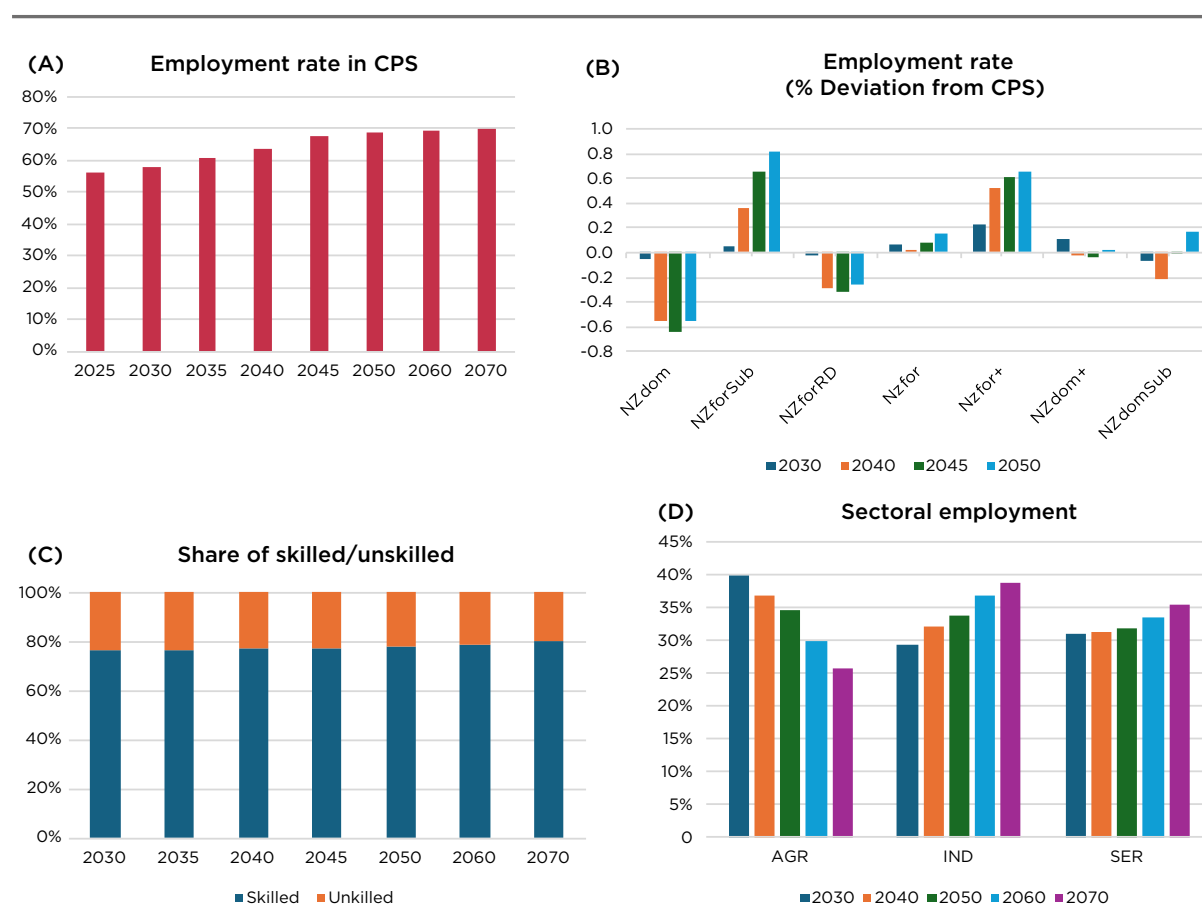
Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

Figure 3.16: Labor market in the Current Policy Scenario and Net Zero Scenario.

(A) Current Policy Scenario employment rate (MANAGE model).

(B) Deviation of employment from Current Policy Scenario in Net Zero Scenarios.

(C) Share of skilled and unskilled labour (MANAGE model)

(D) Employment in three broad sectors (%, MANAGE model).

In the Current Policy Scenario, the broad employment pattern in energy sector largely remains stable with employment of 6 million by 2050. Coal, Oil, gas and Electricity account for the bulk of employment. By 2070, total jobs decline to 4 million primarily due to improvements in energy efficiency and technological progress. As the economy becomes less energy-intensive, fewer workers are required both in direct energy production and in the upstream and downstream sectors that supply or depend on energy, leading to a gradual contraction in employment.

However, in Net Zero Scenario, industry records higher employment than Current Policy Scenario, for both skilled and unskilled workers, reflecting rising demand from clean technology manufacturing and renewable energy infrastructure. With rapid expansion in clean energy, energy sector jobs increase to 7 million by 2050 (1 million higher than Current Policy Scenario) and 4.5 million in 2070 (0.5 million higher than Current Policy Scenario). (Figure 3.17).
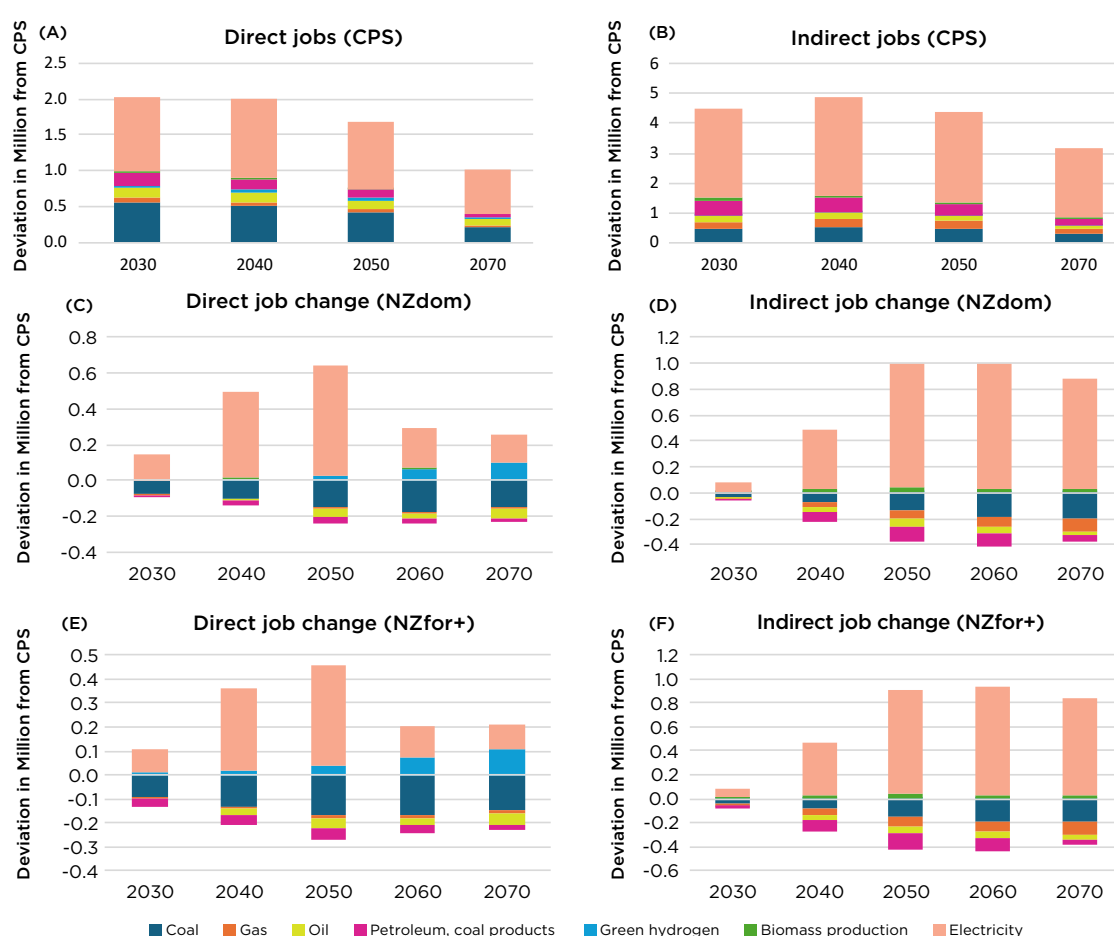
Figure 3.17: Direct and indirect jobs in energy sectors in Current Policy Scenario and Net Zero Scenario (jobs in Millions deviation from CPS)

Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

(A-B) Direct and indirect jobs in energy sectors under CPS (MANAGE model).

(C-D) Direct and indirect jobs change in energy sector under NZdom (compared to CPS) (MANAGE model).

(E-F) Direct and indirect jobs change in energy sector under NZfor+ (compared to CPS) (MANAGE model).

The impact of Net Zero transition on structure of employment varies according to source of financing, productivity of incremental capital and role of complementary policies. By 2050, all Net Zero Scenarios show higher employment in agriculture, ranging between +0.4% (NZfor) and + 3.2%(NZdomsub) compared to Current Policy Scenario. In industry, the Net Zero Scenarios range from -0.1% to -1.5% in domestic-financed scenarios compared to Current Policy Scenario whereas in Net Zero foreign-financed scenarios, the impact ranges between +0.7% to +2% compared to Current Policy Scenario by 2050 (See Table 3.4).

Table 3.4: Sectoral employment (% deviation from Current Policy Scenario, MANAGE model)[12].

	2030	2035	2040	2045	2050	2060	2070
Agriculture							
NZdom+	0.25	0.33	0.19	0.54	1.02	1.71	0.63
NZdom	0.06	-0.18	-0.62	-0.26	0.49	1.77	1.12
Nzfor+	-0.20	0.24	0.39	0.69	0.85	0.86	-0.83
Nzfor	-0.38	-0.27	-0.35	0.03	0.43	0.92	-0.41
NZforSub	-0.48	0.06	0.97	2.17	2.80	2.42	0.51
NZdomSub	-0.04	0.17	0.81	2.16	3.16	3.40	2.13
NZforRD	-0.15	-0.04	-0.02	0.55	1.30	2.15	1.32
Industry							
NZdom+	0.37	0.15	-0.04	0.00	-0.06	-0.10	-0.46
NZdom	-0.05	-0.66	-1.05	-1.09	-1.16	-0.95	-1.05
Nzfor+	1.50	1.77	1.86	2.04	2.04	1.75	1.08
Nzfor	1.10	0.98	0.89	1.04	1.05	1.01	0.56
NZforSub	1.14	0.87	0.61	0.65	0.75	0.83	0.36
NZdomSub	0.01	-0.78	-1.38	-1.55	-1.52	-1.19	-1.32
NZforRD	0.38	-0.12	-0.60	-0.77	-0.99	-0.81	-0.99
Services							
NZdom+	-0.01	-0.05	-0.34	-0.77	-0.95	-0.41	-0.05
NZdom	-0.32	-0.64	-1.13	-1.72	-1.94	-1.20	-0.63

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12 Colours represent the direction and magnitude of deviation relative to the Current Policy Scenario (CPS). Greener shades indicate positive deviations, yellow denotes values close to CPS, and orange to red shades indicate negative deviations, with darker colours reflecting larger absolute changes.

Nzfor+	0.18	0.43	0.40	0.15	0.06	0.46	0.60
Nzfor	-0.12	-0.14	-0.37	-0.73	-0.84	-0.25	0.09
NZforSub	-0.16	0.02	0.11	0.05	0.06	0.32	0.38
NZdomSub	-0.39	-0.48	-0.62	-0.89	-1.00	-0.64	-0.35
NZforRD	-0.30	-0.46	-0.85	-1.39	-1.63	-1.02	-0.50
Total							
NZdom+	0.20	0.15	-0.05	-0.05	0.03	0.33	-0.03
NZdom	-0.09	-0.47	-0.92	-0.98	-0.84	-0.22	-0.34
Nzfor+	0.42	0.77	0.87	0.96	1.00	1.05	0.42
Nzfor	0.13	0.15	0.04	0.12	0.24	0.56	0.15
NZforSub	0.09	0.30	0.58	1.01	1.24	1.13	0.41
NZdomSub	-0.13	-0.33	-0.34	0.00	0.25	0.36	-0.09
NZforRD	-0.04	-0.20	-0.46	-0.49	-0.40	0.00	-0.22

The Net Zero transition impact on wages depends on source of financing. In Net Zero Scenarios real wage deviations from Current Policy Scenario remain small in the near term but widen after 2040. In the NZfor+, real wages are higher by up to 3% above Current Policy Scenario by 2050. In contrast, domestically financed scenarios (e.g., NZdom) put downward pressure on incomes, with wages being lower than Current Policy Scenario by about 5.6% in 2050 (Figure 3.18).

Industry records the strongest real wage gains in the transition. In Net Zero foreign-financed scenarios such as NZfor+, real wages in industry are higher by 5.5% above Current Policy Scenario by 2050, driven by demand for clean technology and renewable energy infrastructure. (Table 3.5).
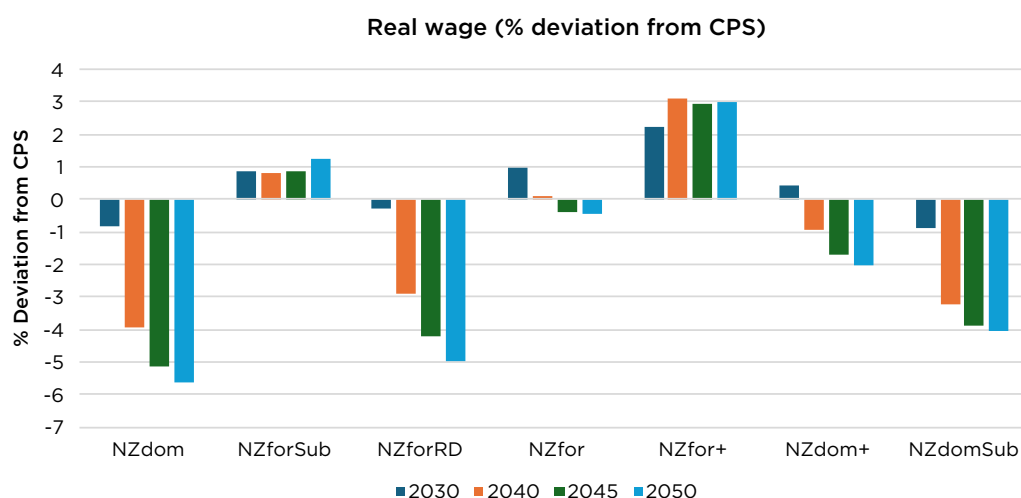
Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

Figure 3.18: Real wages in Net Zero Scenarios (% deviation from CPS) (MANAGE).

The Net Zero transition drives a reallocation of jobs from fossil fuel industries to renewable electricity, requiring complementary policies such as reskilling and relocation support. Under Net Zero Scenario, employment is reallocated across energy sub-sectors. Direct jobs rise in electricity by up to 1.23 million and 1.61 million cumulatively through 2050 and 2070 compared to Current Policy Scenario, supported by large-scale deployment of renewables (solar, wind) and grid expansion, while indirect jobs along clean-tech supply chains add up to 1.48 million and 3.30 million cumulatively through 2050 and 2070 (NZdom) compared to Current Policy Scenario. By 2050 and 2070, the electricity sector is the largest contributor to net job gains relative to Current Policy Scenario.

Beyond the energy sector, the Net Zero transition can deliver substantial economy-wide job gains under supportive policies. Job creation is concentrated in construction, road transport, and trade. Under the NZforSub, construction emerges as the single largest contributor, adding about 4.6 million jobs by 2050 compared to Current Policy Scenario, driven by the labour needs of utility-scale RE build-out, grid expansion, and low-carbon infrastructure. Road transport and trade also expand, with road transport adding 880,000 jobs by 2045, and together with trade contributing a cumulative 5.17 million jobs over 2030–2070. This demonstrates that the Net Zero transition can be a major engine of employment outside the energy sector when combined with targeted complementary policies (Annex Figure B6).

Table 3.5: Sectoral real wages (deviation from CPS)[13]

	2030	2035	2040	2045	2050	2060	2070
Agriculture							
NZdom+	0.52%	0.37%	-0.85%	-1.48%	-1.65%	-0.72%	-0.79%
NZdom	-0.59%	-2.11%	-3.68%	-4.40%	-4.33%	-2.45%	-1.80%
Nzfor+	1.74%	2.56%	2.34%	1.89%	1.54%	1.52%	0.64%
Nzfor	0.61%	0.37%	-0.37%	-0.81%	-0.87%	0.00%	-0.25%
NZforSub	0.49%	0.83%	1.08%	1.37%	1.41%	1.19%	0.33%
NZdomSub	-0.74%	-1.78%	-2.07%	-2.07%	-1.90%	-1.24%	-1.27%
NZforRD	-0.26%	-1.15%	-2.44%	-3.25%	-3.46%	-2.07%	-1.63%
Industry							
NZdom+	0.73%	0.67%	0.55%	0.56%	0.55%	0.65%	0.21%
NZdom	-0.36%	-1.70%	-2.32%	-2.65%	-2.75%	-2.07%	-1.70%
Nzfor+	2.59%	4.07%	4.66%	5.26%	5.52%	5.17%	3.86%
Nzfor	1.48%	1.70%	1.81%	2.12%	2.36%	2.67%	2.11%
NZforSub	1.40%	2.05%	2.67%	3.60%	4.17%	3.74%	2.50%

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13 Colours represent the direction and magnitude of deviation relative to the Current Policy Scenario (CPS). Greener shades indicate positive deviations, yellow denotes values close to CPS, and orange to red shades indicate negative deviations, with darker colours reflecting larger absolute changes.

	2030	2035	2040	2045	2050	2060	2070
NZdomSub	-0.45%	-1.33%	-1.46%	-1.19%	-0.99%	-1.09%	-1.46%
NZforRD	0.24%	-0.57%	-1.14%	-1.61%	-1.97%	-1.53%	-1.40%
Services							
NZdom+	0.40%	-0.54%	-1.47%	-2.26%	-2.50%	-1.39%	-1.83%
NZdom	-0.88%	-3.14%	-4.64%	-5.81%	-6.10%	-4.25%	-3.79%
Nzfor+	1.75%	2.38%	2.19%	2.05%	2.09%	2.61%	1.31%
Nzfor	0.47%	-0.21%	-0.90%	-1.36%	-1.31%	0.02%	-0.47%
NZforSub	0.38%	0.26%	0.18%	0.50%	1.03%	1.50%	0.11%
NZdomSub	-0.98%	-2.67%	-3.54%	-3.94%	-3.80%	-2.85%	-3.33%
NZforRD	-0.53%	-2.15%	-3.50%	-4.73%	-5.27%	-3.77%	-3.54%

Key Messages:

▸ **Employment remains stable:** Net Zero has only modest effects on overall jobs (–1% to +1% relative to Current Policy Scenario), though outcomes vary by financing.

▸ **Jobs shift, wages diverge:** Fossil fuel employment declines while renewables and manufacturing expand; real wages are lower under domestic financing and are higher with foreign capital as compared to Current Policy Scenario.

Summary of the results

Table 3.6 highlights the broad macroeconomic implications across Net Zero Scenario. Pathways reliant on domestic financing (NZdom and NZdom+) generally see lower GDP, consumption, and investment growth in short/medium-run compared to Current Policy Scenario. These scenarios also show lower trade deficits but higher fiscal deficits.

By contrast, the scenarios reliant on higher foreign financing (NZfor, NZfor+) show better macroeconomic performance compared to domestic as the external borrowing does not crowd-out domestic investment. NZfor+ delivers the most positive outcomes, with notable gains in GDP, household consumption, investment, and exports compared to Current Policy Scenario. These pathways also see larger import growth and worsening trade balances. Still, fiscal outcomes strengthen due to higher economic activity, and the employment rate improves in these foreign-oriented scenarios.

Subsidy-based variants (NZforSub and NZdomSub) sit between domestic and foreign extremes: These variants show higher fiscal deficit and face current account pressures. Overall, the results show consistent inter-linkages: GDP, trade flows, fiscal balances, and employment move together depending on whether Net Zero investment relies on reallocating domestic resources or on expanding productive capacity through foreign inflows.

Table 3.6: Impact of alternate Net Zeroscenarios in comparison to Current Policy Scenario on different economic variables

	GDP	Household consumption	Government consumption	Investment	Exports	Imports	Fiscal deficit	Tax revenue on GDP	BOT	CAB	Employment rate
NZdom+	--	-	--	--	--	+	+	+	--	--	-
NZdom	--	--	--	--	---	---	+	+	--	--	-
Nzfor+	++	+++	++	++	+	+++	++	-	--	---	+
Nzfor	-	++	-	++	--	+++	+	-	--	---	+
NZforSub	+	++	+	++	-	+++	++	-	--	---	+
NZdomSub	--	-	--	--	---	--	++	+	--	--	-
NZforRD	--	-	--	--	---	--	++	+	--	---	-

Green symbols indicate positive outcomes, red symbols indicate negative outcomes.

Ranking scale: +/–: positive or negative changes below 1%, ++/––: positive or negative changes between 1 and 2.5%; +++/– – –: positive or negative changes between 2.5 and 5%

4

IMPLICATIONS OF THE NET ZERO TRANSITION FOR GOVERNMENT REVENUE AND THE IMPORT BILL

Implications of the Net Zero Transition for Government Revenue and the Import Bill

4

This chapter examines how India's Net Zero transition will affect government revenues, the import bill, and emerging critical-mineral dependencies, drawing on a comparative assessment of a Net Zero 2070 scenario against a current policy scenario.

4.1 Revenue Implications of the Net Zero Transition at the National level

4.1.1 Context: Revenue Dependence on Fossil Fuels

Fossil fuels constitute a significant share of government revenue. Central government revenue from taxes, duties and cesses on primary fossil fuels (coal and petroleum products) ranged from INR 2.4 trillion to INR 3.2 trillion (in constant 2011-12 prices) during fiscal years FY 2019-20 to 2023-24 (PPAC, 2025). Over this period, revenue from primary fossil fuels accounted for 20 to 33% of total central government revenue (Ministry of Finance, 2025) (Figure 4.1) and 1.5 to 2.3% of national Gross Domestic Product (GDP) in real terms (Ministry of Statistics and Program Implementation, 2024) (Figure 4.2). Petroleum products provided the bulk of these receipts, with coal contributing about 16% and petroleum about 84%, on average, of total primary fossil fuel revenue.
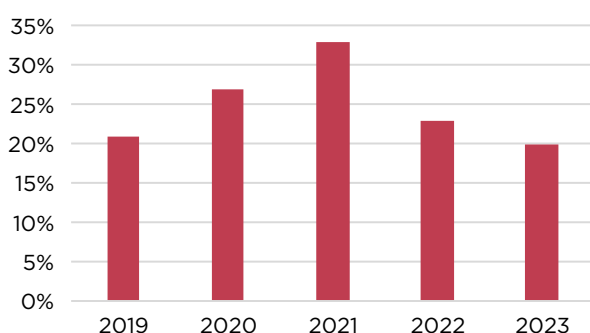
Figure 4.1: Fossil fuel revenue as a % share of the total central government revenue
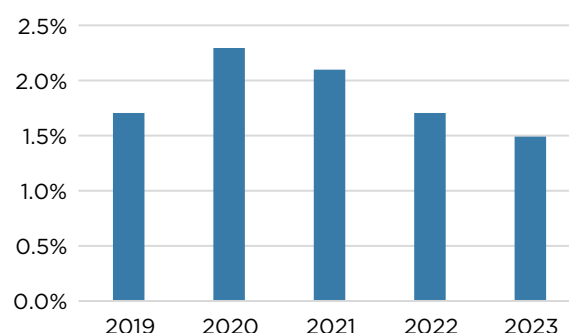
Figure 4.2: Fossil fuel revenue as a % share of national GDP

Subsidies for primary fossil fuels are negligible compared to the revenue earned by the government from them. Since 2010, India has steadily reduced primary fossil fuel subsidies, with an approximately 85% decline between 2013 and 2023 (Asian Development Bank, 2024). In 2023, subsidies to the petroleum sector were about INR 707 billion out of the total estimated subsidies worth INR 3.2 trillion crore for all fossil fuels in the same year (IISD, 2023). These amounts represented only a small fraction of government revenue from the two sectors: for coal, subsidies equaled about 1% of revenue earned, and for petroleum about 4%, primarily to cover under-recovery in the retail price of LPG (Powell et al., 2024).

At the state level, on average, petroleum products contribute about 7% of total state government revenue on average, ranging from 2 to 13% across states. Coal revenues are smaller, accounting for 3 to 16% in major coal-producing states (Upadhyay et al., 2024).

4.1.2 Comparison of Fossil-Fuel Revenues in the Current Policy Scenario and Net Zero Scenario

As a share of GDP, fossil-fuel revenue declines from around 2.3% of GDP at present to around 0.4% of GDP by 2070 in the current policy scenario and to 0.2% of GDP in the Net Zero Scenario (Figure 4.3). The decline in the Current Policy Scenario reflects a combination of structural economic change and policy-driven shifts in energy use. As the economy grows and diversifies, fossil-fuel consumption and associated tax revenues fall, while ongoing efficiency improvements, gradual electrification of end-use sectors, and the increasing competitiveness of renewables reduce demand for taxed fossil fuels over time. Electrification levels in the Net Zero Scenario are significantly higher than in the Current Policy Scenario, accelerating this revenue decline. Figure 4.4 summarizes the breakdown of projected fossil-fuel revenue by fuel for both scenarios in 2030, 2050 and 2070. Across all years and in both scenarios, revenue from diesel makes up the highest share of total fossil-fuel revenue, accounting for around half of government revenue from fossil fuels. Petrol follows, contributing about one-third of total revenue, while coal accounts for the remaining one-sixth.[14]

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14   Details regarding assumptions on start year fuel prices, tax rates and price escalation factors can be found in Annexure C-1.
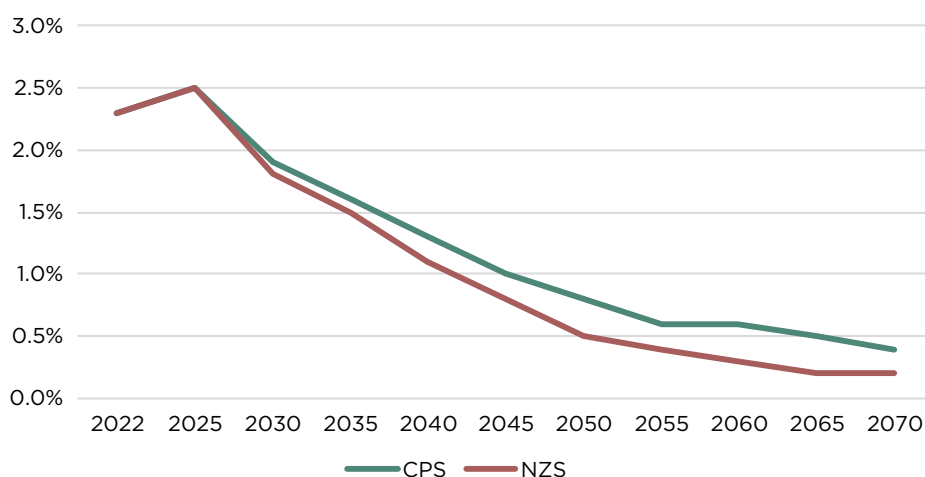
Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

Figure 4.3: Projected total fossil fuel revenue (as % of GDP)
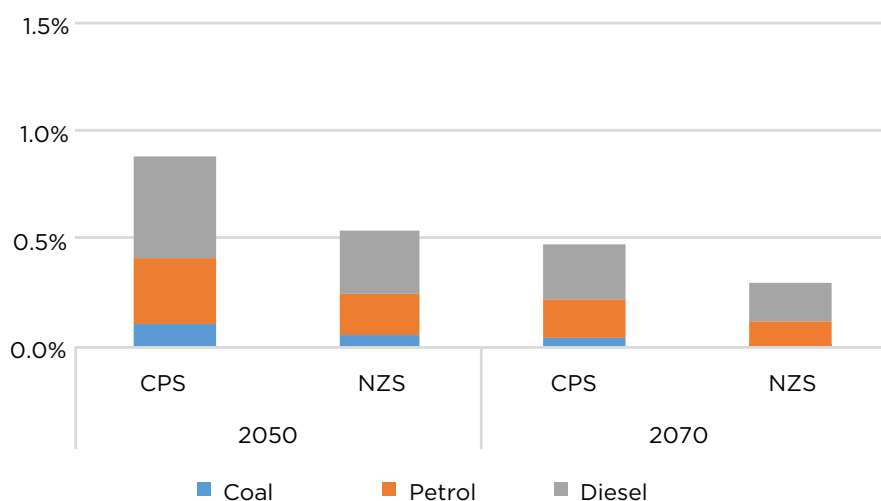
Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

Figure 4.4: Breakdown of projected fossil-fuel revenue (as % share of GDP) by fuel in Current Policy Scenario and Net Zero Scenario

4.2 Impact of the Net Zero Transition on Imports: Fuels and Critical Minerals

4.2.1 Context: India's Present Fuel Imports

India's total primary energy consumption was approximately 850 million tons of oil equivalent (Mtoe), of which around 51% was met through imports in FY 2022-23 (Ministry of Statistics and Program Implementation, 2024).

Oil imports: In FY-2022-23, India met 87% of its crude oil demand through imports (Ministry of Statistics and Program Implementation, 2024). In the past five years, the average oil import

bill has been about INR 4.7 lakh crore (PPAC, Monthly Snapshot of Oil and Gas imports, 2024) (2011 prices; Figure 4.5). Crude oil imports add significantly to national imports, contributing on average 23% of the total import bill during this period. (MoPNG, 2024)(Figure 4.6).
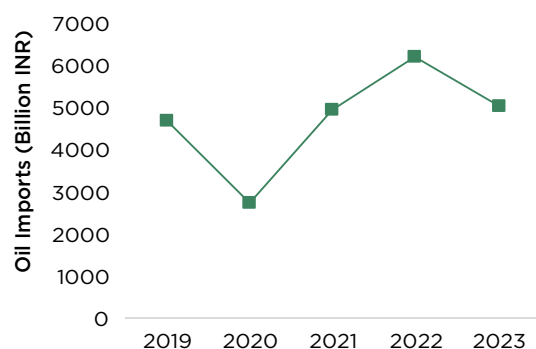
Figure 4.5: Oil Import Bill (billion INR, 2011-12 prices)
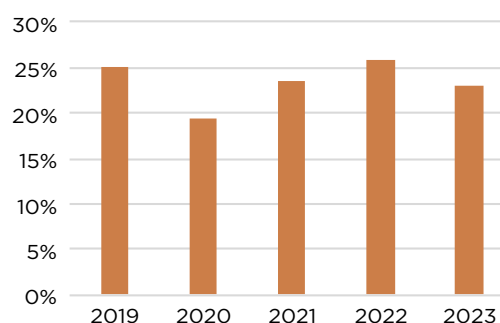
Figure 4.6: Oil Imports as a share of total imports (in value terms)

Natural gas imports: In FY 2022-23, natural gas consumption was 51.83 billion cubic meters (BCM), of which 44% was met through imports (MoPNG, 2024). India's gas import bill has been relatively constant over the past five years, averaging INR 634 billion (2011-12 prices) (PPAC, Ready Reckoner, 2024). In value terms, the gas import bill is only about one-tenth of the oil import bill.

Coal imports: Coal imports averaged INR ₹458 billion (2011-12 prices) between 2019–20 and 2022–23, rising sharply in the last two years (Ministry of Coal, 2025). In value terms, India's coal import bill is roughly equal to the gas import bill (PPAC, Ready Reckoner, 2024). Coal imports are increasing over time, driven by rising energy demand and industrial demand for coking coal. Given the high ash content of domestic coal, coking coal demand must be met through imports (Gupte, 2023). An Inter-Ministerial Committee (IMC) has been constituted in the Ministry of Coal to support coal-import substitution (PIB, 2024)

Nuclear Fuels: Nuclear power generation remains limited, with 8.1 GW operating and 7.3 GW under construction (NITI Aayog, 2024). Nuclear currently generates 48 TWh per year, just over 3% of total electricity generation and 12% of non-fossil sources (NITI Aayog, 2024), amid volatile uranium imports. The recent Government of India announcement of a 100 GW nuclear capacity target by 2047, to be achieved through a mix of conventional reactors and small modular reactors, signals renewed ambition (Press Information Bureau, 2025). A key challenge to this expansion is India's limited uranium reserves, which necessitate heavy reliance on imports. Given the scale of nuclear ambitions, accounting for uranium in the overall fuel import bill is crucial, as reflected in this analysis.

With India's aspiration of robust growth toward *Viksit Bharat*, energy requirements are expected to keep increasing, exerting pressure on imports unless reliance on domestic energy sources increases.

4.2.2   Comparison of fuel imports in the Current Policy Scenario and Net Zero Scenario

The Net Zero transition could generate significant savings in the national fuel import bill, considering declining trend for imports of fossil fuels (coal, oil, and gas). The Net Zero Scenario's fuel import bill is projected to be lower by 38% in 2050 and 47% in 2070 compared to the Current Policy Scenario. This translates to an annual saving of INR 6.6 trillion in 2050 and INR 8.8 trillion in 2070 comparted to the Current Policy Scenario.

As a share of GDP, the total fuel import bill falls steadily in both scenarios. From around 4% of GDP at present, the total fuel import bill falls to about 0.7% of GDP by 2070 in the Current Policy Scenario and to 0.2% of GDP in the Net Zero Scenario (Figure 4.7). Looking at the breakdown of the fuel import bill by fuel (Figure 4.8), oil accounts for the largest share. Majority of savings in fuel import bills in the Net Zero transition are a result of reduction in oil imports, followed by gas and then coal. The increase in the uranium import bill associated with nuclear expansion under the Net Zero transition is negligible compared with the savings on fossil fuel imports.
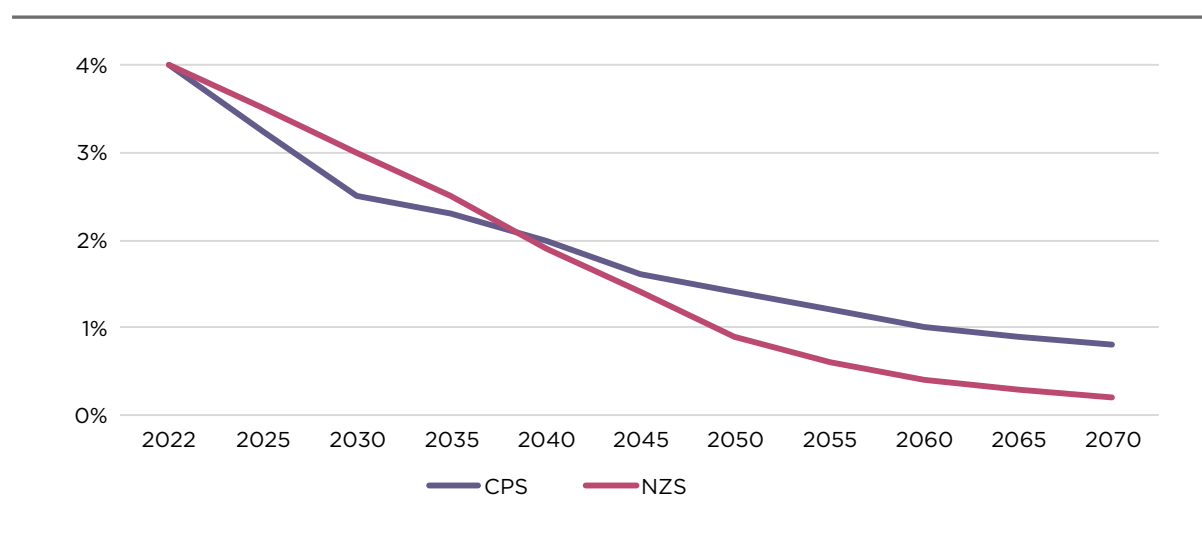
Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

Figure 4.7: Fuel import bill as a % share of GDP
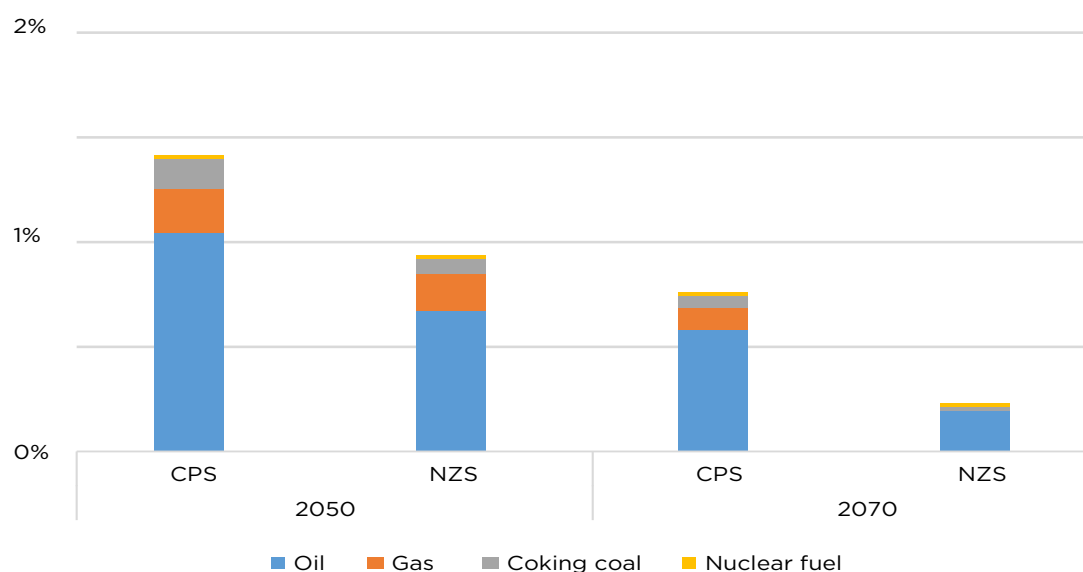
Note: *CPS = Current Policy Scenario; NZS = Net Zero Scenario*

Figure 4.8: Breakdown of fuel import bill by fuel as a % share of GDP

4.2.3   India's Dependence on the Import of Critical Minerals and Components for Energy-Transition Technologies

India's clean energy shift hinges on critical minerals like lithium, cobalt, nickel, rare earths, and copper, which are vital for EV batteries, solar PVs, and storage. Currently, India imports over 90% of copper and is fully dependent on imports for lithium, cobalt, and nickel (PIB, 2023), posing supply risks. China refines over 60% of the world's lithium and 85% of rare earth elements, while the Democratic Republic of Congo (DRC) supplies over 70% of global cobalt (Investing News Network, 2025). The Net Zero transition could reduce fossil-fuel imports but increase dependence on critical mineral imports. The Ministry of Mines has identified key minerals and is pursuing domestic exploration, global partnerships, and recycling (Ministry of Mines, 2023).

Domestic solar PV manufacturing currently meets just 8% of national demand, with 92% imported, mostly from China, requiring investment in polysilicon refining, wafer production and module assembly (IRENA, 2017). India's domestic battery-storage manufacturing is also in its early stages. As India's production-linked incentive (PLI) scheme achieves its targeted capacity of 55 GWh of domestic battery manufacturing by 2030, it would comprise about 6% of the overall projected battery storage requirement (Warrior et al., 2023) necessitating rapid scale-up in cell production, raw material processing, and recycling.

4.2.4 Comparison of the Critical-Minerals and Component Imports in the Current Policy Scenario and Net Zero Scenario

We estimate that the total import bill for solar PV and battery storage under the Net Zero Scenario is about INR 400 billion higher in 2050 and INR 1.2 trillion higher in 2070 compared with the Current Policy Scenario (in 2011-12 prices). Solar imports far outweigh battery-related imports despite EV-batteries accounting for the bulk of the overall battery requirement.

As India's economy grows, the import bill initially rises but later declines relative to GDP, as economic expansion outpaces the increase in mineral-related imports (Figure 4.9). As capacity additions and associated import bills stabilize for both technologies in later years, GDP growth attenuates the effect of import bills when expressed as a share of GDP. Here it is important to note that no price escalation has been assumed for minerals and their associated technologies. The import bill of critical minerals and cell technologies peaks as a share of GDP at 0.13% in 2030 under the Current Policy Scenario and 0.17% in 2035 under the Net Zero Scenario, before stabilizing in later years.
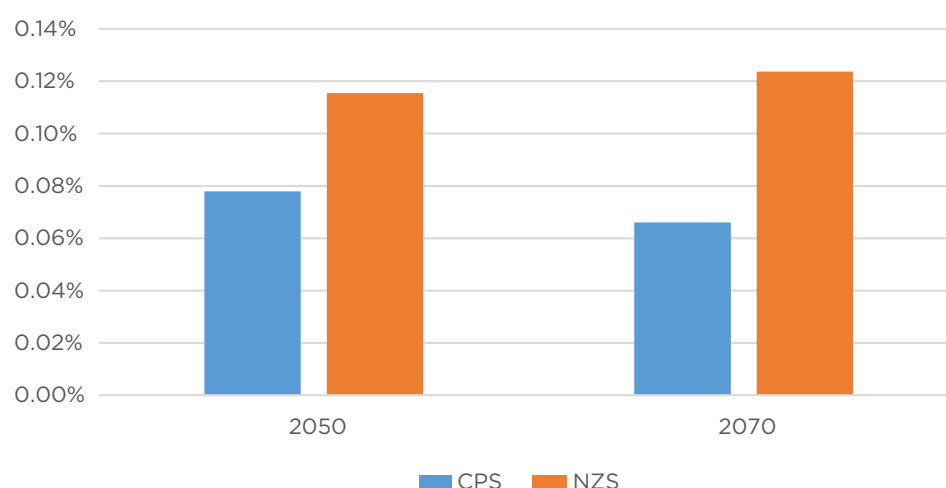
Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

Figure 4.9: Import bills of critical minerals and cell technologies as a % share of GDP

When the total import bill is divided into critical-mineral imports and finished-component imports, critical minerals account for about 2-3% of the total, over time and across both scenarios. Figure-4.10 presents a further breakdown by minerals. Copper and Silicon together constitute the overwhelming share of the import bill in any given year in both scenarios. The relatively small contribution of critical minerals compared with finished components in the import bill reflects the base-case assumption of domestic manufacturing shares of 8% for Solar PV and 6% for battery components that are kept constant.
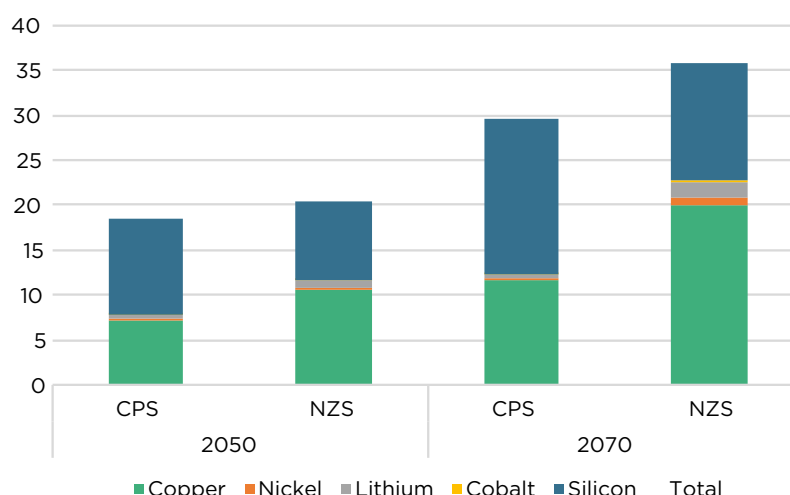
Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

Figure 4.10: Contribution of critical minerals to the import bill, by mineral in Million 2011-12 INR

Scenarios with alternative domestic-manufacturing assumptions: The analysis also tested higher domestic-manufacturing shares for solar PV (30% & 50% by 2070) and batteries (25% & 40% by 2070) against a base case of 8% and 6% (base scenario), respectively. Higher domestic manufacturing shifts imports from finished products to critical minerals, lowering the total import bills significantly for solar PV (because of small cost differences) with reductions of 28% by 2050 and 49% by 2070 compared to base scenario. The equivalent cost reduction is marginal for batteries. In addition to the savings in the import bill from increased domestic manufacturing, scaling domestic PV and battery manufacturing remain crucial for job creation and economic growth.

4.2.5 Implications for the Overall Import Bill (Fuels and Critical Minerals)

Net savings in the overall import bill occur under the Net Zero transition when all imports namely fuels, energy-transition technology components, and critical minerals are considered together. Transitioning to cleaner energy technologies requires additional expenses for imports of critical minerals, solar and battery cells, and nuclear fuel. However, the scale of this increase is modest relative to the sharp and sustained decline in fossil-fuel imports and is more than offset by falling imports of fossil fuels such as oil, gas, and coal, as shown in Figure 4.12. When all imports are considered, the Net Zero Scenario results in substantial savings in the import bill compared with the Current Policy Scenario. Figure 4.11 shows that savings appear as early as 2035, at about 0.07% of GDP, rising to about 0.5% of GDP by 2050-70.
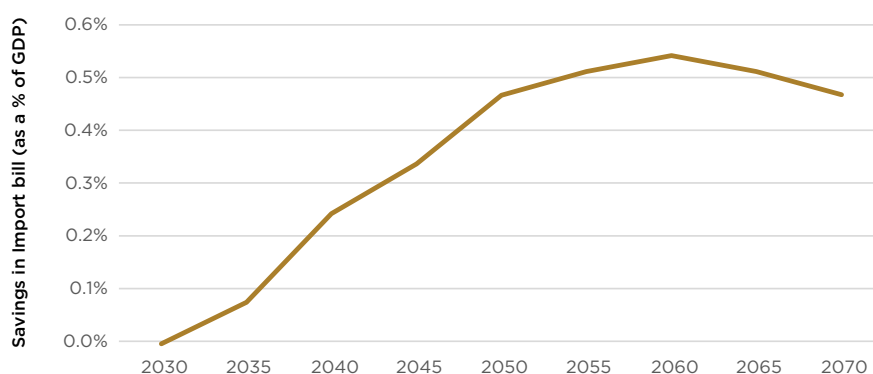
Figure 4.11: Savings in import bill in Net Zero Scenario compared to Current Policy Scenario as a % of GDP (Billion 2011-12 INR)
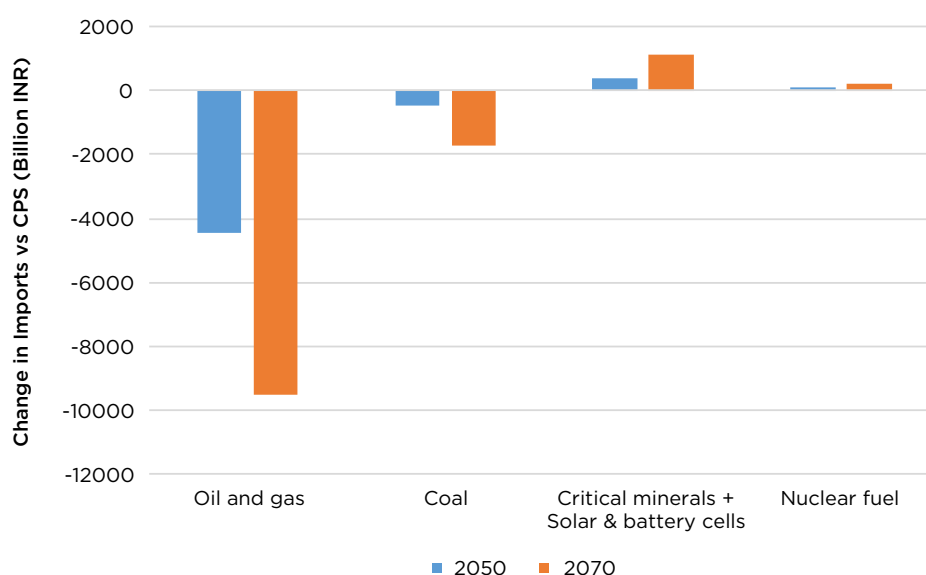
Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

Figure 4.12: Commodity-wise change in imports in Net Zero Scenario compared to Current Policy Scenario in years 2050 and 2070 (Billion 2011-12 INR)

Potential savings in the import bill are possible by enhancing domestic exploration of critical minerals and establishing early-stage recycling programs. Even in the absence of domestic availability of critical minerals, increasing domestic manufacturing can produce savings since the import of finished components is replaced with imports of critical minerals and other raw materials. Greater savings can be achieved through enhanced efforts for exploration of domestic critical-mineral reserves and the development of production capacity. Implementing recycling initiatives for degraded photovoltaic panels and battery cells can significantly reduce dependence on imported raw materials. Recycling not only conserves resources but also mitigates the environmental impacts of mining and processing new materials.

5

INDIA'S NET ZERO PATHWAY: CHALLENGES AND SUGGESTIONS

India's Net Zero Pathway: Challenges and Suggestions

5

India's Net Zero transition will be underpinned by technology & capital, a purposeful development model, reforming fiscal and regulatory systems, and strengthening institutions that deliver change. This chapter distills the key challenges ahead and outlines a reform agenda to turn them into opportunities. If executed as an integrated package, these measures can anchor macroeconomic stability, accelerate emissions reductions, and position India as a global exemplar of sustainable development.

India's successful transition to Net Zero will hinge both on expanding clean technologies and mobilising capital, and on reorienting its broader development model, strengthening institutions, and undertaking deep structural reforms. If pursued as a coherent package, these reforms can convert Net Zero from a constraint into a strategic growth opportunity—enabling India to sustain high employment, enhance export competitiveness, and demonstrate an alternative model of sustainable prosperity. The following chapter is organised into four broad themes:

(1) Building a resilient, low-carbon and globally competitive economy

(2) Mobilising capital for the Net Zero transition

(3) Reforming regulatory and fiscal systems for green growth, and

(4) Advancing green jobs, skills, and innovation.

These themes collectively provide a comprehensive roadmap for enabling India's long-term transition.

5.1 Theme-1: Building a Resilient, Low-Carbon and Globally Competitive Economy

Building a resilient, low-carbon and globally competitive economy is central to sustaining India's growth in an era of rising climate risks and trade protectionist measures. As living standards rise and resource pressures intensify, the development model must increasingly prioritise reforms, efficiency and sustainability. This theme delves into aspects of promoting climate-friendly lifestyles and how India can realign its trade to emerge stronger in a highly volatile global economy.

1. Redefine Development: Leverage India's Civilisational Wisdom and Mission LiFE as Blueprints for Sustainable Growth

The globally promoted development paradigm remains heavily skewed toward resource-intensive growth, often prioritising consumption over sustainability. Across the world, development is increasingly measured through a narrow set of urban and economic indicators, reinforcing a model that equates prosperity with material abundance rather than ecological balance, cultural rootedness, or long-term resilience. If India were to follow this trajectory uncritically, it risks locking itself into energy- and carbon-intensive patterns of growth at odds with its climate commitments and social priorities.

Conventional Development Indicators:

▸ **Per capita Income (USD):** Often treated as the single most important measure of development. US: >85,000; OECD avg: > 45,000; India: ~2700 (2024) (IMF 2024)

▸ **GDP per worker:** Commonly used to compare economic efficiency (USD/worker)

   US: ~153,000; World average: ~48,000; China: ~45,000; India: ~24,000 (Our Word in Data, 2024)

▸ **Per capita electricity generation (kWh):**

   World avg: ~3,780 kWh; High-income countries: >8,900 kWh; India: ~1,400 kWh (Our World in Data, 2024)

▸ **Cooling demand:** Global building stock is moving toward 24/7 HVAC dependence—almost half of global building energy use is now for cooling and heating (IRENA, 2023). AC penetration in developed economies >80%; India: 10% (IEA, 2018)

▸ **Per capita floor area:** Often viewed as a proxy for prosperity. OECD metropolitan cities: > 40–450 sqm (Banquet, A. et al. 2022); India: 12 sqm (NITI Aayog, 2024)

▸ **Car ownership (per 1,000 people):** US: >850; Australia, Canada, Italy: >700; India: ~30, (but growing fast, linked with urban sprawl and energy use) (OICA, 2024)

▸ **Average household size:** OECD average: ~2.4; India: ~4.5. Evidence suggests larger households consume lower per-capita energy and material.

These indicators provide useful benchmarks, but they are not the full story. The aim is not to discard them, but to complement them with measures that capture the quality, sustainability,

efficiency, and resilience of growth. For instance, material wealth alone is a poor predictor of well-being: Japan, with a GDP per capita less than two-thirds of the US, has a life expectancy nearly six years higher (84.8 years vs. 78.9 years)(WHO 2023). Costa Rica, whose GDP per capita is barely one-fifth that of the US, achieves comparable life expectancy (80.3 years) through preventive healthcare, community cohesion, and active lifestyles. These cases highlight that prosperity and well-being can be achieved without replicating high-consumption pathways, opening space for India to advance an alternative development approach by drawing on its civilisational wisdom and climate-conscious practices.

- Traditional Indian homes, built with local materials, natural ventilation, and passive cooling, consume far less energy than the globally favoured glass-and-steel structures reliant on artificial climate control.

- Multi-generational households, a longstanding feature of Indian living, can significantly reduce per capita energy and material demand, especially in dense urban settings.

- According to the Pew Research Center (2021), about 39% of Indian adults identify as vegetarian, far higher than in most Western countries, limiting meat consumption for cultural, religious, or health reasons. These diets are both climate-friendly and supportive of health outcomes.

Key Suggestions:

i. **Energy efficiency has a central role in meeting our developmental needs:** The study estimates that India's cooling demand will increase by 3 times as the living standards of people improve. However, with widespread adoption of high-efficiency appliances and building designs rooted in passive cooling, energy demand can be reduced by 1/3rd. Similar measures across various end-use sectors will result in India's energy intensity of GDP reducing from 0.22 MJ per INR in 2025 to 0.09 by 2047 and 0.05 by 2070, decoupling growth from energy consumption while maintaining quality of life. Therefore, the developmental norms need to shift from energy-intensive practices to promotion of localized resources and climate-resilient designs.

ii. **Mission LiFE and Behavioural Shifts:** The Prime Minister's Mission LiFE (Lifestyle for Environment) provides a crucial platform to mainstream sustainable behaviours. Small but systemic shifts, like setting ACs at 24–25°C, discouraging single-use plastics in favour of reusable fabric bags, harvesting rainwater, promoting public transport systems, promoting multi-generational households, promoting access to clean cooking fuels (reducing the use of traditional biomass) and embracing natural farming, can reshape household consumption and resource use at scale.

iii. **Promoting circularity for sustainable growth:** Operationalizing the circular economy paradigm through interventions such as reduced demand for virgin steel and cement through greater material circularity and recycling of critical minerals will be crucial.

2. Adapt to Geopolitical Fragmentation by Diversifying Exports and Anchoring Low-Carbon Competitiveness

Global trade is entering an era of fragmentation. The post-pandemic world has seen a marked shift from hyper-globalisation towards "geoeconomic fragmentation" (IMF 2023). Rising resource nationalism and supply chain insecurity are reshaping trade strategies. "Just-in-time" efficiency is giving way to "just-in-case" resilience, as countries prioritise supply security over cost optimisation. Analysis of the recent trade-volume patterns suggests that "China+1" has not yet delivered any desired shift with China's export volumes continuing to grow since 2020, while world exports excluding China have remained stagnant. Moreover, much of global import growth has been driven by the United States rather than a widespread reallocation of demand to alternative export hubs. This implies that any meaningful decoupling from China would likely require stronger protectionist or quasi-protectionist measures such as tariffs, local-content requirements, subsidies, and tighter screening which can raise input costs and reduce efficiency, shifting resilience into a higher-cost equilibrium.

This challenge is compounded by the fact that the development context that enabled East Asia's rapid catch-up and industrial upgrading in the 20th century was materially different. The geopolitical backdrop then was more supportive (often described as a "trade–security nexus/umbrella" anchored in U.S. alliances) (Min Gyo Koo et al., 2011), there was no energy-transition constraint, demographics were more favourable, and industrial policy was tightly focused on productivity and performance backed by sustained investment in primary education and vocational training.

In contrast, India is attempting to develop under constraints that China and the rest of East Asia did not face: a global model of capital-intensive growth that sits at odds with India's labour endowment, an energy-transition "double-whammy" for capital-led manufacturing ambitions, and rising AI/robotics pressures that threaten services jobs first and physical labour later together posing risks to social stability if jobs and productivity do not keep pace. For India, the IMF estimates potential GDP losses of 1.5–3.3% if fragmentation intensifies, making it imperative to combine resilience measures such as domestic manufacturing capacity, strategic stockpiling with continued engagement in global value chains (GVCs) and trade agreements.

Prepare for Non-Tariff Barriers and Emerging Carbon Standards: While average global tariffs have declined, recent policy shifts in key markets such as the United States suggest tariff measures could once again play a prominent role in trade tensions. At the same time, non-tariff

measures (NTMs) have surged. The UNCTAD–UNESCAP 2024 database shows that 2,366 NTMs, 2.6% of all such measures, are climate-related, concentrated in CO_2-intensive sectors such as steel, aluminum, cement, and electricity.

The EU's Carbon Border Adjustment Mechanism (CBAM) and Deforestation Regulation (EUDR) are prominent examples. Together, they could affect USD 9.5 billion of Indian exports to the EU, about 12.9% of India's exports to the bloc (Economic Survey 2024-25). Although positioned as green policy, such measures also act as protective trade barriers. At the same time, they reward exporters, European or otherwise, who can demonstrate the lowest carbon footprint. With little steel production capacity remaining in Europe, the most competitive non-European producers will be those that can decarbonise rapidly and credibly.

Since FY 2014–15, India's merchandise trade has grown at a 4.3% CAGR (Ministry of Commerce and Industry), but its share of world exports remains just 1.8%, compared to China's 14.6% (WTO, 2025). China's success was built on high-volume specialisation in "network products" such as electronics, an area where India has potential. It will be critical to review the current export potential, accelerate industrial decarbonisation and strengthen compliance systems to expand India's share in global trade.

Key Suggestions:

In a fragmented trading system, market access is increasingly shaped by standards, subsidies, investment screening, and climate-linked compliance not tariffs alone. Export diversification and low-carbon competitiveness therefore need to be pursued as a single strategy: diversifying into products and services less exposed to carbon and compliance shocks, while building credible, verifiable low-carbon production to reduce exposure to instruments such as CBAM and to compete in green procurement markets. In parallel, FDI and supply chains are being re-routed by geopolitical alignment ("friend-shoring"), so trade agreements must increasingly function as investment corridors supporting technology transfer, scale, and predictable rules rather than relying on tariff relief alone.

    i.   **Diversify Exports and Build Monitoring Systems for Global Standards:** Climate action will reshape India's trade profile**.** Modeling from the current study indicates that under a Net Zero global scenario, India's exports could be lower than the exports under the Current Policy Scenario by 4.75% by 2050 and 2.2% by 2070 in a Net Zero domestic-financing pathway, driven largely by falling demand for carbon-intensive goods. Imports would also dip modestly, although foreign-financed Net Zero pathways could see higher imports. This reinforces the urgency of diversifying into low-carbon export sectors and investing in certification and monitoring infrastructure to comply with emerging global standards.

ii. **Strengthening Domestic Manufacturing to Leverage Shifting Global Manufacturing Patterns and GVC Realignments**: A focused industrial strategy under the National Manufacturing Mission can raise manufacturing's GDP share and GVC integration. Priority sectors include electronics & semiconductors; apparel & textiles; automobiles & components; toys, capital goods, etc. Low-carbon production could become a significant comparative advantage in each of these sectors, not only where price incentives like CBAM are in play, but also in meeting the evolving sustainability demands of global customers.

Participation in these value chains will also require India to import parts and equipment efficiently, implying the need to lower selected import barriers and to attract greater foreign direct investment (FDI) to bring in technology, scale, and market access. Recent Economic Survey 2024-25 data points to early trends:

- Apple assembled 14% of its global iPhones in India in FY24.

- Foxconn is building component plants in Karnataka and Tamil Nadu.

- India attracted interest from 28 of 130 global firms seeking supply chain diversification.

iii. **Leverage FTAs to Secure Market Access and Align Regulations:** Strategic free trade agreements (FTAs) are critical to India's future market access. FTAs can unlock market opportunities, but with Non-Tariff measures proliferating, their success will depend on India's ability to meet regulatory, sustainability, and carbon standards. Future agreements should move beyond tariff cuts to include cooperation on certification systems, carbon measurement protocols, and digital trade rules. Aligning domestic regulations with those of key partners, will be critical to sustaining competitiveness in a fragmented trade environment.

Prioritise FTA sequencing using a "demand + capital" lens: partners that combine (a) large shares of global manufactured imports (as end-markets) and (b) large shares of global outward FDI (as sources of capital, technology, and production networks) should be treated as first-order priorities. This points to the EU and the United States at the top of the list, alongside major outward investors such as Japan, the United Kingdom, and the Republic of Korea.

For these partners, FTAs should be structured as deep economic partnerships not just tariff schedules covering investment facilitation, supply-chain cooperation, workable rules of origin, and regulatory alignment to reduce behind-the-border friction and unlock sustained GVC participation.

Finally, embed low-carbon competitiveness into these priority FTAs through cooperation on Monitoring, Reporting, and Verification, carbon accounting,

interoperability of sustainability certifications, and digital rules that enable traceability and reporting at scale so exporters face lower, more predictable compliance costs as standards tighten.

5.2 Theme-2: Mobilising Capital for the Net Zero Transition

Mobilising capital at scale is central to India's Net Zero transition and its broader development vision for 2047. Investment needs far exceed current flows, making it essential to expand financing for infrastructure, industry, and emerging low-carbon technologies while safeguarding macroeconomic stability. This theme focuses on how a balanced mix of domestic savings, patient foreign capital, and sustained public investment can crowd in private finance, lower the cost of capital, and ensure that the Net Zero transition strengthens, rather than constrains, long-term growth.

1. Finance the Green Transition with a Balanced Mix of Domestic and Foreign Capital

As per the Scenarios towards Viksit Bharat and Net Zero: Financing Needs (Vol. 9) report, investment requirements even in the Current Policy Scenario (CPS) are estimated at ~ USD 14.7 trillion until 2070, translating to roughly USD 300 billion per year, compared to current inflows (2024) of only about USD 135 billion (of which ~USD 87 billion corresponds to clean sources (IEA 2025)). This means that mobilising significantly more capital toward infrastructure and industrial capacity will be essential for achieving the 2047 development vision, regardless of whether Net Zero is pursued. Further, pursuing Net Zero will significantly raise the investment demand to USD ~22.7 trillion (USD 500 billion per year).

Avoid Over-Reliance on Domestic Financing: Model results indicate that Net Zero pathways relying solely on domestic financing (NZdom, NZdom+, NZdomsub) tend to exert a negative impact on investment relative to the Current Policy Scenario, most notably between 2040 and 2050, when investment is lower than the Current Policy Scenario by 3–5%. The mechanism is straightforward: higher domestic borrowing lifts real interest rates, making capital more expensive for both public and private projects. This aligns with IMF findings that heavy reliance on domestic debt in emerging markets can crowd out private investment by raising financing costs (IMF 2024).

In these scenarios, higher interest rates encourage savings over consumption, reducing household spending. While productive-investment variants (NZdom+) raise household incomes enough to offset this effect, the domestic-financing cases see small but significant net consumption declines.

Leverage External Capital to Ease Rate Pressures: External capital can ease financing pressures and sustain growth. In contrast to domestic-only pathways, externally financed scenarios (NZfor, NZfor+) tend to increase investment relative to Current Policy Scenario. By lowering interest rate pressures, foreign capital allows more projects to be financed on competitive terms, supporting the view that blended finance is essential to scaling climate investments in emerging markets and developing economies (World Bank 2023).

However, the external-financing scenarios carry a higher current account deficit (CAD), around 3–3.5% of GDP compared to 2–2.5% in domestic-only cases. A CAD in this range should be sustainable, especially if India maintains high growth rates near 7-8% per year, as global patterns show several fast-growing economies financing even higher CADs without instability. As the IMF notes, "a country can run as large a CAD as the rest of the world is willing to finance" But in a world where developed economies are also competing for green capital, India must actively court this investment rather than assume it will arrive.

Key Suggestions:

i. **Crowd-In Patient Foreign Capital:** Strengthen India's ability to attract long-term foreign capital by expanding technology partnerships, demonstrating a long-term policy vision, and building a pipeline of bankable projects. Scale co-investment platforms in GIFT City to attract foreign institutional investors like sovereign wealth funds, global pensions funds, etc.

ii. **Broaden Domestic financial savings:**

    a. Deepen the corporate bond market by lowering issuance costs, enabling bank refinancing through bonds, and broadening the investor base to include PFs, Insurers, retail investors, supported by risk guarantees, improved financial literacy, and more diverse savings products. Unlock domestic insurance and pension funds investment into investment-grade green bonds; deepen the corporate bond market beyond AA/AAA issuers via partial credit guarantees (SEBI, 2024).

    b. Leverage recent advances in digital banking and offer households attractive, low-risk savings products transparently linked to infrastructure and green investment.

iii. **Lower Cost of Capital via De-Risking:** Establish clear and predictable policies, strengthen payment-security mechanisms, and apply blended finance for early-stage technologies.

iv. **Shift to Targeted Subsidies:** Replace universal electricity subsidies with direct benefit transfers (DBTs) for vulnerable households. This approach preserves fiscal

space, maintains consumption resilience and strengthens the financial viability of DISCOM sector.

v. **Develop a Pipeline of Bankable, De-Risked Projects:** India needs a pipeline of bankable, de-risked projects with transparent revenue models and predictable policy environments. Lessons can be drawn from the National Monetisation Pipeline (NMP) and mega-project execution in renewable parks, highways, and DFC corridors, demonstrating that large-scale, well-structured projects can mobilise significant private capital.

A balanced financing mix, anchored in domestic savings but amplified by long-term patient foreign capital, can maintain investment momentum, keep trade competitive, and ensure the Net Zero transition strengthens rather than strains macroeconomic stability.

2. Continue and Intensify Infrastructure Investments for a Net Zero Future

India has already scaled up infrastructure investments, with visible gains in access to services and productivity. These efforts must be sustained and intensified to meet the country's development objectives for 2047. Rapid urban population growth, rising economic output, and surging energy demand require large investments in core infrastructure systems. These needs will be further magnified by climate change impacts and the necessity of building resilience into new infrastructure.

Key Suggestions:

i. **Frontload Investment to Enable the Net Zero Transition**: As per the Scenarios towards Viksit Bharat and Net Zero: Financing Needs (Vol. 9) report,, over the course of India's Net Zero transition, investment requirements rise sharply, reflecting both the scale and urgency of low carbon transition. In the near to medium term (2026-2050), Current Policy Scenario calls for USD 5.8 trillion in investments, while the Net Zero pathway demands USD 8.05 trillion, creating an incremental gap of USD 2.25 trillion–about USD 90 billion annually, equivalent to about 2-2.5% of India's GDP in 2025. These early years are the most challenging, as investments must be front-loaded in renewable capacity, grid expansion, and industrial decarbonisation technologies.

Over the long-term horizon (2050–2070), Current Policy Scenario investments total USD 8.86 trillion, compared with USD 14.69 trillion under Net Zero Scenario. The incremental gap widens to USD 5.83 trillion, with annual needs climbing to around USD 290 billion during 2050-70. Although the absolute financing requirement peaks in this period, its share of GDP becomes more manageable as India's economy

expands, the near term remains the harder test, given the urgency of accelerating clean energy and enabling infrastructure. Although the costs are higher in the near term, they are offset by reduced operational costs and energy imports. These investments deliver high returns and accelerate technological upgradation and productivity growth, explaining why the transition has a small impact on GDP and income growth in macroeconomic simulations.

ii. **Use Public Investment to Unlock Private Capital**: Public sector investments, particularly in basic infrastructure and network systems are critical especially in areas such as electricity transmission and distribution, which enable the integration of privately-financed renewable energy. Similarly, public support for EV charging stations, can catalyse larger flows of private investment in e-mobility, including e-buses.

iii. **Prioritize Key Infrastructure Areas for Green Growth:** To maximize productivity gains, leverage private investments, and support rapid growth consistent with a Net Zero pathway, India should focus on the following areas:

- The electricity grid;
- Urban infrastructure, such as bus and bike lanes;
- Charging infrastructure for e-mobility;
- Multimodal transport and logistics systems, including electrified railways and waterways;
- Efficient irrigation systems and water storage;
- Energy efficiency and electrification end-use sectors;
- Sanitation and wastewater treatment;
- Solid waste management.

5.3 Theme-3: Reforming regulatory and fiscal systems for green growth

As India's economy grows and evolves, its institutional, regulatory and fiscal systems need to keep pace so they can better support new industries and promote low-carbon growth. This theme examines how India can strengthen institutions, streamline regulatory frameworks, and reorient fiscal tools to support a greener, efficient and competitive economy.

1. Strengthening Institutions to Deliver the Green Transition

India's ability to deliver on its energy transition and broader growth ambitions is not constrained only by capital or technology, it is equally limited by the capacity, mandate, and incentives

of the institutions tasked with implementation. Be it agriculture or manufacturing, buildings or power or transport, enforcement, fragmented mandates, and fiscal stress in nodal agencies risk delaying or distorting outcomes. Strengthening and, where necessary, restructuring these institutions, including through private participation, can unlock efficiency, reduce fiscal leakages, and attract investment at scale.

In the power sector, state-owned DISCOMs remain the weakest institutional link in India's energy system, with chronic AT&C losses (~15–20%), delayed subsidy payments, and tariff freezes. The Revamped Distribution Sector Scheme (RDSS) ties central funding to loss reduction and cost recovery targets, but enforcement has been inconsistent. Similarly in the transport sector, State Road Transport Undertakings (SRTUs) and urban bus agencies remain fiscally stressed, with outdated fleet procurement models that focus on vehicle ownership rather than contracting services. As a central institution in India's green transition, the role of the Bureau of Energy Efficiency needs to be strengthened as it rolls out Carbon Credit Trading Scheme (CCTS) and implements Energy Conservation and Sustainable Building Code (ECSBC) and Energy Conservation-New Indian Way for Affordable & Sustainable Homes (ECO NIWAAS) norms.

Key Suggestions:

i. **Align Agriculture Energy Support with Climate Outcomes:** The PM-KUSUM scheme's solar irrigation component may be paired with groundwater metering and buyback of surplus solar power.

ii. **Strengthen the role of Bureau of Energy Efficiency:** Multi-year cap-and-trade roadmaps for CCTS, harmonised monitoring, reporting and verification protocols aligned with global standards, and predictable compliance and penalty frameworks will be essential for improving CCTS's operational effectiveness. The same institutional strengthening can support more consistent, on-ground implementation of Energy Conservation and Sustainable Building Code (ECSBC) and Energy Conservation-New Indian Way for Affordable & Sustainable Homes (ECO NIWAAS) norms, creating an integrated regulatory architecture for industrial and building-sector decarbonisation.

iii. **Fix DISCOM Finances Through Tariff Reform and Private Participation:**

a. Privatisation, full or partial, whether through full sale (as in Delhi's BSES model) or input-based franchisees, has shown measurable improvements in collection efficiency and service quality. The Ministry of Power's evaluations suggest AT&C losses can fall by 30–50% within three years of private management.

b. Tariff rationalization is equally urgent. Many states maintain very high cross-subsidies, with industrial/commercial tariffs over 150% of cost and agriculture/residential tariffs at 50% or less. The *National Tariff Policy* (2016) recommends reducing cross-subsidies to within ±20% of average cost of supply, but state regulators have been slow to act.

iv. **Shift from Asset Procurement to Service-Based Contracts in Transport**: Under PM-eBus Sewa and FAME-II, agencies are pivoting to gross-cost contracts with standardised payment-security mechanisms, aggregated state-level procurement, and integrated depot/charging infrastructure. Institutionalising this service-based approach can reduce operating costs, improve utilisation, and accelerate deployment of clean public transport.

2. Overhaul Regulatory Systems to Accelerate the Green Transition

IMF Article IV Staff Report (2024) highlights that state-level clearance delays and inconsistent environmental permissions remain barriers to clean tech adoption. It also highlights that if India narrowed its distance to the EM frontier[15] by 25% in areas such as credit market, it could unlock a ~5% rise in private investment. Embedding these improvements into building, labour, and compliance reforms will not only advance India's green transition, but also structurally elevate investor confidence and growth potential.

The Energy Conservation Building Code (ECBC) and Eco-Niwas Samhita (ENS) provide a national framework for energy-efficient construction, but state adoption and municipal enforcement remain patchy. The Ministry of Housing and Urban Affairs' Model Building Bye-Laws (2016) and the Bureau of Indian Standards' codes are often diluted at the city level, with excessive setbacks, mandatory parking minima, and outdated FAR norms locking in high lifetime energy demand.

Key Suggestions:

i. **Enforce Energy Codes and Modernise Municipal Bylaws**: Linking budgetary allocations to verified ECSBC/ENS enforcement rates, and streamlining digital building approvals, can make energy-efficient construction the default. Harmonise state building codes with the Model Building Bye-Laws (MoHUA, 2016) and the National Building Code (BIS) to optimise setbacks, ground coverage, floor area ratio (FAR), and parking requirements. Permit higher FAR and mixed-use zoning along transit corridors to reduce commuting distances and transport energy demand.

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15 Distance to the frontier is defined as the difference in values between the frontier (best performer) and India.

ii. **Promote land-neutral RE solutions:** Agrivoltaics (APV) present a promising pathway, combining agricultural production as the primary use with electricity generation as the secondary. This model reduces land-use conflict while allowing efficient water use, since water withdrawn for panel cleaning can be reused for irrigation. Similarly, floating solar and decentralized solar can reduce the demand for land.

Further, India's extensive stock of degraded lands offers an underutilised opportunity for clean energy. These lands have limited agricultural value but can host solar and wind projects with relatively low social cost. Additionally, repurposing the 2,500 km² of land already mined for coal and lignite (Kiesecker et al., 2024) would serve dual goals: advancing decarbonisation while supporting a just transition in mining-dependent regions by creating new jobs and infrastructure.

iii. **Streamline Approvals through the National Single Window System:** Expand coverage to construction, power, and environment clearances, integrate digitally with state pollution control boards (SPCBs) and urban local bodies (ULBs) through APIs; and publish state-wise median and 95th-percentile clearance timelines.

iv. **Streamline Dispute Resolution and Compliance**

a. **Fast-Track Dispute Resolution**: Extend commercial court and mediation fast tracks to EPC and O&M disputes in clean energy and manufacturing; align with Insolvency and Bankruptcy Code (IBC) timelines to reduce investor risk.

b. **Simplify Compliance**: Consolidate overlapping returns and inspections into a single compliance calendar; expand self-certification and risk-based inspections under labour codes; adopt "no-surprise" inspection protocols.

v. **Ensure Regulatory Predictability**

a. **Sustain Corporate Reform Momentum:** Continue decriminalising minor company law offences and digitising RERA processes to reduce friction for smaller developers and green real estate projects.

b. **Build Investor Confidence:** Stable, transparent regulations will lower the cost of capital for climate-aligned infrastructure, making projects bankable for both domestic and foreign long-term investors. Introduce performance standards for key sectors, such as appliances, vehicles, and industrial equipment, five to ten years in advance to give businesses the certainty needed to invest in low-carbon technologies.

Many of these reforms, particularly those involving land-use norms, zoning, and outdated labour restrictions, will require substantial amendments to state-level regulations. Ensuring

close Centre–State coordination, model guidelines with fiscal incentives, and capacity support for state departments will be essential. Without alignment at the state level, the pace and impact of national green-transition reforms will remain constrained.

3.   Reform Subsidies and Fiscal Instruments

India's central government subsidies have risen over the past decade, rising from 1.3% of GDP in 2016–17 to 2% in 2022–23, with a pandemic peak of 3.6% in 2020–21 (Ministry of Finance, 2024). Over 90% of this spending is concentrated in food and fertiliser support.

In FY 2022, total public support for the energy sector, including subsidies, PSU capital expenditure, and PFI lending, was about INR 5 lakh crore (USD 68 billion). Subsidies alone accounted for INR 2.25 lakh crore, with fossil fuels receiving more than four times the support allocated to clean energy. While clean energy subsidies doubled for the first time since FY 2017—reaching INR 11,529 crore, largely driven by a 155% surge in solar PV installations, they remain far below what is required to meet climate targets (IISD, 2022).

RBI's *State Finances: A Study of Budgets 2023–24* (2022–23 RE) reveals sharp interstate variation in subsidy intensity, measured as a share of GSDP. While most large states allocate between 1% and 2% of GSDP to subsidies, several diverge sharply from this range:

- High-burden states: Chhattisgarh (5.8%), Tamil Nadu (5.0%), Madhya Pradesh (3.2%), and Punjab (3.0%), largely due to expansive power tariff support, public distribution schemes, and farm input subsidies. These elevated commitments reduce fiscal flexibility to fund infrastructure, green transition projects, and climate resilience measures.

- Mid-range states: Karnataka (1.4%), Gujarat (1.2%), Maharashtra (1.2%), Andhra Pradesh (1.1%), and West Bengal (1.1%), which combine targeted welfare with some fiscal space for development.

- Low-burden states/UTs: Kerala (0.2%), Assam (0.3%), and Union Territories such as Delhi, Goa, and Sikkim, maintain minimal subsidy outlays relative to GSDP, often reflecting narrower welfare portfolios or reliance on centrally funded schemes.

The contrast underscores a structural policy challenge: high subsidy-to-GSDP ratios risk crowding out productive public investment unless schemes are better targeted and efficiency is improved.

Key Suggestions:

i.   **Rationalize inefficient fossil subsidies:** Rationalise inefficient fossil fuel subsidies over the medium term while ensuring targeted support for vulnerable groups.

ii.   **Scale Direct Benefit Transfers (DBTs) to Improve Targeting**: A transition from

untargeted price subsidies to DBTs, leveraging India's JAM stack (Jan Dhan–Aadhaar–Mobile), offers a proven pathway to improve targeting, cut leakages, and preserve equity. Scale DBTs across electricity, fertiliser, and PDS, with Aadhaar-linked beneficiary lists and public dashboards on coverage and savings.

iii. **Broaden the Tax Base to Support Green Transition**: The *Economic Survey* highlights India's narrow personal and corporate tax base. A coordinated Centre-State approach, modeled on the GST Council, could review personal income tax thresholds, remove exemptions, and simplify compliance, thereby widening fiscal capacity without hurting small farmers.

iv. **Earmark savings for a "Green Fiscal Space"** to finance renewable integration, grid upgrades, and storage.

5.4   Theme-4: Advancing green jobs, skills, and innovation.

India's demographic window is open until the 2040s. UN DESA's *World Population Prospects* projects India's working-age population (15–59 years) will keep rising until about 2044, adding millions of job seekers each year. The challenge is structural: nearly 46% of workers are in agriculture, while organised manufacturing accounts for just 2.8% of total share (compared with China's 28.8%) (Economic Survey 2023-24). Expanding labour-intensive manufacturing and modern services, while raising agricultural productivity, is therefore critical. Without targeted measures, compared with the Current Policy Scenario, Net Zero could mean 16 million cumulative job losses by 2045. With the right policy package, it could deliver 32 million net job gains by 2070.

India's ability to convert its demographic strength into green jobs will depend not only on expanding labour-intensive sectors but also on building the technological capabilities that anchor future industries. The transition demands a workforce equipped for new energy systems and climate-resilient value chains, making innovation, skilling, and R&D central to sustaining competitiveness.

India invests just 0.65% of GDP on R&D, less than half the average of top economies according to World Bank's Development indicators. India's R&D expenditure is far below global innovation leaders such as South Korea (~5.2%), Japan (~3.4%), and the US (~3.5%).

R&D (as % of GDP)-2022
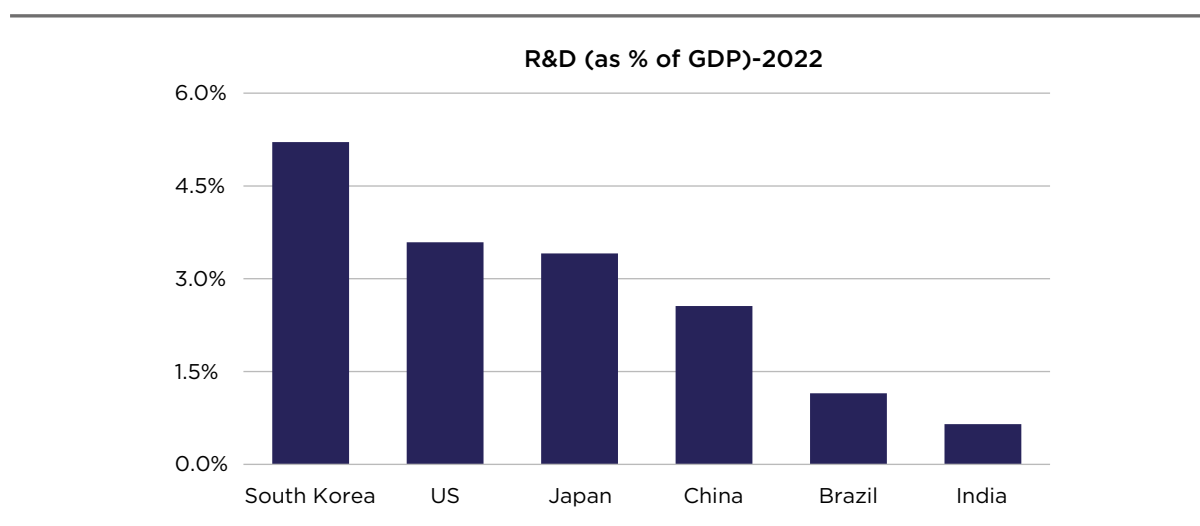
Figure 5.1: R&D as a % of GDP for various countries

Source: World Bank

Business sector contribution remains India's weak link. Private industry accounts for only 37% of total R&D spending, far below the 68% average among the world's top ten economies (UNESCO, 2023). Moreover, India's R&D effort is concentrated in a narrow band of sectors, namely pharmaceuticals, IT, transport, defence, and biotech, with limited investments in cleantech and industrial decarbonisation.

India has export strengths and manufacturing capabilities in products and technologies that will be in high demand during the global green transition (*International Monetary Fund's 2025 Article IV Report*). However, India has produced comparatively few environment-related patents (2,800 in the last decade, only 10 percent of what China or Germany have produced) and ISO 14001 certifications (3.7% of total global share).

1. Make "Jobs for the Green Transition" a National Mission

Net Zero job outcomes hinge on financing and complementary policies. Model estimates show the employment impact of Net Zero is moderate in aggregate, but varies sharply depending on financing and policy support:

▸ **Domestic-financed pathways (NZdom):** Employment is lower by nearly 1% compared to Current Policy Scenario; cumulative jobs less than Current Policy Scenario by ~16.1 million by 2045; real wages are lower than Current Policy Scenario by up to 6% due to reduced productivity and tighter capital.

▸ **Foreign-financed pathways with subsidies (NZforSub):** Employment is higher by 1.0–1.2% compared to Current Policy Scenario from 2045–2060; cumulative jobs more than Current Policy Scenario by ~32.45 million jobs by 2070; real wages are higher than Current Policy Scenario by about 3% as green investment boosts productivity.

➧ **Complementary measures:** particularly renewable energy subsidies, targeted reskilling, and flexible labour regulations, turn the transition into a net job creator rather than a drag.

These findings are consistent with international experience: across economies, the impact of climate mitigation policies on employment tends to be modest and either net positive or neutral, although distributional outcomes can be uneven (Godinho, 2022).

Sectoral shifts will be significant, and policies must enable workers to move where demand grows. Without supportive measures, Net Zero could slow the shift from agriculture to services. In NZdom scenario, services' employment share is lower than Current Policy Scenario by 0.35% while agriculture is higher than Current Policy Scenario by 0.60%. Even in the NZdomSub scenario, services jobs are lower than Current Policy Scenario by 0.40%, agriculture jobs are higher than Current Policy Scenario by 1.0%, signaling a need to smooth labour mobility. Manufacturing shows mixed results, gains in some scenarios, declines in others, depending on specialisation and technology uptake.

Coal mining, petroleum and coal products manufacturing jobs see significant decline in Net Zero Scenario compared to Current Policy Scenario by mid-century

In contrast, the non-fossil energy sector employement (especially nuclear and wind) is higher by 140–300% compared to Current Policy Scenario, adding about 400,000 jobs by 2050 and up to 2.5 million cumulatively by 2070 (NZdom).

Key Suggestions:

i. **Harnessing the Demographic Dividend through Green and Digital Skills:** India's young population (~65% under 35) presents a once-in-a-generation opportunity. Yet, only 51.25% of youth are currently deemed employable, up from 34% a decade ago (Economic Survey 2023-24). Skilling efforts must now scale and focus on green and digital sectors.

This push must be grounded in strong foundational capabilities, particularly literacy, numeracy, and problem-solving, so workers can adapt to evolving technologies rather than being locked into skills that may quickly become obsolete. To convert India's demographic edge into economic strength, skilling must align with market demand, particularly for green, digital, and gig economy jobs. A "Green & Digital Skills Stack" should include:

● National Skill Qualification Framework (NSQF)-aligned green skills catalogue consisting of solar O&M, battery assembly, efficient building retrofits etc.

● Dual training/apprenticeship models tied to MSME clusters.

- Micro-credentials enabling laddered progression from technician to supervisor to manager.

- Industry-co-designed curricula in ITIs/polytechnics with modern CNC/PLC/energy-efficiency labs.

ii. **Prepare the Workforce for AI and Automation:** AI is reshaping the global labour market, and India must prepare its workforce. Technology, especially artificial intelligence (AI), is becoming a strategic economic differentiator. While it can boost productivity, it also threatens labour displacement. According to Cazzinaga et al. 2024, 26% of Indian workers are in high AI-exposure occupations.

- 14% are in roles where AI is complementary (e.g. diagnostics, logistics), potentially raising productivity and wages.

- 12% are in high-risk jobs, vulnerable to displacement without reskilling.

India's relative insulation, 46% of the workforce still in agriculture, may delay immediate AI shocks, but this advantage will erode as structural transformation advances. Without preparing the labour force, AI could worsen inequality and constrain job creation for youth.

iii. **Integrate Gig Economy Roles into the Green Transition:**

- Expand social protection via full operationalisation of the Code on Social Security (2020).

- Ensure portability of benefits and aggregator contributions for gig and platform workers.

- Recognise gig roles like, EV drivers, solar installers, e-waste handlers, as part of India's green economy.

iv. **Fully Implement Labour Codes across States:** Operationalise new labour codes uniformly to improve hiring flexibility, promote formalisation, and attract industrial investment, especially in labour-intensive manufacturing.

However, it is important to recognise that these projections operate amid significant "unknown unknowns" around technological change, labour mobility, and global market shifts.

2. Launch a Bold Innovation Push for India's Net Zero Ambitions

Many critical green technologies are not yet commercially viable and public-private R&D must bridge the gap. According to the IEA's *Energy Technology Perspectives* (ETP 2023) and *Net Zero by 2050 Roadmap*, nearly 50% of the required emissions reductions by 2050 depend on technologies that are still at prototype or demonstration stage, especially in:

▸ Clean hydrogen and ammonia.

▸ Carbon Capture, Utilisation and Storage (CCUS).

▸ Battery chemistries for long-duration storage.

▸ Green steel and cement

▸ Advanced biofuels and sustainable aviation fuels (SAFs)

Without a robust R&D and demonstration pipeline, India risks being a technology follower, dependent on costly imports, and missing the strategic opportunity to lead in areas such as green hydrogen, battery manufacturing, or process innovations for low-carbon manufacturing.

Progress in near-commercial products and technologies is best promoted by creating niche markets where they can compete. This can be achieved through demand creation by public & private entities , such as voluntary offtake agreements, green procurement, long-term contracts by anchor firms, and early-adopter coalitions that provide revenue certainty and incentivise firms to invest in applied R&D and demonstration.

Key Suggestions:

i. **Scale Business-Sector R&D Capacity:** Increase business contribution to R&D personnel and researchers from 30% and 34% respectively to levels closer to the top-ten economy average (58% and 53% respectively) by 2035 (Economic Survey 2020-21).

ii. **Create Mission-Driven R&D Clusters:** Like China, establish mission-driven R&D clusters pooling resources across academia, national labs, and industry, with a focus on commercialization of breakthrough technologies.

iii. **Mandate Sectoral Innovation Funds:** Require large carbon-emitting sectors (steel, cement, refining) to invest in dedicated innovation funds for low-carbon technology. Anchor these missions at leading CSIR labs, IITs, IISc, and other institutions with clear tech-to-commercialisation pathways.

ANNEXURES

Annex A

Description of the Models

The analysis of India's Net Zero transition relies on a two CGE models to provide an assessment of the economy-wide impacts. First, a long-run GDP growth pathway, the *Reform Scenario*, is produced with the World Bank's Long-Term Growth Model (LTGM). This projection serves as the official reference baseline. Subsequently, two different Computable General Equilibrium (CGE) models: the MANAGE-WB CGE model and the NCAER CGE model use this baseline to analyze how various Net Zero (NZ) policy scenarios would cause the economy to deviate from its projected path, assessing impacts on GDP, employment, and other key indicators. This section summarizes the three modeling approaches, with detailed descriptions provided in the Annex A (NCAER) and Annex B (MANAGE).

Annex A.1. NCAER Methodology

A.1.1 Introduction

Historically, there has been a significant association between the energy consumption and countries' development, a composite indicator of human well-being (Pasternik 2000, WEO 2004). There is a positive causality between the level of electricity consumption which is a representative of modern energy, and human development of a country. The higher the income of a country, the greater is its electricity consumption and the higher is its level of human development (Niu, et al., 2013). Considering the importance of energy in social and economic development of a country, the energy systems and the energy security problems, ranging from energy poverty to climate change also vary across different countries. Energy security based on the principles of affordability, availability, accessibility and acceptability, is one of the main drivers of energy policies in countries (Cherp & Jewell, 2014). Being under the grip of energy poverty and mostly being a net importer of fossil fuel energy resources, energy security is crucial for India (Bhide & Monroy, 2011). Affordability, availability, accessibility and acceptability of energy is of central focus when drafting the national energy policy.

India has already taken steps towards the goal of sustainable energy development by setting the goal to make available 24x7 power to all by 2019, achieve 175 GW of renewable energy

generation capacity by 2022, reduce imports of oil and gas by 10 per cent by 2022-23, and continue to reduce emission intensity of GDP in a manner that will help India achieve the intended nationally determined contribution (INDC) target of 2030 (Niti Aayog, 2018). At the Glasgow COP Summit, India revised its commitment that its renewable energy capacity will reach 500 GW by 2030, meeting 50% of the country's energy requirements by then. It would reduce its total projected carbon emissions by one billion tonnes by 2030, reduce the carbon intensity of its economy by 45% by the same year, over 2005 levels, and achieve Net Zero emissions by 2070.

The transition to a low carbon pathway requires a methodology to provide an economy wide assessment of alternative policy choices towards sustainable and inclusive economic development. Only by understanding the combined forces of behavioral realities, markets and prices, and technological innovation and infrastructure together, can coherent responses be built to transition energy systems (Grubb, Hourcade, & Neuhoff, 2015).

The relations between the economy, the energy sector and the environment are described in two broad classes of models called top-down and bottom-up respectively. Usually to assess long term climate policies, a top-down macro-economic model and a bottom-up technology-energy-environment model are coupled to a hybrid top-down/ bottom-up model producing a macro-economic scenario with detailed technology description (Drouet, et al., 2005). The top-down models describes the whole economy and emphasize the possibilities to substitute different production factors in order to optimize social welfare. The production functions describe the interplay of factors of production and intermediate products, and changes in their combinations through the elasticities of substitution. The bottom-up models include interaction among the numerous individual energy technologies that make up the energy system of an economy, from primary energy sources, via conversion and distribution processes to final energy use (Helgesen & Tomasgard, 2018).

It is important to analyze the issues in a modelling framework that determine prices in the system. This is possible only if price is endogenously determined in the model through sectoral demand/supply equation. In that case, economic equilibrium (where demand and supply in the economy meet) would result in determination of price and output in the economy. In an economic model, demand and supply equations for all the sectors of the economy including energy sector are explicitly built in and hence price and As the above discussion suggest, the duality of energy and economic system is captured in an economic model. The Computable General Equilibrium Model (CGE) is a class of economic model that use actual economic data to estimate how an economy might react to changes in policy, technology or other external factors. In such model, sectoral growth as well as market driven prices are endogenously determined through optimizing behavior of agents (typically consumers, producers) of the economy. For this reason, the impact on the economy due to policy can be analyzed in CGE

model. Since, energy related sectors are a part of the overall economy, effects of shocks on same can also be analyzed. If price in the energy sector between different sources vary, consumer of energy would substitute away from high energy source to low one and as well as make innovation in the medium to long term to reduce energy demand. If the consumer (producer) income (revenue) do not change, the economic agent can reduce the demand. Furthermore, an economic model typically integrates trade with rest of world. So, it is capable to capture the impact of trade in energy sectors on the economy as well as the price effects of energy sector from the global market to domestic economy and their effects on the energy system.

As an improvement to the existing studies available in Indian landscape of deep decarbonization and Net Zero, the current study emphasizes on establishing a structured mechanism to endogenize energy demand in the system model framework linked with macroeconomic growth factors. The uniqueness of the study is thus on integrating macroeconomic impacts on sectoral energy demand and subsequent assessment energy supply mix in a least cost manner. In this structure of analysis, the additional advantage will be to capture the cross sectoral linkages of economic activities and substitution impacts of fuel and technology changes over the model horizon. The study proposes to derive the sectoral energy demand through macroeconomic general equilibrium model which will provide robust demand pattern of energy through sectoral output growths. General equilibrium approach-based energy demand assessment considering intra and inter sectoral impacts of other commodities (transformation and substitution). While projecting the future energy demand for each of the economic sectors, this approach considers the recursive dynamic approach. CGE based energy demand estimate are more inclusive and reactive to other economic performances. The improvements we envisage in this study are as follows:

- Obtaining much deeper understanding of the socio-economic impacts of deep decarbonization or Net Zero condition
- Understanding of the investment demand for various new and upcoming low carbon/carbon neutral technologies like CCS, Green Hydrogen etc.
- Obtaining wider policy options for deep decarbonization at national level
- Assessment of potentiality of implementing Article 6 in achieving NDC/ Net Zero conditions
- Stronger methodology for generating long term demand scenarios

Section 2 describes the modeling structure of our CGE model, along with the working of recursive dynamic model. Section 4 shows our results from integrated modelling framework while section 5 provides concluding remarks.

A.1.2 NCAER's CGE Model of India

Below, we describe the structure of our CGE model.

The India Energy Model is patterned after the ORANI-G Model, which was developed by Dixon et al (2012). The multi-household structure of the model is adapted from the work of Corong and Horridge (2012).

Given that the focus of the model is to analyze issues relating to low carbon pathway, the model has incorporated in detail both primary and commercial energy sectors. The sectors of our model is shown in Table 2-1. As this table shows, all major sources of electricity productions in India are modelled as separate sectors. Similarly, energy intensive sectors like cement, aluminum, iron and steel figures as independent sectors. ic vehicles in the policy declaration, there is a switch towards rail transport by electrical transmission and increased use of waterways for cargo movement in order to reduce logistics cost. Hence, we have included a disaggregated transport sector in our model. In all, we have 56 sectors in our model.

Table A2-1: Sectors of India model

1.	Agriculture	21.	Solar electricity
2.	Livestock	22.	Wind electricity
3.	Forestry	23.	Hydro electricity
4.	Fishing	24.	Gas electricity
5.	Coal	25.	Coal electricity
6.	Natural Gas	26.	Rest of electricity
7.	Crude Petroleum	27.	Electricity distribution
8.	Mining (others)	28.	Railway Transport
9.	Textiles	29.	Land Transport
10.	Paper products	30.	Water transport
11.	Petroleum Products	31.	Air transport
12.	Cement	32.	Other transport supporting activities
13.	Ferrous Metals	33.	Trade
14.	Aluminum	34.	Storage Warehouse
15.	Other Non-Ferrous Metals	35.	Communication
16.	Fertilizers	36.	Hotels & Restaurants
17.	Other Chemicals	37.	Finance & Insurance Services
18.	Other Manufactured products	38.	Water Distribution
19.	Construction	39.	Dwelling
20.	Nuclear electricity	40.	Other Services

There are four factors of production (land, capital, unskilled labor and skilled labor), three types of domestic institutions (households, enterprises and government), and an external sector. In a country like India where there are significant variations in income across household classes and across location (rural, urban), any discussion on policy interventions always focuses on whether the same change is inclusive across income classes or not. The same debate recurs in the case of adoption of low carbon pathway for India. For this reason, our CGE model of India incorporates 5 income quantile classes each for rural or urban households.

Our model economy assumes that perfect competition prevails across all sectors of the economy and thereby each producer, firm, industry is a price taker. Demand and supply equations for private-sector agents are derived from the solutions to the optimization problems (cost minimization, utility maximization, etc.) which are assumed to underlie the behavior of the agents in conventional neoclassical microeconomics. The agents are assumed to be price-takers, with producers operating in competitive markets which prevent the earning of pure profits. Given a production technology, the producers try to minimize their costs so as to optimize their returns. Consumers try to optimize by price minimization and utility maximization. The production technology assumes constant returns to scale, though we may introduce increasing returns to scale in some of the sectors of our model at a later stage. The endowments are assumed to be fixed within a period, so over period due to influx of foreign capital, and population growth respectively, the supply of land is assumed to be fixed.

A.1.2.1 Production Structure

Each producing sector has a nested production function, and the structure of nesting being the same across sectors. The producer's input and output decisions are governed by costs minimization while deciding on the optimal mix of inputs and profit maximization while choosing the optimal mix of products to be produced. A series of nests as depicted in Figure A2-1 represents the producer's behavioral parameters.

At Stage 1, input of aggregated labor composite by skilled and unskilled occupation type is combined using constant elasticity of substitution (CES) for each industry. At stage 2, all the primary factor inputs of capital, land and composite labor are combined to form a CES primary factor aggregate. All intermediate inputs from domestic and imported commodities are combined using another Armington-CES function, which represents imperfect substitutability between domestic and foreign commodity inputs. Stage 3 depicts Leontief production function using intermediate commodity inputs, primary factors and other costs such as stamp duties etc. Stage 4 and 5 represent the output supply decisions of the firm, in which stage 4 is for multi-products firms to decide on optimal mix of products to produce through a Constant Elasticity of Transformation (CET) function and stage 5 depicts the firm's decision of supply of products to the domestic and export markets through Armington-CET function. In our

model, we have assumed that electricity distribution sector facilitates electricity to all the agents of the economy.
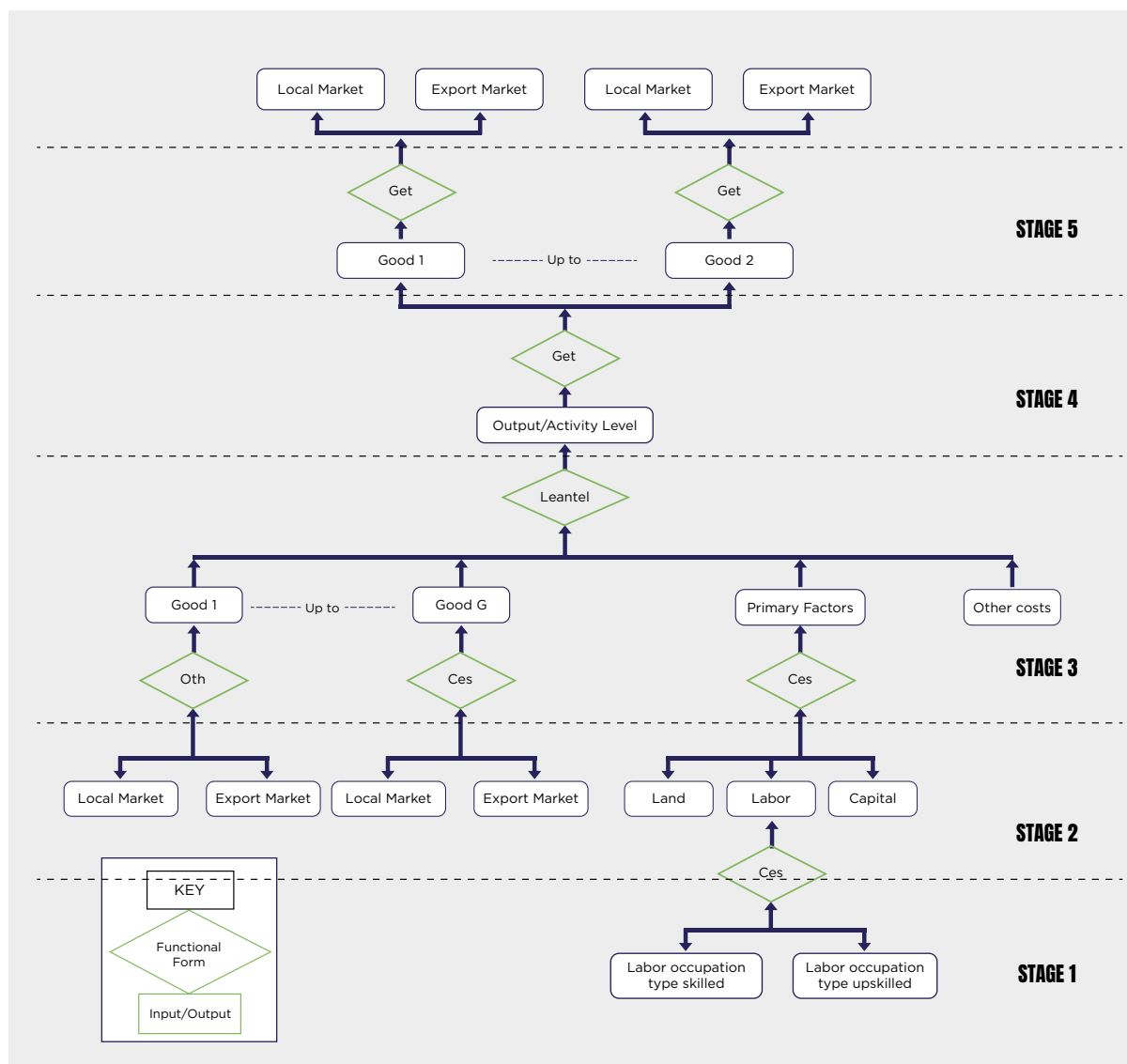
Figure A2-1: Production Structure of Industries

This sector buys electricity produced by all modes and distribute them to the various agents depending on their needs. The production structure for the distribution industry is illustrated in Figure A2-2. The input structure for the distribution industry is similar to other industries in that the distribution industry choose a combination of composite intermediate inputs and the decision to create a composite electricity commodity is facilitated via a number of nests. Equations in each nest solves a specific optimisation problem. At the top level, the composite electricity commodity is created via a combination of electricity generated from nuclear, renewable sources (green) and from fossil fuels. The composite renewable electricity commodity is created via the combination of solar, wind and hydro while electricity from fossil fuels is created via a combination of natural gas, coal and other fossil fuels.

In the bottom nests, the fuel sources are sources domestically or imported. In describing the input decisions by the electricity distribution industry, we begin by the topmost input-demand nest.
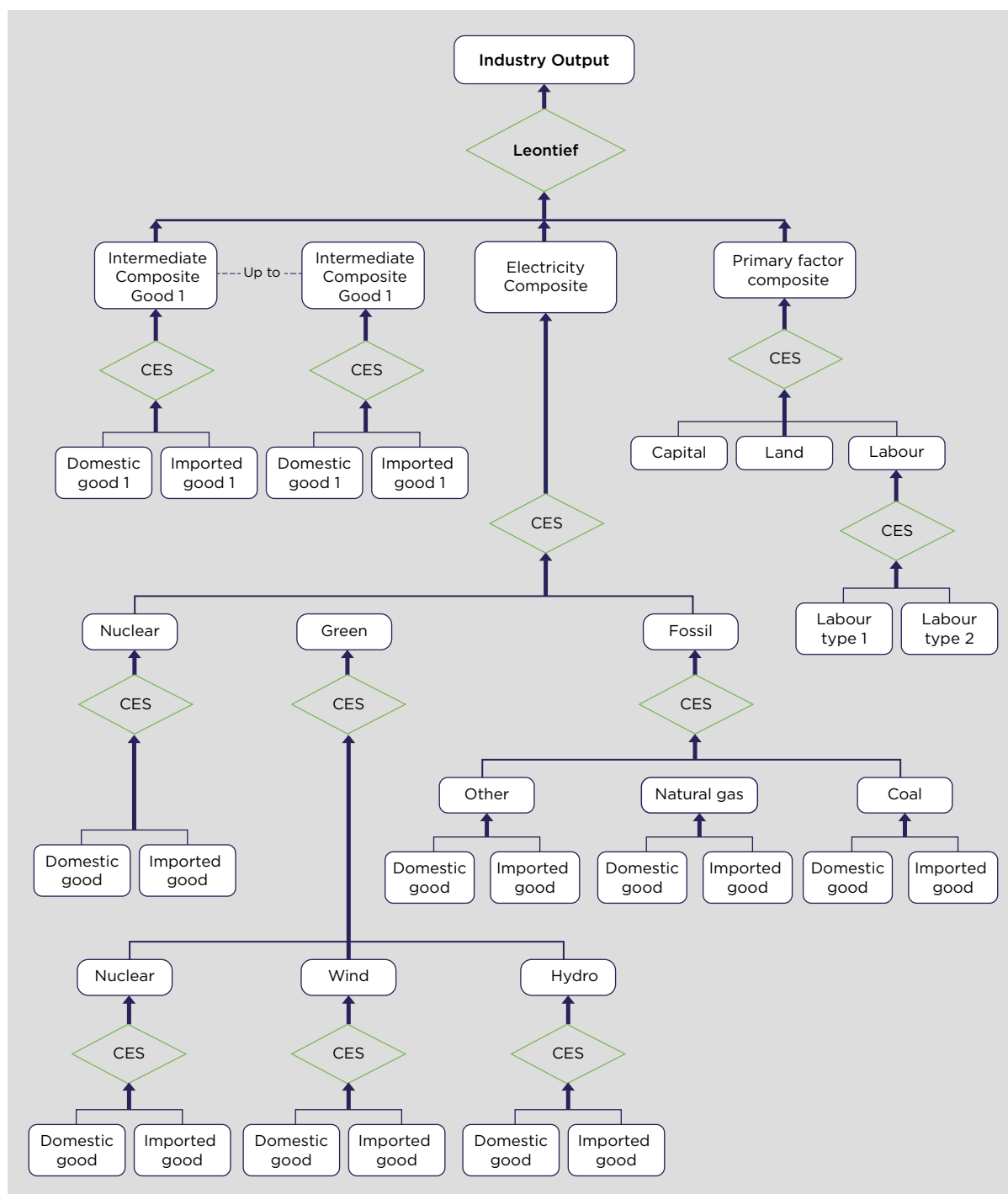
Figure A2-2: Production structure of the Electricity Distribution industry

A.1.2.2 Investment Demands

The investor combines commodities to produce new units of capital. Figure A2-3 shows two stage nested structure to produce new units of investment/ capital goods as illustrated in stage 1 where optimal demand for source specific capital inputs is determined by imposing imperfect substitutability between domestic and imported capital
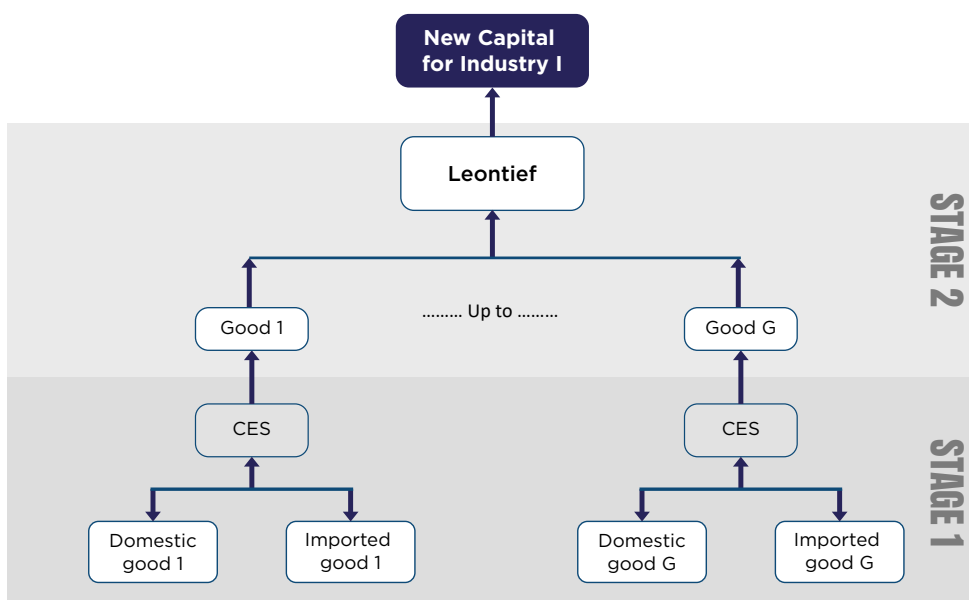
Figure A2-3: Structure of Investment Demand

A.1.2.3 Household Demands

At stage 1, a nested CES Armington function is employed for the imperfectibly substitutable domestic and imported goods governed by utility maximization and cost minimization of the economy-wide household.

Multiple categories of households, of five rural and five urban classes, have been prepared to showcase their varied consumption pattern. Stage 2 denotes the optimal consumption of various goods as per the Klein-Rubin function, which requires each household to first buy subsistence consumption regardless of its price and later allocate budget for luxury goods. A small value of the parameter indicates a subsistence commodity, while a large value corresponds to a luxury. Given consumption prices, each household chooses the optimal consumption of commodities for utility maximization.
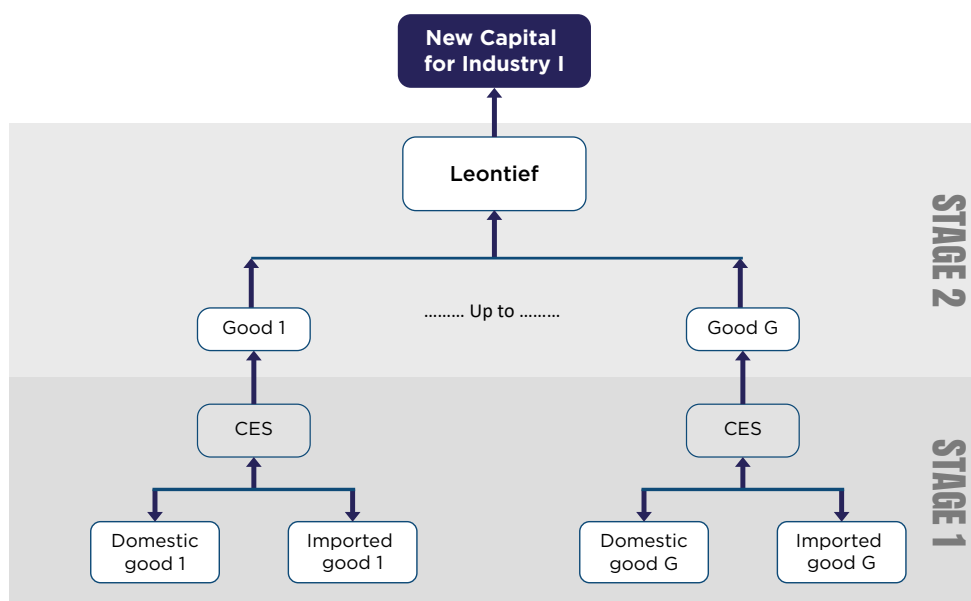
Figure A2-4: Structure of Consumer Demand

A.1.2.4 Trade Demands

Imperfect substitution between domestically produced and imported goods is allowed in CGE models. In other words, producers/consumers are free to sell or buy goods from the domestic or foreign market based on relative prices. The Armington function is used to capture the substitution possibilities between domestically produced and imported goods. The import demand function, derived from the Armington function, specifies the value of imports based on the ratio of domestic and import prices. sIn our model, we have followed two approaches to model export functions. The principal sectoral exports are modelled individually and foreign demand responds to sectoral foreign/domestic prices. However, as exports have a weak relationship with prices in case of service exports, they are modelled collectively. The collective exports on the other hand all move together in collective group by taking average price of the collective group and via a constant elasticity of demand curve.

A.1.2.5 Government Demands

Government expenditure is on the consumption of goods and services, transfers to households and enterprises, and subsidies. Government income is from taxes (direct and indirect), capital, public and private enterprises, and rest of the world. Direct tax implies income tax, while indirect taxes include excise duty, import and export tariffs, sales, stamp, service, and other indirect taxes. hold consumption requires more government services Government savings which is the difference between government expenditure and income is determined residually in the model.

A.1.2.6 Inventory Demands

Demand for Inventories is assumed to follow domestic production. The change in the volume of each source specific commodity going to inventories is a fixed share (measured at current prices) of the change in domestic production of that commodity.

A.1.2.7 Margin Demands

Margin commodities are required to facilitate the transfer of each source specific commodity to each user. If the margin technology terms is held constant, each user's effective demand for margin commodities is proportional to the commodity flows with which the margins are associated.

A.1.2.8 Total Demand for Commodities

The ordinary change in supply of domestically produced commodities is equal to the ordinary change in the demand by all agents in the economy. Similarly the ordinary change in supply of imported commodities is equal to the ordinary change in the demand for imported commodities by all agents in the economy.

A.1.2.9 Purchasers' Prices

Purchaser's prices are calculated as a sum of basic prices of commodities, commodity taxes and margin costs. Owing to different sales tax rates and different margin costs, purchaser prices for producers, investors, households, exporters, government are different. The purchaser's prices are calculated by summing the basic prices, commodity taxes and margins. The base prices are the value received by the producers and the amount paid by the importers including the import duties.

A.1.2.10 Gross Domestic Product

The income-side of GDP comprise of economy-wide factor payments of land, capital and labor, aggregate economy wide indirect taxes, value of other costs, production taxes or subsidies.

The expenditure side of GDP comprise of summation of quantity and price indices of aggregate real household consumption, investment, aggregate exports, aggregate value of public consumption expenditure and inventories. In the case of inventories the price index is computed using the basic prices of source specific commodities. The GDP in income and expenditure forms must be equal. There is a separate check in the model to ascertain that.

A.1.2.11 Dynamics

The model is multi-periods in nature, where the unit of period is one year. It is a recursively dynamic (RD) model and is solved as a sequence of static single-year CGE models, after

updating sectoral capital stocks, available labor supply each year and other plausible policy shocks over the year. The logic for using a recursive dynamic model is that India government has set policy target for short, medium and long term for low carbon pathway. To some extent, RD version of model can attempt to simulate these changes. The sectoral capital stocks are exogenously given at the beginning of a particular period. Between two periods, there will be additions to capital stocks in each sector because of the investment undertaken in that sector in the previous period. More precisely, the sectoral capital stocks for any year t are arrived at by adding the investments by sectors of destination, net of depreciation, in year t-1 to the sectoral capital stocks at the beginning of the year t-1. Labor supply is updated each year by adding the new entrants to the labor force, which is governed by population growth. Apart from the above variables, dynamic version of the model needs assumption regarding changes in foreign prices for future years, sectoral productivity growths of endowments, technology and preferences (tastes). These may be shocked depending on the policy interventions.

Our CGE model has been calibrated to the benchmark equilibrium data set of the Indian economy for the (financial) year 2024-25, which has been a practically normal year for India. The core data base of the model comes from the Supply Use table for India for the year 2018-19 and the social Accounting Matrix (SAM) with 10 household class (5 rural, 5 urban) for the year 2021-22, which we prepared ourselves for this study (2014). The model also requires other parameters and elasticities which are drawn from literature surveys with focus on India.

Most of the parameters, elasticities, are for the paper are drawn from Ojha, Pohit and Pal (2009). The sectoral productivity numbers are collated from various Indian studies and India KLEMS database.

A.1.3   Policy analysis with a dynamic model

The ORANI-India model is a versatile and flexible comprehensive analytical framework that explicitly traces each variable through time at annual intervals. As illustrated in Figure 3-1, policy analysis with a dynamic CGE model requires two simulations. The first simulation is the baseline forecast or business-as-usual simulation. This simulation models the growth of the economy over time in the absence of the policy change under consideration. The second simulation is the policy simulation. n generates a second forecast that incorporates all the exogenous features of the baseline forecast, plus policy-related shocks reflecting the details of the policy under consideration. The impacts of a policy are typically reported through percentage deviations away from the baseline forecast.
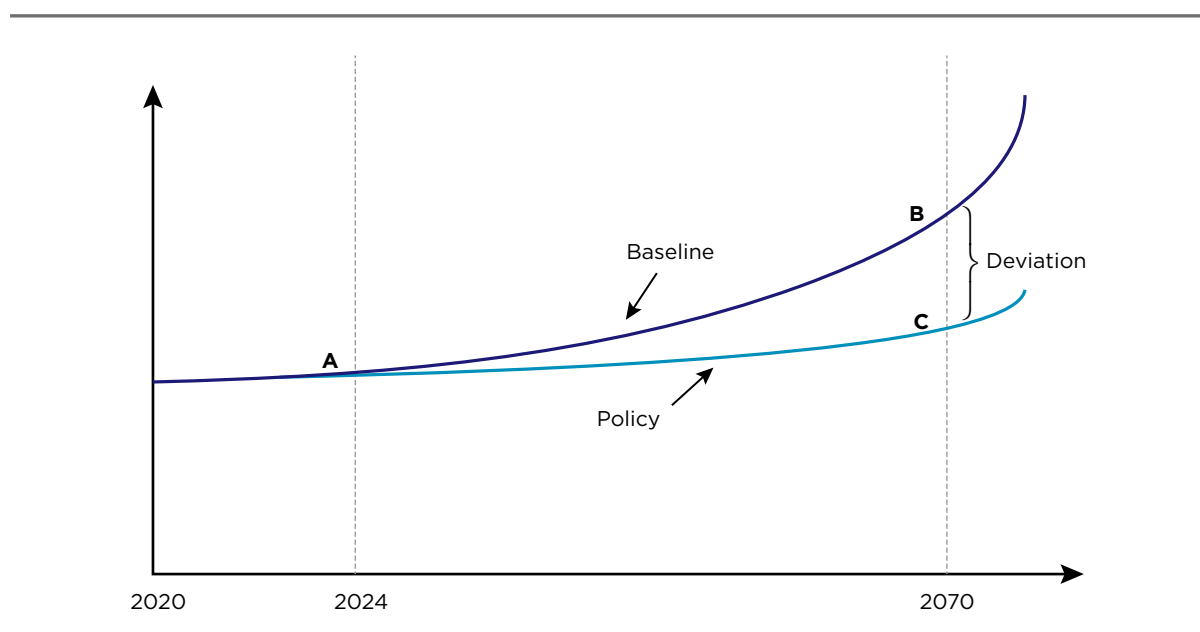
Figure A3-1: Policy analysis with a dynamic model

The CPS simulation is the control projection against which policy scenarios are compared (See Figure A3-1). In building the baseline for this study, the simulation period was divided into two parts. The first, covering the years 2019 to 2022, should be viewed as the period where the database is updated to the most recent year. The second part, covering 2025 to 2070, incorporates forecasts period.

To accommodate the extraneous information supplied to the model, numerous naturally endogenous variables in the model are made exogenous. To allow the naturally endogenous variables to be exogenously determined, an equal number of naturally exogenous variables are made endogenous. For example, real GDP is a naturally endogenous variable in the model while the economy-wide technology variable is naturally exogenous. To accommodate the exogenous settings of real GDP, the economy-wide technology variable is set endogenously and allowed to adjust as to accommodate change in real GDP.

Assumption for the CPS and NZ

Table A3-1: The Aspirational GDP growth rate (%) for the model until 2070 is summarised below

Year	2026-2030	2030-2035	2035-2040	2040-2045	2045-2050	2050-2055	2055-2060	2060-2065	2065-2070
Growth Rate	7.6	7.4	6.9	6.8	6.1	4.9	4.0	3.2	2.4

▶▶ Achievement of Female Labour Force Participation (FLFP) rate of 70% by 2047 (Target embedded in the Viksit Bharat Vision document) and saturate thereof. 70% is close to 50th percentile of FLFP seen in High Income (HI) economies. In-case of

       Male Labour Force Participation Rate (MLFP), 77.5% reported in 2024 is already close to 50th percentile seen in High Income economies. Therefore, MLFP is assumed to be constant.

▸ We have assumed an inflation of 4% inflation till 2047 and 3% after 2047

▸ We have assumed that exchange rate would depreciate by 1.5% till 2047, after 1% thereafter.

▸ Population trajectory follows UN population after 2035 and India projection till 2035.

▸ Urbanisation is expected to reach 65% by 2070.

▸ Due to the compactness of urban agglomerations, the urban population have reduced demand for transport by 15%

▸ The share of rail rises to 40% in 2070 in freight movement.

▸ The share nuclear electricity increases from 2% (2025) to 12% in 2070.

▸ We have assumed the adoption of carbon emission capture technology in emission-intensive sectors, like cement, aluminum, small iron and steel, and all types of fossil fuel electricity. The adoption starts in 2035, reaching 3-5% by 2050 and 95% of required 1255 MT capacity by 2070.

▸ The use of fuels (coal, crude oil, natural gas, refined petroleum) in current production becomes more efficient over time with advancements in the energy-saving technologies in use. An improvement of 1% per annum.

▸ The use of refined petroleum by households becomes more efficient by 0.50% per annum with energy-saving apparatus and increasing consciousness.

▸ Efficiency of carbon sequestration increased by 5% per annum with the increasing popularity of urban forestry, vertical and roof gardening, municipal and panchayat proactiveness, community forestry and farming in rural areas, etc.

▸ Green hydrogen rises by 10 times between 2030 and 2070.

However, as our model is sequentially solved and output and prices are endogenously determined, we are not in a position to hit the exact targets that are specified. We can only attempt to arrive close to it.

Annex A.2: MANAGE Methodology

A.2.1 Production structure

The MANAGE-WB model is a recursive-dynamic, single-country Computable General Equilibrium (CGE) framework designed by the World Bank to analyze the macroeconomic implications of policy changes[16]. It is built on a neoclassical growth foundation, capturing economic growth through the core drivers of capital accumulation, labor stock, and productivity growth. The model simulates the behavior of key economic agents—including firms, households, and the government—and captures the complex interplay between different sectors of the economy through market-clearing mechanisms. Its structure is particularly well-suited for analyzing the energy transition, as it allows for detailed substitution between capital, labor, and different energy sources.

Production in each sector follows a nested structure based on constant elasticity of substitution (CES) functions, enabling the model to capture varying degrees of substitutability among inputs such as capital, labor, energy, and intermediate inputs. This nesting framework is further **adapted to reflect decision-making** in the energy sector.

At the top of the **production nest**, output is formed by combining **value added** and **intermediate inputs**, with intermediate inputs treated as **complements**. To account for the role of energy, the model broadens value added inputs to explicitly integrate energy demand nest, characterized by an additive CES function. This specification allows for more flexible substitution patterns among energy sources while maintaining constraints on overall energy-capital-labor substitution. The model allows for substitution between an energy bundle and a combined capital-and-skilled-labor bundle, capturing how firms can reduce energy use either through capital investment in efficient technologies or by employing skilled labor for better energy management. Within this energy nest, production processes draw on electricity (both generation and distribution), refined petroleum products, coal, gas, green hydrogen (GH), and biomass.

The nesting structure varies across sectors to reflect heterogeneous production technologies. Energy-intensive industries such as iron and steel, cement, and chemicals have different substitution elasticities compared to service sectors, capturing their limited flexibility in replacing energy with other inputs. Hence, the model allows for customized nesting patterns and elasticity values for each industry and activity.

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16 Here is the correct link to the latest documentation. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099543511132534267

A.2.2. Production Structure in MANAGE
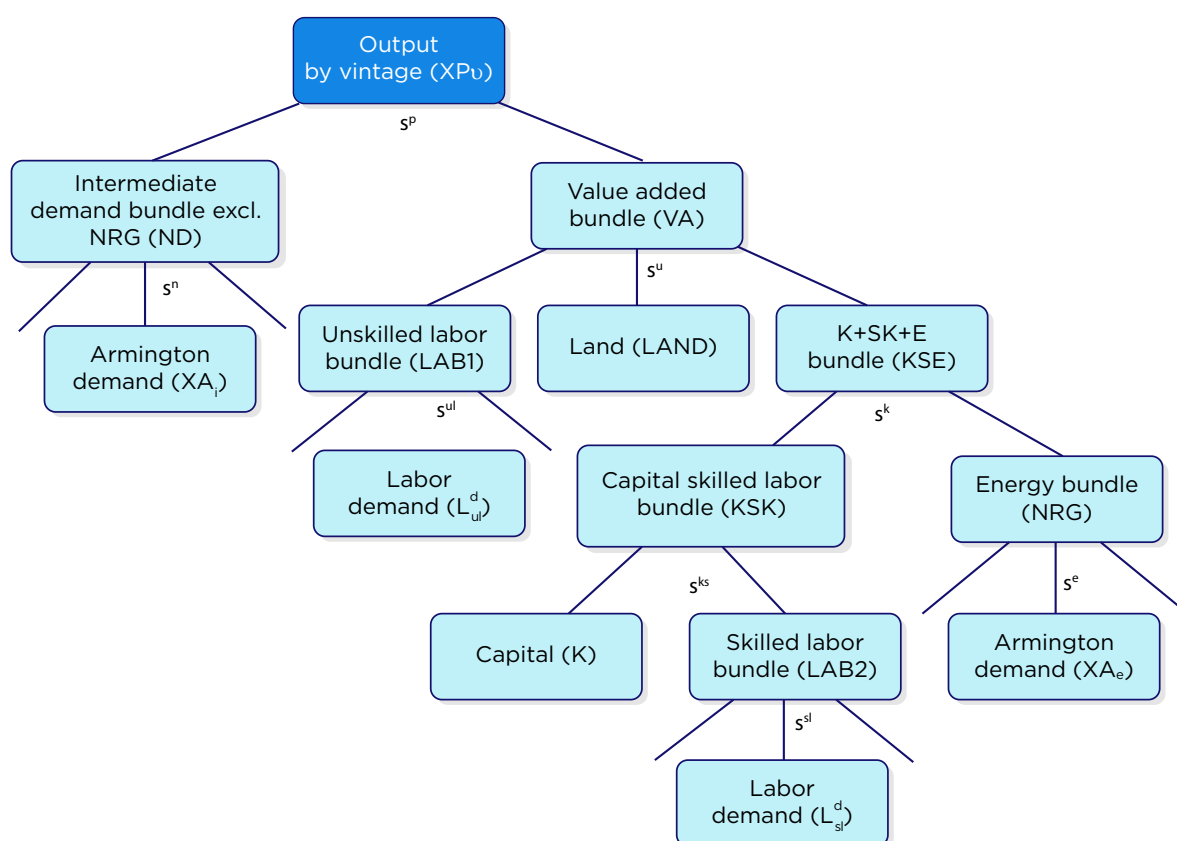
A.2.3. Household and Government Behavior

Household Income and Consumption Households receive income from multiple sources: factor payments (wages, capital returns, and land rents), transfers from other institutions, and debt service payments from the government. The model distinguishes between 10 household categories, differentiated by location (urban/rural) and income quintile, allowing for detailed distributional analysis. Each household type has specific shares in total factor income, reflecting differences in asset ownership and labor market participation across income groups. After paying personal income taxes and making transfers to other institutions, households determine their disposable income, which forms the basis for consumption and savings decisions. Household consumption follows a Constant Difference in Elasticity (CDE) utility function, which provides flexibility in capturing non-homothetic preferences and allows calibration to observed income and price elasticities across different commodity groups.

Household Savings Behavior Household savings decisions respond endogenously to relative returns through a Constant Elasticity of Transformation (CET) function. Households adjust their savings rate based on the composite returns to savings relative to consumption prices. When interest rates rise or inflation erodes the real value of consumption, the relative return to savings increases, inducing households to save more. There is a transformation elasticity

parameter that governs this responsiveness: higher elasticity means households more readily shift between consumption and savings in response to changes in interest rates, inflation, or investment returns. This specification ensures macroeconomic consistency as household savings adjust to clear the market for loanable funds, equilibrating savings supply with demand from government and private investment.

Government Revenue and Expenditure The government sector operates through a comprehensive fiscal framework encompassing multiple revenue streams and expenditure categories. Revenue sources include factor taxes, production taxes and subsidies, commodity taxes (both domestic and import), trade taxes, direct taxes on households and enterprises, and carbon taxes on emissions. On the expenditure side, the government provides transfers to households, finances public consumption, undertakes public investment, and services debt obligations.

Fiscal Balance and Closure Rules Government fiscal behavior is governed by targeting specific fiscal balance ratios as a share of GDP, with government consumption adjusting endogenously to meet these targets. When the government balance is negative, new borrowing equals the deficit; when positive, the government provides additional savings to finance private investment. Real public investment is fixed as a share of GDP following targeted growth paths, while tax revenues can adjust through a general tax shifter that scales all tax rates proportionally. The framework monitors debt dynamics separately for domestic and foreign borrowing, ensuring that government financing needs are met through an appropriate combination of expenditure adjustment and new borrowing that equilibrates with available domestic and foreign savings.

A.2.4. Trade

Import Demand Structure The model employs the Armington assumption, treating domestically produced and imported goods as imperfect substitutes within a CES framework. All agents (households, firms, government) are assumed to share identical preferences between domestic and imported varieties of each good, allowing aggregation to the national level. The Armington elasticity of substitution determines how readily agents switch between domestic and imported goods in response to relative price changes. High default Armington elasticities suggest domestic and foreign suppliers are easily substitutable. These elasticities can be adjusted to reflect sector-specific characteristics, allowing for heterogeneous substitution patterns across the economy based on empirical evidence or policy analysis needs.

Import prices faced by agents are converted to domestic currency via the exchange rate, then augmented by import tariffs, trade and transport margins, and value-added taxes. For key energy commodities, world prices follow exogenous trajectories based on international market projections provided by the energy model.

Export Supply Mechanism Domestic producers allocate output between domestic and export markets through a CET function, maximizing revenue given relative prices. The transformation elasticity governs how readily producers can shift sales between domestic and export markets. As with import elasticities, these transformation parameters can be calibrated to capture sector-specific realities and structural changes over time. Export prices are determined by world prices adjusted for exchange rates, with domestic producers receiving the world price less any export taxes and trade margins.

Balance of Payments Closure The nominal exchange rate serves as the numerarire, anchoring domestic prices and inflation. With domestic prices fixed, the exchange rate must adjust endogenously to maintain external balance through the balance of payments identity, where the current account deficit (imports minus exports plus net transfers) equals capital inflows (foreign savings). Foreign savings are fixed as a share of GDP, following projected current account trajectories. Under this closure, when foreign savings are fixed, any increase in import demand or decrease in export competitiveness triggers real exchange rate depreciation, restoring equilibrium through relative price adjustments.

A.2.5. Investment

Savings-Investment Balance Total investment in the economy is determined by the availability of loanable funds through the savings-investment identity. This macroeconomic balance ensures that all investment is financed, with the allocation between government bonds and private capital determined through a market mechanism where savers seek the highest returns. Investment influences GDP through its effects on the capital stock and productivity–productive investments increase the capital available for production, enhancing output and long-term growth. On the other hand, unproductive investment for instance, an incremental cost of capital goods with lower GHG emissions than the least-cost option does not contribute to the economy's productive capacity and divert resources from more productive uses, potentially slowing economic growth in the short run.

Foreign versus Domestic Investment Foreign investment introduces additional capital that complements domestic savings, thereby increasing total resources available for productive sectors. Unlike domestic investment, which competes with government borrowing for limited domestic savings, foreign investment helps avoid crowding-out effects where private investment is reduced due to government financing needs. This additional capital from abroad allows the economy to maintain higher levels of productive investment even when domestic resources are constrained by government deficits or large-scale transition investments. The availability of external capital thus helps mitigate potential negative impacts on GDP that might arise from crowding out within the domestic economy.

A.2.6. Labor

Labor Market Dynamics and Demographics Labor force growth is driven by demographic changes in the working-age population, which enter exogenously based on population projections. Labor supply also responds endogenously to real wages, which are determined by market-clearing mechanisms featuring an upward-sloping supply schedule. This allows the model to capture discouraged worker effects.

Labor Supply and Structural Transformation The model distinguishes between four labor categories based on skill level (skilled/unskilled) and employment type (formal/informal), capturing the heterogeneity of the labor market. The flexible nesting structure allows different degrees of substitutability between labor types, with skilled and unskilled workers typically being imperfect substitutes within the same formality category.

Labor allocation across sectors follows a CET function, with transformation elasticities determining the degree of intersectoral mobility. Finite positive values allow gradual reallocation in response to wage differentials–higher elasticities indicate more flexible labor markets. This mechanism works in conjunction with the labor mobility constraints and wage differentials to determine the actual pace and pattern of sectoral reallocation. The model ensures labor market equilibrium by equating sector-specific labor demand with available labor supply across all sectors.

A.2.7. Emissions

Emissions are calculated through three primary channels: (i) consumption of emission source commodities by Armington agents for both intermediate and final demand, including energy-related emissions from fossil fuel use; (ii) factor-based emissions from production inputs such as livestock or land use; and (iii) output-based emissions from production processes. Consumption-based emissions follow trajectories directly linked to energy use patterns, with emission coefficients improve over time to reflect technological progress and efficiency gains. The provided emission trajectories undergo validation against energy models to derive appropriate improvement rates for emission coefficients, ensuring internal consistency between projected energy consumption and corresponding emissions throughout the modeling period.

A.2.8. Key assumptions

The methodological framework incorporates several structural assumptions. The GDP deflator serves as the numeraire, anchoring domestic prices and inflation. Since domestic prices are fixed by this numeraire choice, the exchange rate must adjust endogenously to maintain external balance. This endogenous adjustment of the exchange rate ensures equilibrium in the external sector by aligning domestic relative prices with international prices.

Meanwhile, land supply for agriculture is treated as fixed. However, as India's economy develops, the model assumes that there is an improvement in land productivity, resulting from enhanced fertilizers and better crop varieties over time, mirroring productivity gains observed in other rapidly developing economies.

A.2.9. Social Accounting Matrix (SAM)

The model is tailored to India's economic structure by calibrating it to India Social Accounting Matrix (SAM), which was built on 2019 Supply and Use Tables (SUT) from the Ministry of Statistics and Programme Implementation (MoSPI)[17]. The SAM includes current, fiscal, and debt accounts, populated with data from the National Account Statistics (NAS) published by MoSPI, and cross-verified against the Macro Poverty Outlook (MPO) Databank[18]. Subsequently, the SAM was macro-updated to 2022 using key macro economic indicators from the NAS.

In the original SUT, all electricity generation is aggregated into a single sector. However, to accurately capture the energy transition, this sector is disaggregated into seven distinct sectors—solar, wind, nuclear, gas, coal, hydro, and other. The cost structures for these segments are derived from the GTAP 11 database, while the electricity mixes are informed by NITI's energy model.

Beyond the standard set of activities presented in the Supply and Use Tables (SUT), we include two emerging sectors with significant projected growth: modern biomass and green hydrogen (GH). Although modern biomass does not appear explicitly in the original SUT, the chemical sector (producing organic chemicals) offers a suitable proxy, given the similarity in feedstock-based transformations and chemical processing.

To capture the emerging role of green hydrogen (GH) in India's energy mix, we introduce to the SAM a dedicated GH sector, which was absent in the original SUT. Although currently nascent, GH is projected to become a significant energy carrier, according to the energy demand projections provided. We assume that the cost structure of PEM electrolysis for GH production is assumed to follow that of the US, based on data from the H2A Hydrogen Analysis models developed by the National Renewable Energy Laboratory (NREL), with electricity costs for operating the electrolyzer and capital expenditures as the primary cost drivers.

The resulting SAM, with dimensions 251×251, features 74 activities and 148 commodities, including 7 distinct power sectors (coal, gas, solar, wind, hydro, nuclear, and other). It also identifies 3 primary factors of production (labor, capital, and land) and 4 labor types, differentiated by skill level and formal/informal status. On the household side, 10 household

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categories are distinguished (urban and rural across income quintiles), while 7 separate tax and subsidy items are captured, covering production taxes, commodity taxes, direct taxes, subsidies, and tariffs. Finally, 3 investment accounts—public GFCF, private GFCF, and stock changes—are included, along with 1 debt account to track financing of the government's fiscal deficit.

Annex B

Figures and Tables
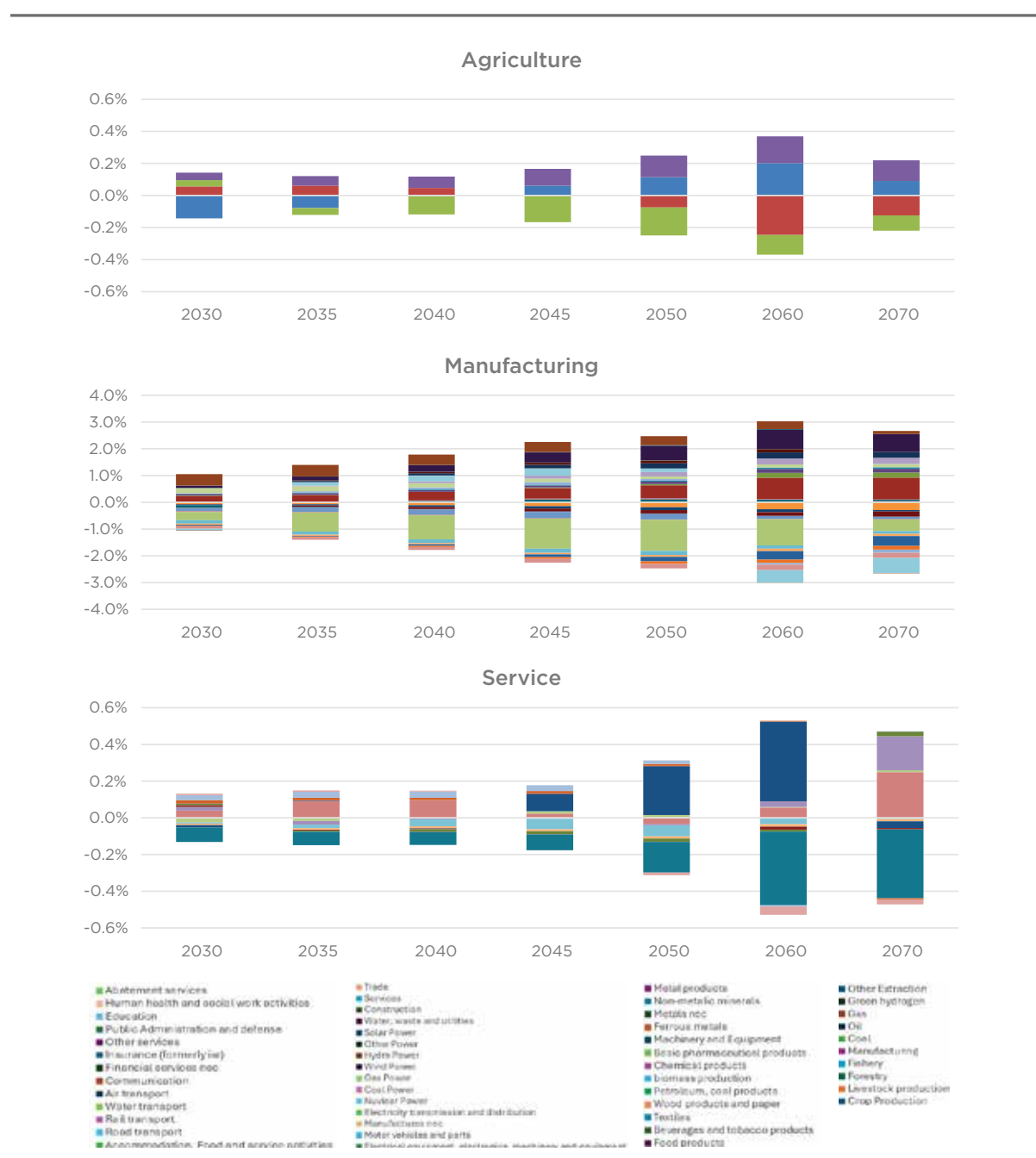
Figure B1: Deviation of sub-sector shares in NZfor from CPS (in percentage points) (MANAGE).

Scenarios Towards Viksit Bharat and Net Zero: Macroeconomic Implications

Figure B2: Impact of NZ transition on fossil fuels output (% deviation from CPS) (MANAGE).

Exports on GDP (% deviation from CPS)

NZdom Nzfor+

Imports on GDP (% deviation from CPS)

NZdom Nzfor+
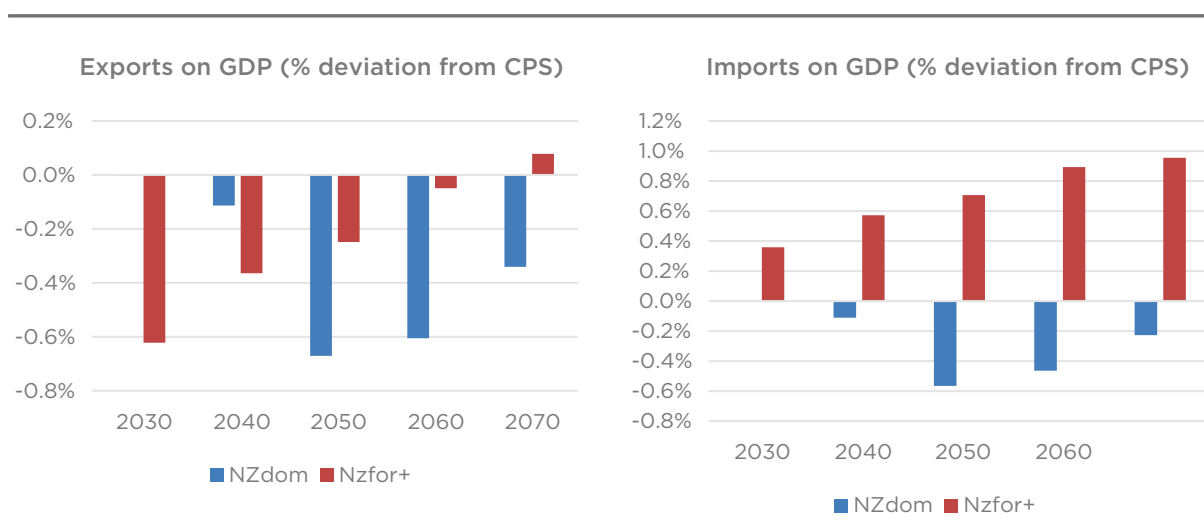
Figure B3: Exports and imports as a percentage of GDP (% deviation from CPS).

Agriculture (NZdom)

Agriculture (NZfor+)

Manufacturing (NZdom)

Manufacturing (NZfor+)

Service (NZdom)

Service (NZfor+)
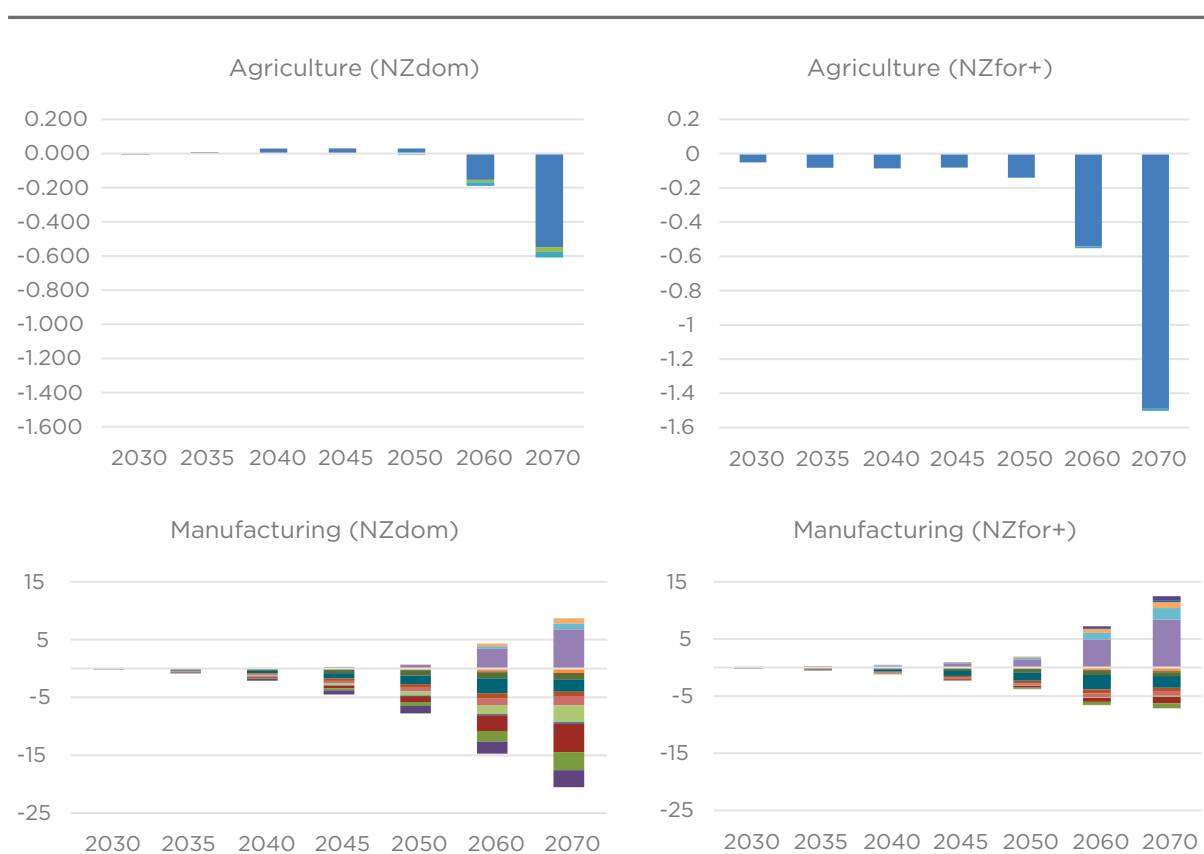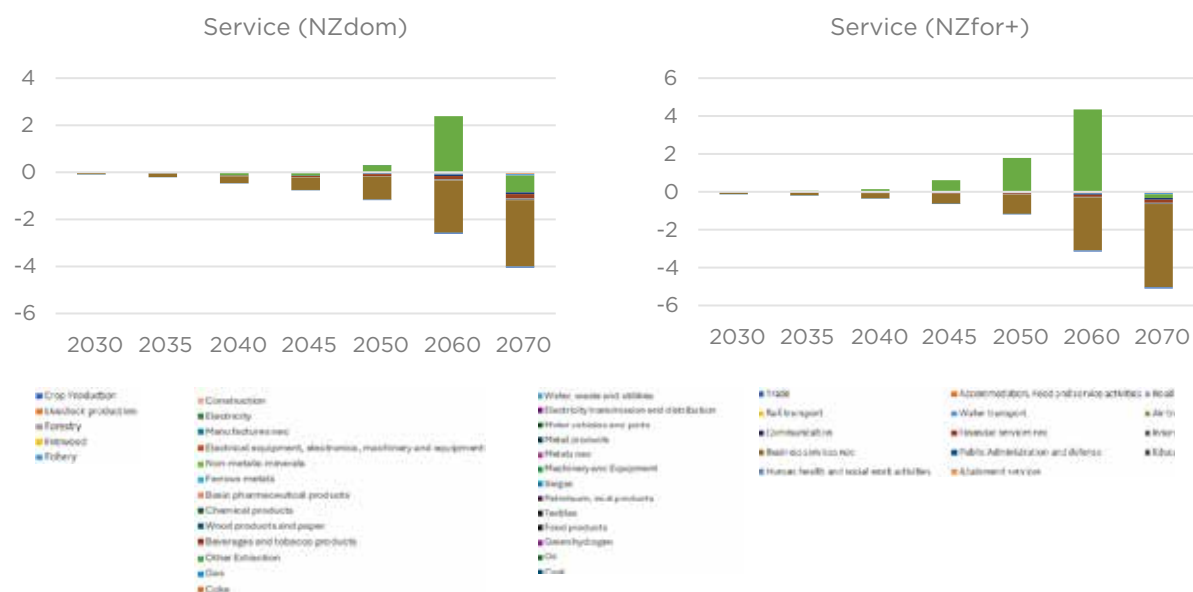
Figure B4: %Change of export revenue by sector in NZ scenarios compared to the CPS. (MANAGE)

CAD-NZ (% of GDP)
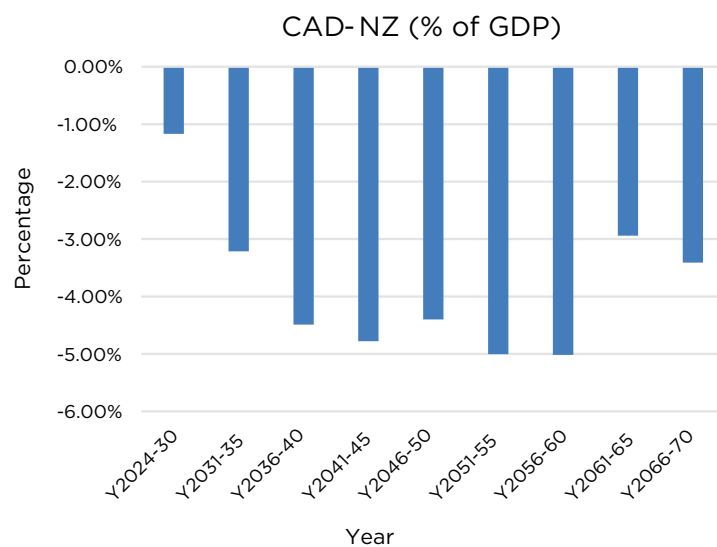
Figure B5: Current Account Deficit (NCAER)

NZdom

NZforSub
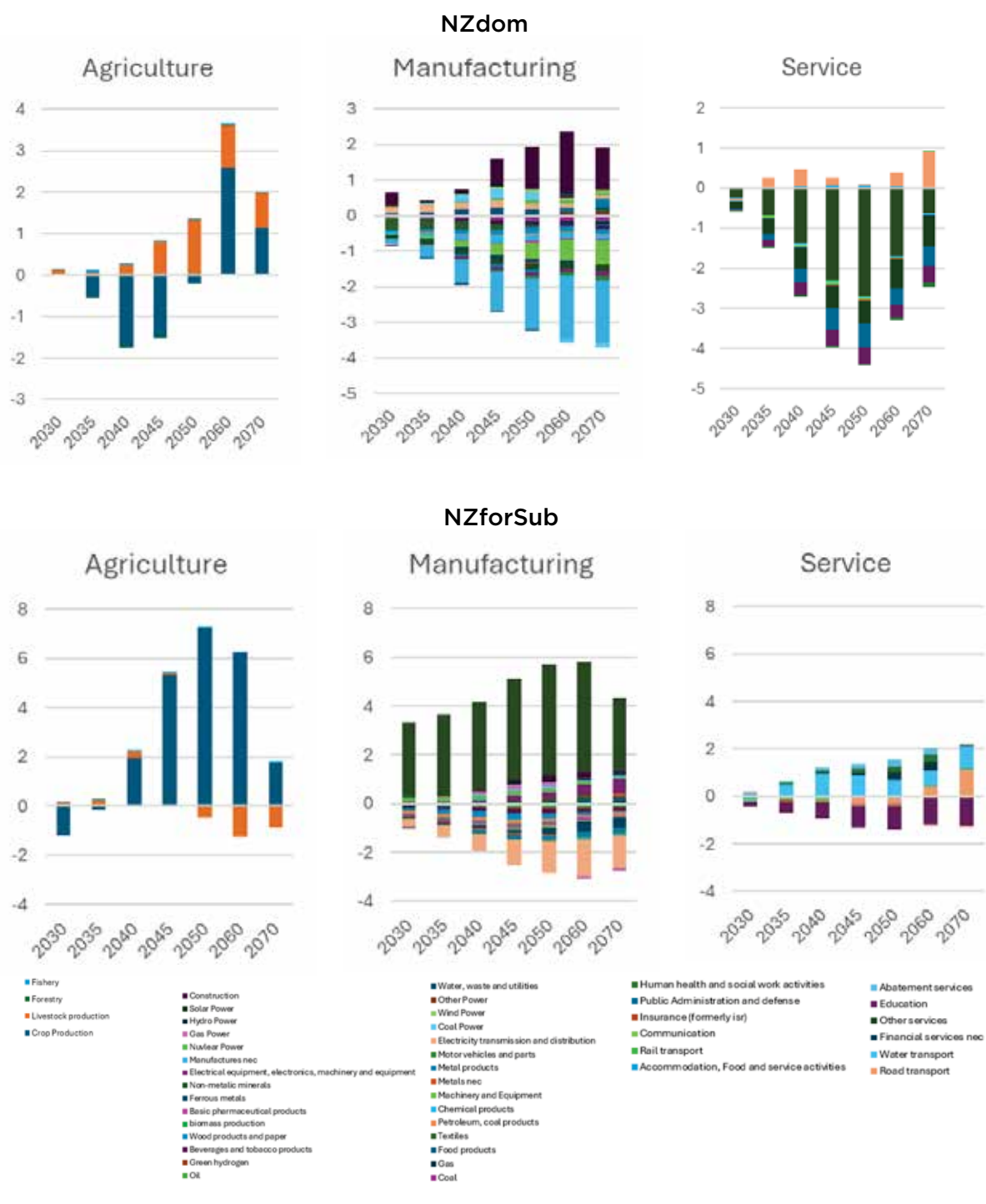
Figure B6. Sectoral employment deviation from CPS (million people) (MANAGE)
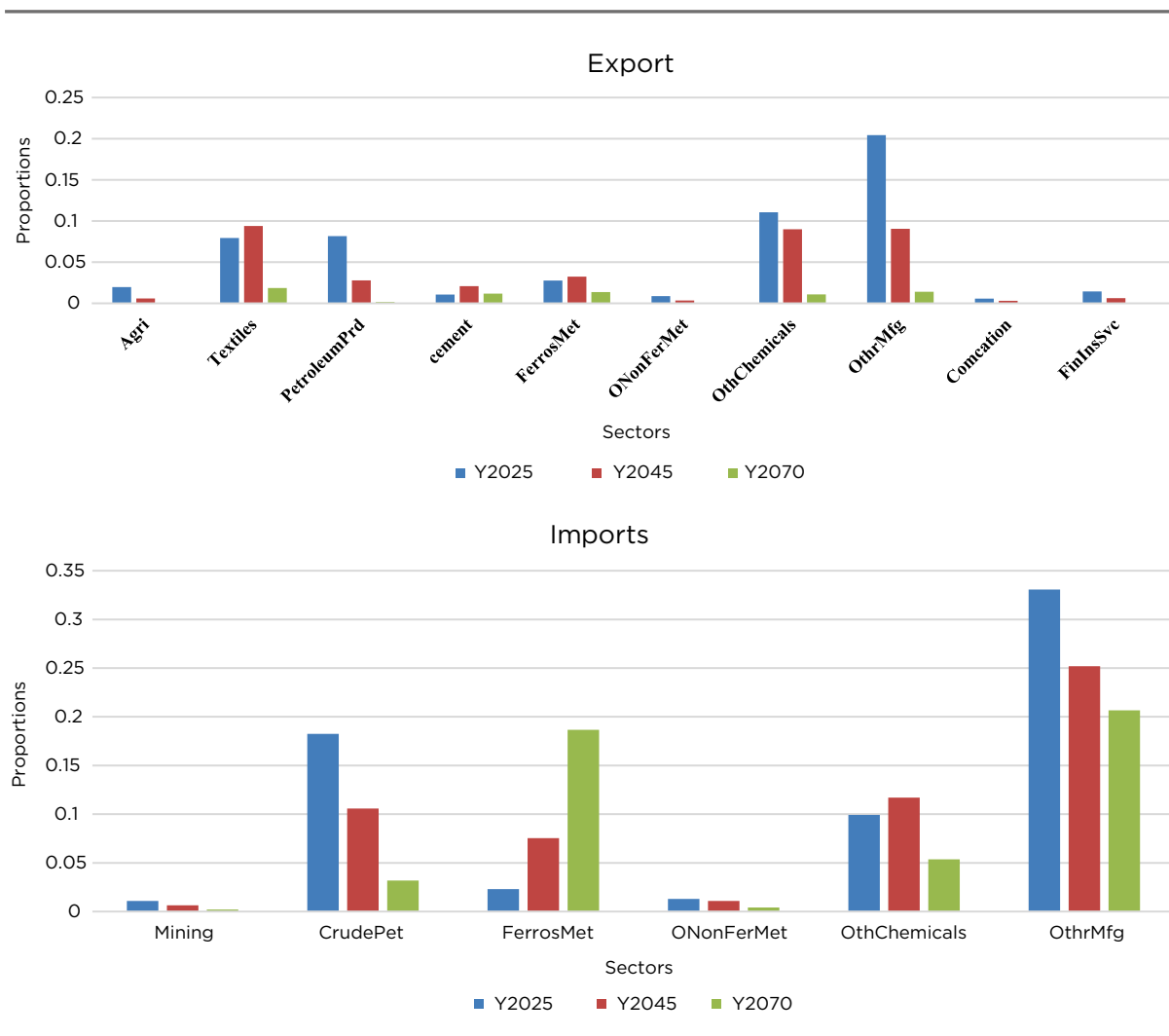
Figure B7: %Change of export and import expenditure by sector in NZ scenarios compared to the CPS (NCAER)
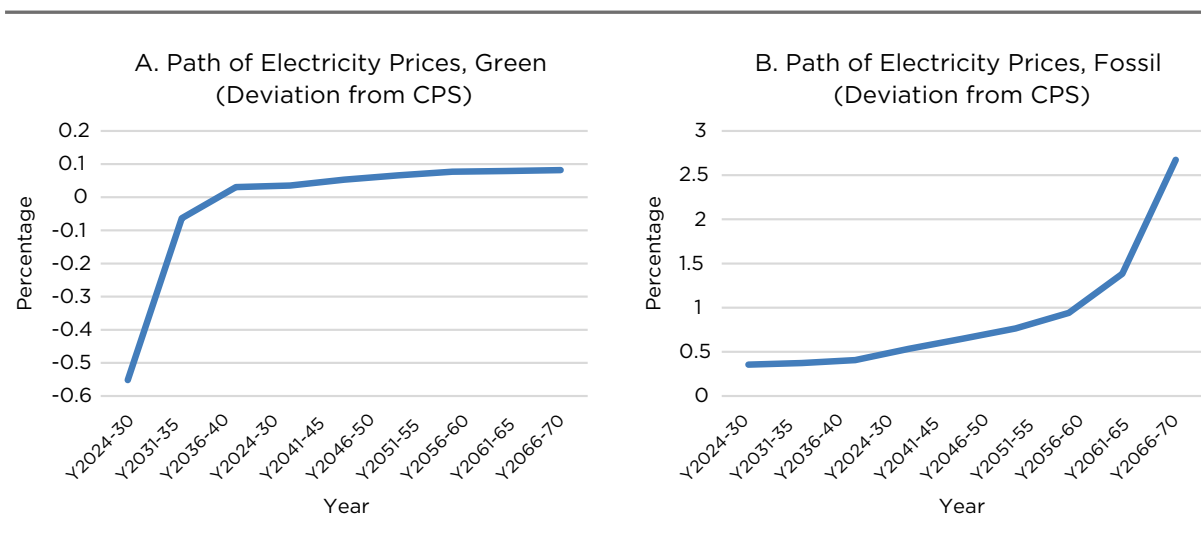
Figure B8: Path of electricity prices (NCAER)
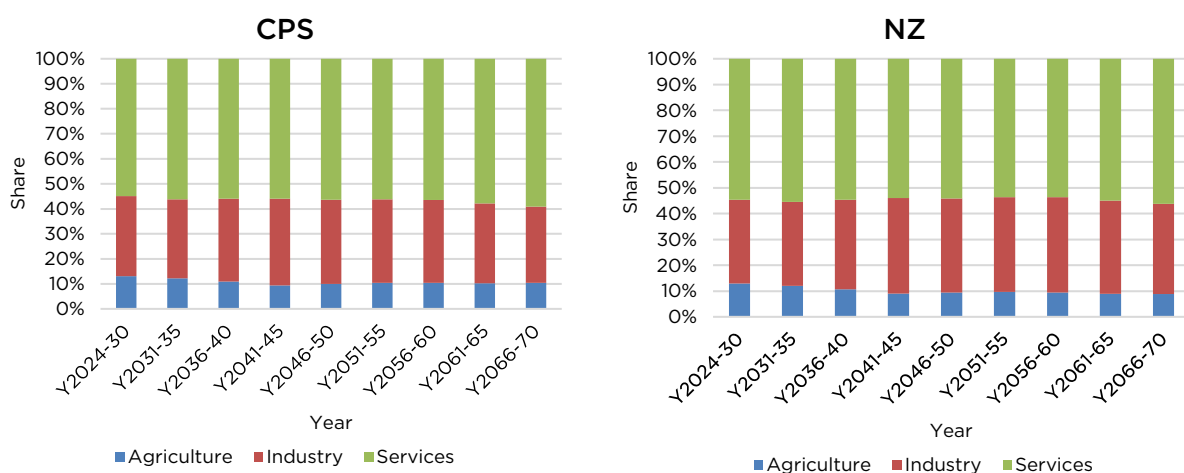
Figure B9: Sectoral shares under CPS and NZ (NCAER)
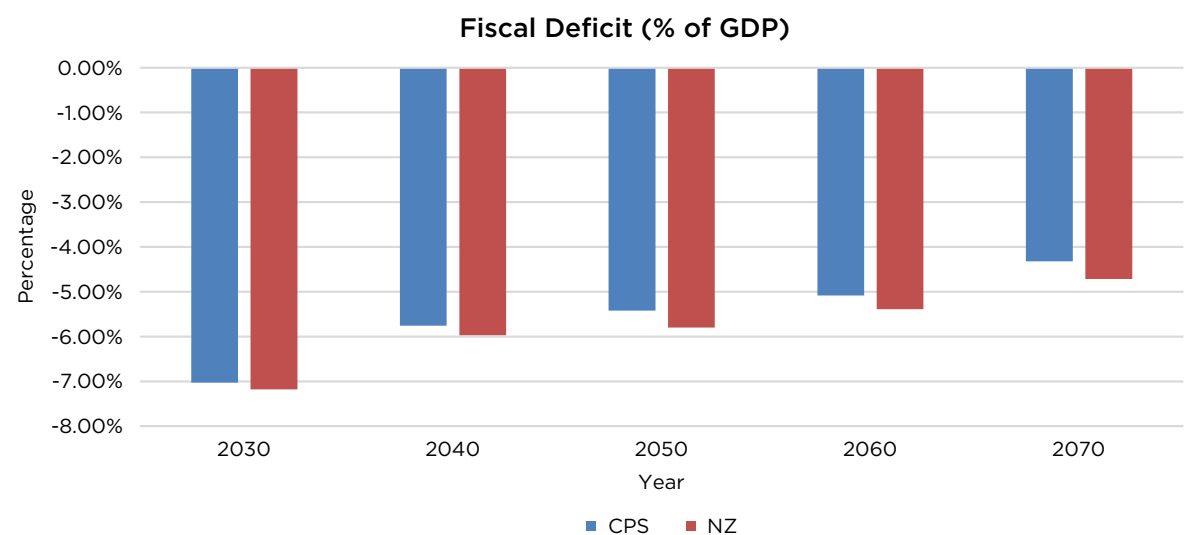
Figure B10: Fiscal deficit (% of GDP) (NCAER)

Annex C

Assumptions on Price Series, Consumption and, Import Trends of Fossil Fuels in the CPS and Net Zero Scenarios

Annex C.1

a. Starting-year Fuel Prices (2011 INR per BTU)

Fuel	Price
Coal	0.00010824
Petrol	0.0018037
Diesel	0.00143806
Crude oil	0.00060852
Gas	0.00051556

b. Assumed Fuel-Price Escalation Rates (based on Annual Energy Outlook 2023[1])

Price escalation trend for fossil fuels					
Year	Coal	Petrol	Diesel	Oil	Gas
2023	1.000	1.000	1.000	1.000	1.000
2025	1.008	0.998	1.024	1.011	0.965
2030	1.027	1.068	1.094	1.081	1.078
2035	1.038	1.132	1.151	1.142	1.139
2040	1.053	1.180	1.191	1.186	1.145
2045	1.072	1.241	1.250	1.246	1.131
2050	1.091	1.301	1.288	1.295	1.191
2055	1.104	1.362	1.352	1.357	1.228
2060	1.120	1.423	1.405	1.414	1.261
2065	1.136	1.483	1.458	1.470	1.295
2070	1.152	1.543	1.511	1.527	1.328

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1 Annual Energy Outlook 2023–U.S. Energy Information Administration (EIA)

c. Consumption Trend of Fossil-Fuels (TIMES model, figures in MToE)

Year	Oil products (petrol + diesel) consumption		Coal consumption	
	CPS	NZ	CPS	NZ
2022	219	219	437	437
2030	319	304	641	602
2035	382	329	790	633
2040	441	361	940	652
2045	468	344	981	632
2050	480	293	979	532
2055	476	271	965	442
2060	495	289	927	161
2065	475	288	848	100
2070	451	296	711	61

d. Import Trends of Fossil-Fuels in the CPS and Net Zero Scenarios (TIMES model, oil and gas figures in MToE; coal in million tons)

Year	Oil Imports		Gas imports		Coking coal imports	
	CPS	NZ	CPS	NZ	CPS	NZ
2022	227	222	30	30	54	54
2030	274	261	39	36	75	81
2035	328	283	61	44	95	92
2040	379	310	82	58	115	101
2045	402	295	100	70	148	101
2050	413	251	117	69	137	91
2055	409	233	117	50	169	75
2060	426	248	115	19	198	57
2065	408	247	110	0	198	38
2070	387	254	90	0	195	24

Annex C.2: Capacity and Price Assumptions for Nuclear Fuel Use

a. Total Installed Nuclear Capacity 2022-2070 (in GW)

Year	CPS	NZ
2022	7	7
2030	16	29
2035	23	50
2040	34	71
2045	45	92
2050	56	113
2055	67	133
2060	78	154
2065	89	175
2070	100	196

b. Assumptions on Price Estimation and Projections based on Kryzia and Gawlik[2]

	Uranium price trend (study)	Scaled actual uranium prices (per kg, in 2011 INR terms)
2020	91	150
2025	90	163
2030	91	164
2035	97	175
2040	108	195
2045	118	213
2050	130	235
2055	130	236
2060	137	249
2065	144	261
2070	151	273

The scaling of actual uranium prices was carried out in line with the price projections suggested by the above study

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2   Forecasting the price of uranium based on the costs of uranium deposits exploitation

Annex C.3: Critical-Minerals Related Assumptions

a. Elements Identified as "Critical Minerals" by the Indian government[3] and considered in this analysis

Antimony	Gallium	Lithium	Phosphorous	Strontium
Beryllium	Germanium	Molybdenum	Potash	Tantalum
Bismuth	Graphite	Niobium	REE	Tellurium
Cobalt	Hafnium	Nickel	Rhenium	Tin
Copper	Indium	PGE	Silicon	Titanium
Tungsten	Vanadium	Zirconium	Selenium	Cadmium

• Colour Key

Blue	for battery
Yellow	for PVs
Green	for both

b. Total Installed solar PV capacity (Utility and Distributed) in Gigawatts for the CPS and Net Zero Scenarios (TIMES)

Year	CPS	NZ
2022	105	105
2030	250	325
2035	400	650
2040	700	1140
2045	950	1800
2050	1300	2600
2055	1700	3500
2060	2150	4400
2065	2550	5250
2070	2850	5800

c. Li-ion Battery Storage Capacity in Gigawatt for the CPS and Net Zero Scenarios (TIMES)

Year	CPS	NZ
2022	0	0
2030	180	200
2035	340	760

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3   Press Release:Press Information Bureau

Year	CPS	NZ
2040	820	1740
2045	1400	3280
2050	2180	5360
2055	3160	8040
2060	4060	9880
2065	5040	10400
2070	5700	12080

d. EV Critical-Mineral Use Coefficients[4] and Starting-Year Prices[5]

For EVs	ton/GWh	Price/ton (USD 2022)	Price/ton (lakh 2011 INR)
Nickel	483	16403	6
Cobalt	133	47621	18
Lithium	100	8232	3
Copper	333	9476	4

e. Annex B.3.5 Solar Critical Minerals-Use Coefficients[6] and Prices[7]

For photovoltaics	Tons per MW	Price per ton (2022 USD)	Price per ton (lakh 2011 INR)
Copper	3.2	9476	3.6
Silicon (polycrystalline)	3	3663	1.4

f. Solar Cell Cost Assumption[8] and Conversion

0.04	dollars per watt
40	dollars per kilowatt
40,000	dollars per megawatt
0.33	Cr per MW (2022 INR)
0.17	Cr per MW (2011 INR)

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4   Based on The key minerals in an electric vehicle–Mining Doc

5   Based on averaged annual prices listed from Daily Metal Price: Copper Price (USD / Pound) Chart for the Last Month

6   Based on ETC-Materials-Report_highres-1.pdf

7   Based on averaged annual prices listed from Daily Metal Price: Copper Price (USD / Pound) Chart for the Last Month

8   Based on Solar price trend–EnergyTrend

g.   Annex B.3.7 Li-ion Battery Cell Cost Assumption[9]
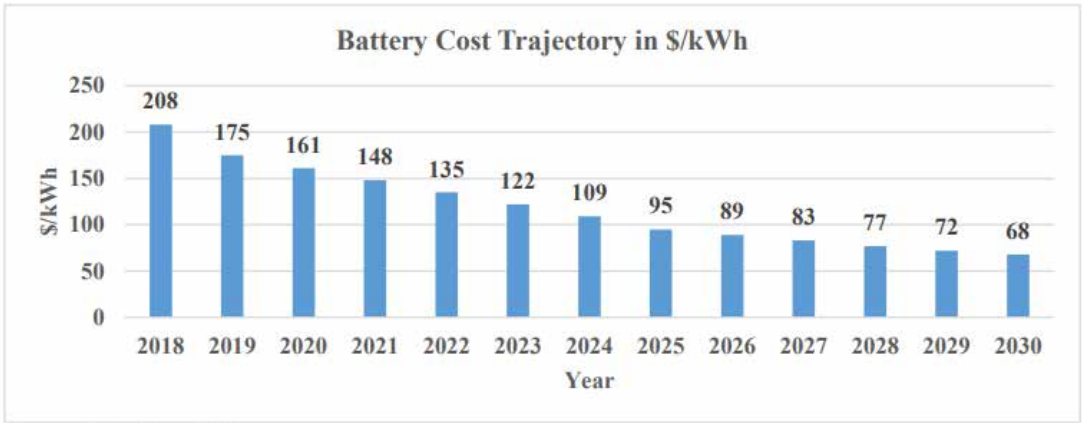
Source: Bloomberg NEF

For this analysis, the cost of batteries is fixed at USD 68 per kWh (or 2,573 INR per kWh in constant 2011 prices). No decline in lithium-ion battery prices is assumed over the modelled timespan.

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9   Based on NEP 2023–Generation

Annex D

Annex D.1 Assumptions on Price Series, Consumption and, Import Trends of Fossil Fuels in the CPS and Net Zero Scenarios

Starting-year Fuel Prices (2011 INR per BTU) from relevant sources (Ministry of Coal, 2019), (Our World In Data, 2024), (MoPNG, 2020)

Fuel	Price
Coal	0.00010824
Petrol	0.0018037
Diesel	0.00143806
Crude oil	0.00060852
Gas	0.00051556

Fuel tax rates expressed as average share of price that is tax

Taxed fuel	(present, dimensionless)
Coal (incl GST @5%, coal cess and royalty)	0.233
Petrol (incl. Excise duty, Sales Tax)	0.491
Diesel (incl. Excise duty, Sales Tax)	0.373

Assumed Fuel-Price Escalation Rates based on Annual Energy Outlook 2023 (EIA, 2023))

Price escalation trend for fossil fuels					
Year	Coal	Petrol	Diesel	Oil	Gas
2022	1.000	1.000	1.000	1.000	1.000
2025	1.008	0.998	1.024	1.011	0.965
2030	1.027	1.068	1.094	1.081	1.078
2035	1.038	1.132	1.151	1.142	1.139
2040	1.053	1.180	1.191	1.186	1.145
2045	1.072	1.241	1.250	1.246	1.131
2050	1.091	1.301	1.288	1.295	1.191
2055	1.104	1.362	1.352	1.357	1.228

Price escalation trend for fossil fuels				
Year	Coal	Petrol	Diesel	Oil	Gas
2060	1.120	1.423	1.405	1.414	1.261
2065	1.136	1.483	1.458	1.470	1.295
2070	1.152	1.543	1.511	1.527	1.328

Consumption Trend of Fossil-Fuels (TIMES model, figures in MToE)

Year	Oil products (petrol + diesel) consumption		Coal consumption	
	CPS	NZ	CPS	NZ
2022	238	238	415	415
2025	263	266	526	528
2030	304	297	620	605
2035	350	328	763	719
2040	385	335	951	823
2045	408	325	1077	856
2050	412	284	1127	804
2055	415	263	1038	653
2060	414	231	949	478
2065	405	207	831	312
2070	396	196	719	83

Import Trends of Fossil-Fuels in the CPS and Net Zero Scenarios (TIMES model, oil and gas figures in MToE; coal in million tons)

Year	Oil Imports		Gas imports		Coking coal imports	
	CPS	NZ	CPS	NZ	CPS	NZ
2022	208	208	28	28	38	38
2030	222	224	30	29	39	39
2035	259	252	35	43	43	43
2040	301	279	50	54	58	50
2045	332	281	66	68	80	56
2050	350	267	82	77	108	58
2055	348	221	92	74	133	56
2060	345	194	93	42	142	50
2065	339	156	90	25	145	41
2070	323	125	85	7	141	30

Annex D.2: Capacity and Price Assumptions for Nuclear Fuel Use

a. Total Installed Nuclear Capacity 2022-2070 (in GW)

Year	CPS	NZ
2022	7	7
2030	16	29
2035	23	50
2040	34	71
2045	45	92
2050	56	113
2055	67	133
2060	78	154
2065	89	175
2070	100	196

b. Assumptions on Price Estimation and Projections based on Kryzia and Gawlik (Dominik Kryzia, 2016)

	Uranium price trend (study)	Scaled actual uranium prices (per kg, in 2011 INR terms)
2020	91	150
2025	90	163
2030	91	164
2035	97	175
2040	108	195
2045	118	213
2050	130	235
2055	130	236
2060	137	249
2065	144	261
2070	151	273

The scaling of actual uranium prices was carried out in line with the price projections suggested by the above study

Annex D.3: Critical-Minerals Related Assumptions

a. Elements Identified as "Critical Minerals" by the Indian government (PIB, 2023) and considered in this analysis

Antimony	Gallium	Lithium	Phosphorous	Strontium
Beryllium	Germanium	Molybdenum	Potash	Tantalum
Bismuth	Graphite	Niobium	REE	Tellurium
Cobalt	Hafnium	Nickel	Rhenium	Tin
Copper	Indium	PGE	Silicon	Titanium
Tungsten	Vanadium	Zirconium	Selenium	Cadmium

- Colour Key

Blue	for battery
Yellow	for PVs
Green	for both

b. Annual Solar Capacity Additions (Utility and Distributed) in Gigawatts for the CPS and Net Zero Scenarios (TIMES)

Year	CPS	NZ
2022	105	105
2030	218	239
2035	236	406
2040	251	419
2045	354	636
2050	499	741
2055	618	1042
2060	618	1042
2065	825	1548
2070	825	1548

c. Li-ion Battery Storage Capacity in Gigawatt for the CPS and Net Zero Scenarios (TIMES)

Year	CPS	NZ
2022	0	0
2030	168	792
2035	360	552
2040	342	1134
2045	1260	2934
2050	1650	3594
2055	2184	3468
2060	2460	4926
2065	2808	5676
2070	2322	9222

d. Battery Storage Critical-Mineral Start-Year Prices based on Ministry of Commerce and Industry Estimates (Ministry of Commerce and Industry, 2025). Prices remain fixed for the modelled timespan

| For EVs	Price/kg (2011 INR)
Copper	406
Cobalt	1946
Nickel	1582
Lithium	559

e. Solar Critical Minerals Prices (Ministry of Commerce and Industry, 2025). Prices are assumed to remain constant through the modelled timespan

For photovoltaics	Price per kg (2011 INR)
Copper	406
Silicon (polycrystalline)	663

f. Solar Cell Cost Assumption (Energy Trend, 2024) and Conversion. No change in prices assumed for the solar cells in the modelled timespan

0.04	dollars per watt
40	dollars per kilowatt
40,000	dollars per megawatt
0.33	Cr per MW (2022 INR)
0.17	Cr per MW (2011 INR)

g. Li-ion Battery Cell Cost Assumption (BloombergNEF, 2024)
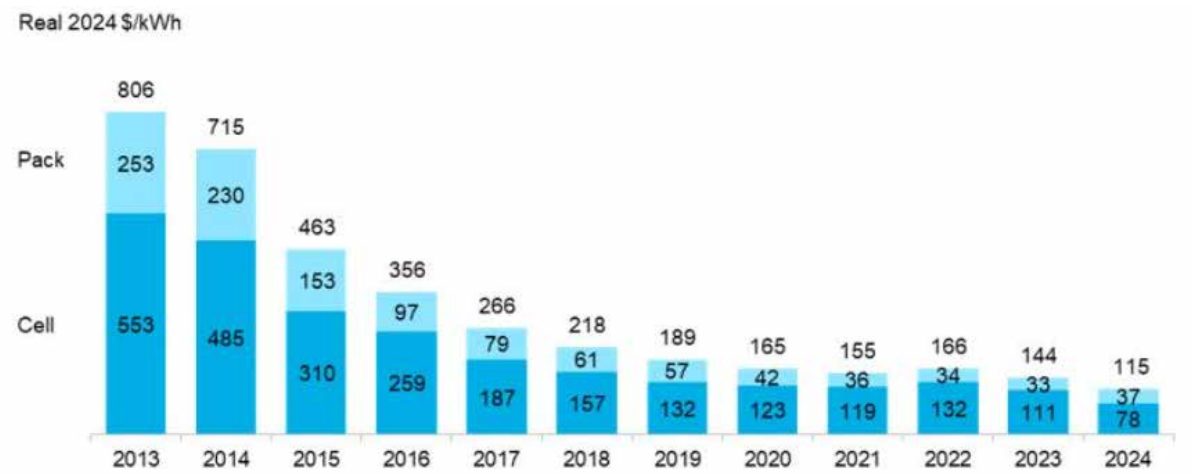
Source: BloombergNEF. Note: Historical prices have been updated to reflect real 2024 dollars. Weighted average survey value includes 343 data points from passenger cars, buses, commercial vehicles and stationary storage.

For this analysis, the cost of batteries is fixed at 50 lakh per MWh in constant 2011 prices based on price conversion of final figures in the Bloomberg source. No decline in lithium-ion battery prices is assumed over the modelled timespan.

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