UNPACKING

Decarbonising India: Charting a pathway for sustainable growth

The Climate Futures Project

BRIDGING CLIMATE POLICY AND MODELS

SUSTAINABLE FUTURES COLLABORATIVE

March 2025

Authors

Aman Srivastava
Nikita Shukla
Easwaran J. Narassimhan

Acknowledgements

Srishti Jain
Sonali Verma
Karthika J

Design

Kunal Agnihotri

Citation:
The Climate Futures Project. 2022. Unpacking 'Decarbonising India: Charting a pathway for sustainable growth'. New Delhi: Sustainable Futures Collaborative. March 2025. Available at: www.climatefuturesproject.in

Overview:
Models are powerful analytical tools that shape policy priorities, targets, and international negotiations on climate change. The Climate Futures Project is an initiative of the Sustainable Futures Collaborative, originally an independent initiative co-developed by the Centre for Policy Research and the Indian Institute of Technology Delhi, that aims to foster the informed and measured use of climate policy modelling studies by decision makers, scientists, journalists and concerned citizens. We apply a common framework to assess, compare, and interpret the assumptions and results of modelling studies.
www.climatefuturesproject.in

About SFC:
The Sustainable Futures Collaborative (SFC) is a New Delhi-based independent research organisation that analyses issues at the frontier of addressing climate change, managing the energy transition, and limiting environmental threats in India and globally; informs policymakers, stakeholders, and the public about key policy and governance levers, and their implications; and accelerates the transition to an environmentally and socially sustainable future by enabling strategic action for systemic change.

Highlights

The stated purpose of the report is to define two possible roadmaps to the decarbonisation of the Indian economy in the context of continued economic growth, and identify emission-reduction initiatives and cross-cutting approaches to decarbonise six sectors (power, automotive, aviation, steel, cement and agriculture) that contribute to 70% of overall emissions.

Key Merits

- Bottom-up, in-depth sectoral modelling of six sectors allows for a granular view of mitigation levers.
- The report offers a set of policy priorities for the next decade, and reflects on the implications of mitigation levers for land use, household spending, and India's energy system.
- The report provides clear estimates of the investment required to finance decarbonisation within each of these six sectors, and indicates how these investments could bring about shifts in demand and technology to accelerate low-carbon transitions.

Scope for Improvement

- The report acknowledges job transformation due to decarbonisation but lacks detailed analysis on job impacts from transition and demand shifts.
- Equity issues and non-economic aspects like health and environmental quality are addressed only nominally.
- Uncertainties around technological change, policy implementation, urbanisation, economic growth, finance, and energy competitiveness are discussed qualitatively, but the impact on modelled scenarios is unclear, limiting discussion on alternative development pathways.

The Climate Futures Project

Models are powerful analytical tools that shape policy priorities, targets, and international negotiations on climate change. These models, however, can feature unclear and widely divergent assumptions, resulting in overly simplistic or conflicting recommendations about an uncertain future. It is imperative that the construct and results of these various studies be adequately understood and contextualised.

The Climate Futures Project is an independent initiative to foster an informed and measured use of such modelling studies by policymakers, scientists, journalists and concerned citizens. We apply a common framework to assess, compare, and interpret the assumptions and results of modelling studies. This project is an initiative of the Sustainable Futures Collaborative, originally independent initiative co-developed by the Centre for Policy Research and the Indian Institute of Technology Delhi.

Model Factsheets

A model factsheet, such as this one, employs a common framework to assess, compare, and interpret the assumptions and results of current climate modelling studies. Each factsheet is structured to include:

1. An overview of the stated purpose of the model, key merits, and scope for improvement, model type and structure, and key scenarios included in the model.

2. An assessment of modelling approach through an evaluation along five parameters.

3. The five parameters are as follows: transparency and credibility of model inputs, appropriateness of model structure to research objective, scenario construction process, approach to uncertainty, and transparency and validation of outputs.

4. Comparison of results: A summary table of results from the model, including core assumptions, emissions outcomes, energy and electricity projections, and projected costs and investments.

5. Outcomes of the model are interpreted along six categories of implications: development pathway, energy transition implications, emissions, investments, equity and resource impacts and energy security.

I: Introduction

Purpose and Type

Purpose of study: This study seeks to define two possible roadmaps to the decarbonisation of the Indian economy, initiatives and cross-cutting approaches to decarbonise six sectors: power, transport, aviation, steel, cement and agriculture.

Source: McKinsey and Company, 2022. Decarbonising India: Charting a pathway for sustainable growth. October 2022. McKinsey Sustainability. (Link)

Model Type:
McKinsey's Decarbonisation Scenario Explorer (DSE) builds bottom-up emissions abatement scenarios using activity levels, demand projections, emissions factors, costs, technologies, and abatement levers. The DSE is supplemented by a least-cost optimisation model for India's power sector and a financial model to estimate capital expenditures.

Model Structure

DSE: Five sectors—Power, Transport, Agriculture, Steel, and Cement are modelled in detail,[1] with breakdowns of activity levels, demand, emissions, and costs. Other sectors, like buildings, waste, and industries such as aluminium and ammonia, are modelled at a high level using McKinsey's Decarbonisation Lever Library (DLL).

Cross-cutting enablers such as carbon capture, utilisation, and storage (CCUS), material circularity, natural climate solutions (NCS) and green hydrogen are modelled bottom-up based on inputs from the sector-wise models and integrated into the DSE.

The financing model looks at the full system Capex required for production as well as the Capex and Opex incurred in adopting decarbonisation levers. The capital cost reductions for some critical technologies such as batteries and electrolysers are based on the learning rate.

Cost outlooks for various commodities and technologies are defined based on inputs from the offline sector deep-dives as well as the DLL.

For fossil fuels, prices are assumed to decline with falling oil demand.

Power and hydrogen prices are dynamically modelled in the McKinsey Power Model and used as input for the demand sectors in the DSE.

1 The model does not include the aviation sector.

Key Scenarios

This McKinsey report spotlights two scenarios and the actions and circumstances that may result in the realisation of these scenarios.

Line of Sight (LoS) scenario

This scenario assumes “current (and announced) policies and foreseeable technology adoption”. It also assumes the implementation of India’s Nationally Determined Contribution under the Paris Agreement.

Accelerated scenario

This scenario considers faster adoption of decarbonisation levers and quicker reduction in technology costs. More importantly, it considers new regulations (like carbon price through an emission-trading scheme) and faster maturing of new technologies (e.g., CCUS).

II: Assessment of Approach

This section comprises an evaluation of the robustness and appropriateness of the modelling exercise along a set of parameters.

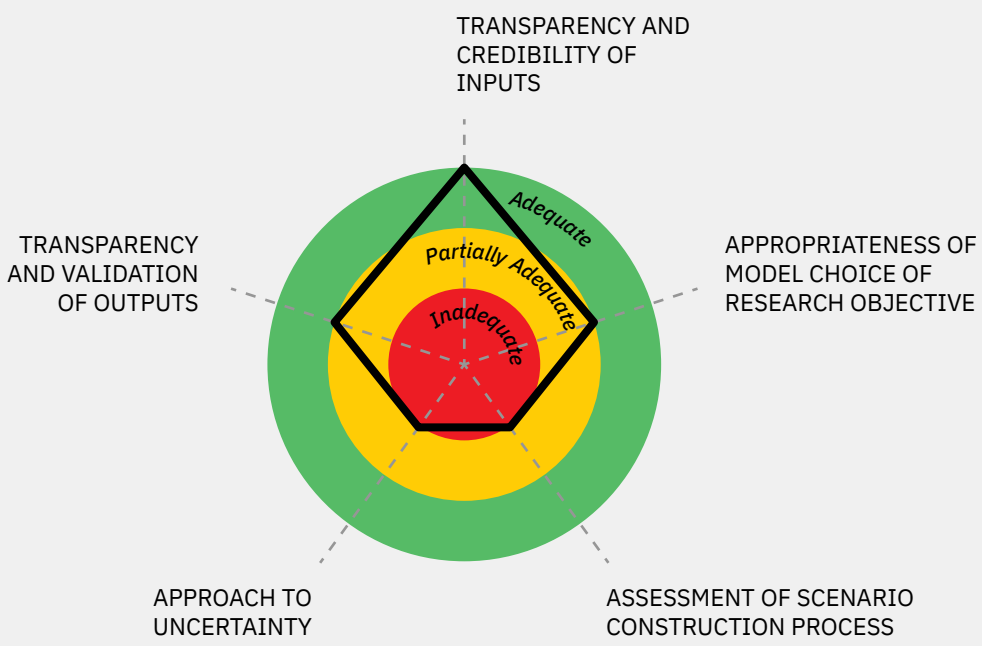
The framework for assessment employed in this section was developed based on studies of good practices for computational models which inform decision-making. A review of these papers indicated a few common themes: clarity of purpose, importance of model specification and the process involved, assessing data quality, dealing with uncertainty, and validation of the model and its results.

We arrived at the final indicators through an iterative process of applying the indicators to contemporary modelling studies, gauging their applicability and usefulness, and engaging in a peer review process for the framework. The five criteria used for assessment of the modelling approach are:

1. Transparency and credibility of inputs to the model
2. Appropriateness of model choice to research objective
3. Assessment of scenario construction process
4. Approach to uncertainty
5. Transparency and Validation of outputs

The figure below provides a summary of how the McKinsey modelling approach fares along the five criteria mentioned above. The following pages include a detailed description of each criterion and a rationale for the final score. They also include responses from the authors of the underlying study to the assessment.

Figure 1: Scoring McKinsey Modelling Approach on Five Evaluation Criteria



1. Transparency and credibility of inputs to the model

Assessment of whether key inputs are transparent and have an adequate empirical basis. Key inputs include:

- Techno-economic data (demand trends, costs of technologies, fuel costs, technology options)
- Socio-economic drivers, i.e., population, and economic growth

Overall Assessment Score: Adequate
Inputs to the study have been transparently presented and discussed, and clearly cited. Uncertainties have been qualitatively discussed. The model is not designed to address uncertainties in socio-economic drivers, which the study acknowledges.

The study is:
Adequate if all three parameters are met for both techno-economic data and socio-economic drivers
Partially adequate if parameter 1 and 2 are met, but 3 is unmet for both techno-economic data and socio-economic drivers
Inadequate otherwise

Assessment Parameters	Detailed Assessments
1. Are data and data sources transparently stated and, where possible, based on multiple corroborating sources?	**Yes** Data on growth, emissions, population, energy demand trends and investments are presented transparently. However, certain demand and technology inputs are sourced from McKinsey's proprietary tools and frameworks. This limits transparency on some assumptions and cost estimates.
2. Are the data up-to-date, with the bounds of data availability constraints?	**Yes** The report uses 2019 as the base year for emissions, with some 2020 and 2021 sector-specific data based on availability. This data may not capture post-pandemic shifts in demand or emissions trends, which the authors acknowledge.
3. Are inputs justified sufficiently through clear reasoning, particularly when they are based on projections? In particular (rated yes if any one of the sub-questions are true):	**Yes** Sector-specific inputs were validated by 50+ industry experts. In addition, consistency checks ensure coherence across sectoral forecasts.
3.1. Is the basis for future projections explained and justified? For example reasonable justifications include expert interviews and validation includes consistency checks.	**Yes** The report details how sector-specific data, sources, and assumptions are validated using expert input. Projections are also aligned with India's official estimates, and referenced appropriately.
3.2. Do inputs adequately reflect growing uncertainties over time?	**No** The report only lists out a few factors that could evolve differently in the future, without incorporating them in projections.

Response from study authors:

There was no response from the study authors

2. Appropriateness of model choice to research objective

Assessment of whether the purpose of the study is aligned with the choice of model and whether this can be transparently assessed. This is important, as choice of model both enables the user to answer some types of questions and precludes users from answering others.

Overall Assessment Score: **Partially Adequate.** The model is suited for the purpose of identifying emissions abatement levers and quantifying their costs and potential. However, its reliance on proprietary datasets makes replication challenging. While it uses a least-cost optimisation approach and emphasises finance and investment, outcomes are

The study is:
Adequate if parameters 1, 2 and 3 are marked 'yes',
Partially adequate if parameters 1 and 2 are marked 'yes',
Inadequate otherwise

Assessment Parameters	Detailed Assessments
1. Is the model structure transparent? (rated yes if at least 2 of the following are true)	**No** The report takes a bottom-up approach to modelling demand and emissions for each sector. The structure of the model is clear. However, some tools and inputs remain proprietary.
1.1. Has the model structure been described adequately through text and/or figures?	**Yes** The sectoral model structures are clearly explained. The optimisation model used for the power sector is explained using a figure that lists its inputs and outputs.
1.2. Is the model itself open-source?	**No** Certain inputs are based on proprietary data sets.
1.3. Is there sufficient description and accessibility to data and model structure to enable replication of the model?	**No** The report provides enough detail to allow broad replication of trends and scenarios but lacks accessibility to specific proprietary data.
2. Is there adequate discussion of the strengths and weaknesses of the model structure, with respect to its fitness for purpose?	**Yes** The model's limitations in addressing uncertainties, including socio-economic variables, policy impact variability, and sector-specific economic assumptions are qualitatively discussed – in detail.

Assessment Parameters	Detailed Assessments
3. Is the application of the model consistent with its design and structure? Is the purpose of the study aligned with the choice of model; i.e., is the modelling approach fit for purpose (rated yes if at least 2 of the following are true)?	**Yes** The approach adopted in the study uses tailored models for each sector to ensure the analysis captures the nuances, challenges, and potential of each area. Cross-sector enablers and interlinkages are modeled to reflect real-world complexities, while transparent assumptions enhance reliability.
3.1. Is the level of model detail appropriate for the purpose? [e.g. detailed representation of energy system for renewable integration]	**Yes** Granular sectoral demand projections and assumptions around technological change are laid out in considerable detail.
3.2. Are key conclusions drawn based on the strengths of the model structure, and qualified for limitations of the model structure?	**Yes** Key conclusions related to emissions abatement and investment are drawn based on the strengths of the model structure. One limitation, however, is that there is little discussion of how changes in policy implementation could influence specific scenario outcomes.
3.3. If the study makes clear policy recommendations, is the model equipped to evaluate the impact of policy actions?[2]	**No** The model is not equipped to evaluate the social impact of decarbonisation, or the effect of specific policies and policy challenges.

Response from study authors:

There was no response from the study authors

3. Assessment of scenario construction process

Assessment of whether the scenario construction is transparently and well-designed to evaluate policy actions and outcomes across a range of high-impact, high-uncertainty contextual factors.

Overall Assessment Score: Inadequate. The scenarios are sector-specific, and are discussed in great detail. However, there is insufficient detail on the process of designing these scenarios and their incorporation of socioeconomic variabilities.

The study is:
Adequate if parameters 1, 2 and 3 are marked 'yes',
Partially adequate if parameters 1 and 2 are marked 'yes',
Inadequate otherwise

Assessment Parameters	Detailed Assessments
1. Is the rationale for alternative scenario 'storylines' appropriate to study purpose, and adequately discussed and explained (marked yes if both of the following are true)? • **Is there an explanation of the rationale for each scenario and how different scenarios relate to each other?** • **Are the scenarios well-designed to address the research question?**	**Yes** The scenarios are explained in depth. Their rationale and complementarity is explicitly tied to India's decarbonisation objectives, which the study aims to explore. The report contrasts their projected outcomes, to highlight their complementarity. **Yes** The research question is how can India achieve sustainable economic growth while transitioning to a low-carbon economy and meet its net-zero target by 2070. The scenarios are well-designed to address this by offering a baseline (LoS scenario) and an ambitious pathway (Accelerated scenario) to explore feasible measures for decarbonisation.
2. Is the process through which these storylines were developed explained? (marked yes if at least 2 of the following are true) • **Is the process transparent?** • **Did the process involve users, notably policy-makers?** • **Was the process iterative?**	**No** While the report provides in-depth sectoral analysis and cites expert inputs, it lacks transparency on the development process for the scenarios themselves. The process does not mention an iterative approach or active involvement of policymakers in scenario design.
3. Do the scenarios account for alternative socio-economic pathways, in addition to technology development and adoption pathways? OR have the implications of not exploring those uncertainties on the results been discussed qualitatively?	**No** The study notes that accounting for varying socio-economic pathways is not the focus of this model. Socio-economic factors such as urbanisation and population are fixed inputs. Uncertainties inherent in the results are discussed qualitatively.

Response from study authors:

There was no response from the study authors

4. Approach to uncertainty

Assessment of the study's approach to addressing and communicating uncertainty across the various criteria identified above. Across:

- Economic growth
- Technology options
- Cost trajectories
- Any other uncertainties in input assumptions or model processes?

Overall Assessment Score: Inadequate. While the study explains its limitations in detail, and identifies uncertainties that may influence results, qualitatively, it fails to analyse how uncertainties may evolve with time.

The study is:
Adequate if parameters 1, 2 and 3 are marked 'yes',
Partially adequate if parameters 1 and 2 are marked 'yes',
Inadequate otherwise

Assessment Parameters	Detailed Assessments
1. Have uncertainties in the input assumptions and results been analysed and presented transparently? Specifically, do figures include uncertainty bands, wherever reasonably quantifiable OR where not quantifiable, are qualitative explanations included? (E.g., does the study discuss contextual changes which may make trend-based projections less certain or conversely, account for insights or knowledge about future projections not present in historical data?)	**Yes** Uncertainties related to technology, policy implementation and microeconomic factors are discussed qualitatively and transparently, even if they are not quantified in the model's inputs or results. The report does not include quantitative uncertainty bands on figures.
2. Have uncertainties associated with the model's causal mechanisms through which inputs are translated into key outputs been analysed and presented transparently? Approaches include through modelling of alternative possible causal mechanisms, and their consequences on outputs, OR through discussion of alternative mechanisms?	**No** The report does not explicitly explain the causal pathways or mechanisms through which these inputs directly lead to the stated outputs. How inputs influence outputs is largely implied rather than explicitly detailed.
3. Do the model results analyse and represent how uncertainty may change with time?	**No** The report notes uncertainties in technology adoption and policy implementation, especially regarding advancements and cost reductions, but does not analyse how these may evolve over time, focusing instead on fixed scenarios.

Response from study authors:

There was no response from the study authors

5. Transparency and Validation of outputs

Assessment of whether the key outputs are presented transparently and validated.

Overall Assessment Score: **Partially adequate.** The study provides a thorough explanation of the drivers of model results. If the results are validated by experts remains unclear. The study could have engaged more with the results of other comparable studies.

The study is:
Adequate if parameters 1, 2 and 3 are marked 'yes',
Partially adequate if parameters 1 and 2 are marked 'yes',
Inadequate otherwise

Assessment Parameters	Detailed Assessments
1. Have outputs been presented in a manner that facilitates consideration of how they (outputs) are shaped by input assumptions, model mechanics, and scenarios?	**Yes** Uncertainties related to technology, policy implementation and microeconomic factors are discussed qualitatively and transparently, even if they are not quantified in the model's inputs or results. The report does not include quantitative uncertainty bands on figures.
2. Have the implications of uncertainties in inputs and model structure been considered in reporting of results and consequent policy implications?	**Yes** Uncertainties have been qualitatively discussed, and each sectoral chapter discusses a set of policy, technology and finance-related challenges that must be understood to contextualise results.
3. Have results been validated with efforts at validation clearly presented? Forms of validation include: • **Expert validation** • **Peer review** • **Validation through literature** • **Empirical validation** • **Cross-country analysis**	**No** The report does not explicitly present detailed efforts at validation. Though the report mentions the contributions from a multidisciplinary team of sector experts, its unclear how and if experts were engaged in the scenario development process or the validation process.

Response from study authors:

There was no response from the study authors

III: Summary of Outputs

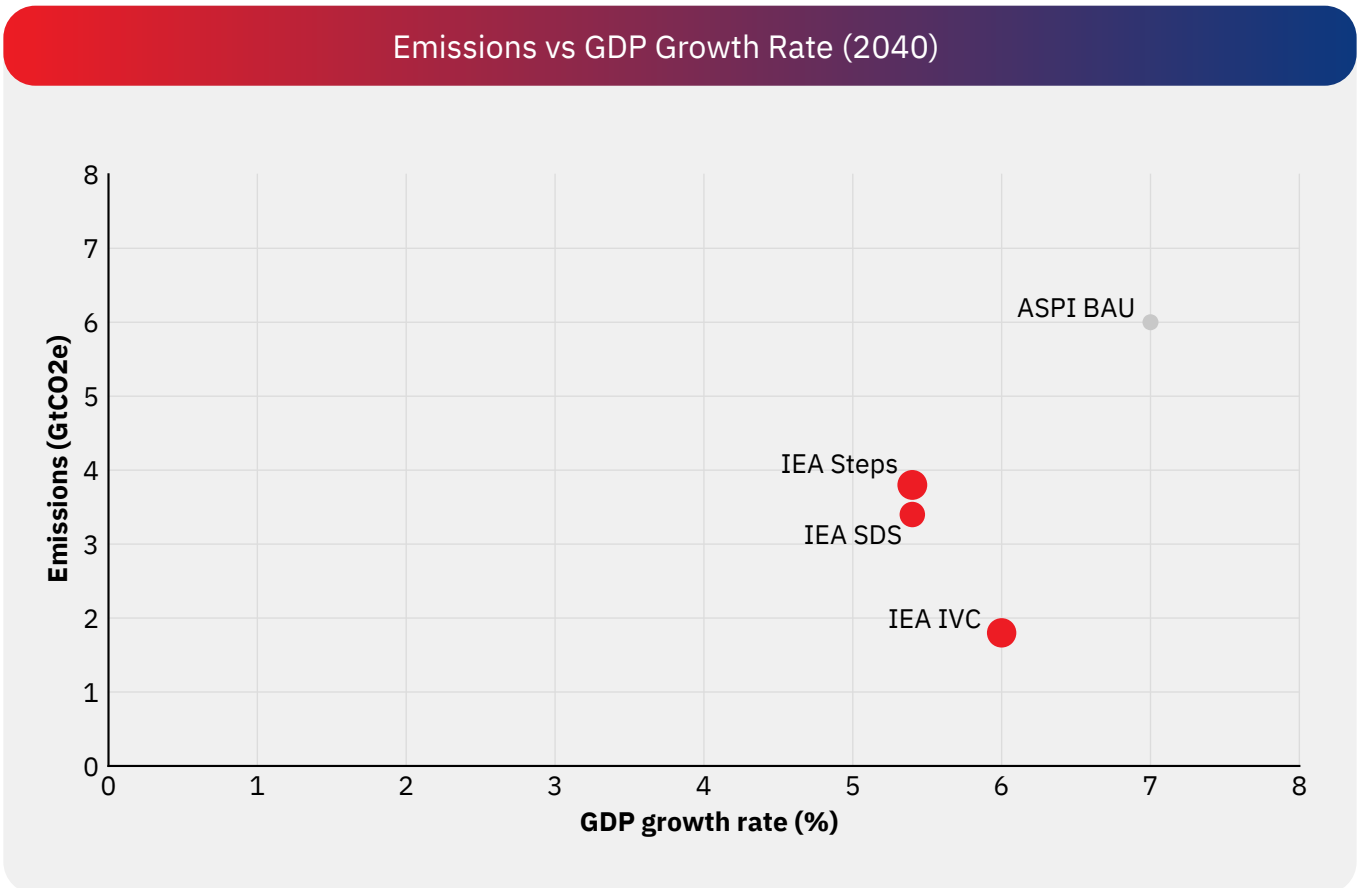
Key Findings Across Studies

This section presents key projections related to emissions, GDP growth, final energy demand, installed capacity, and energy supply for the years 2040, 2050, 2060, and 2070.

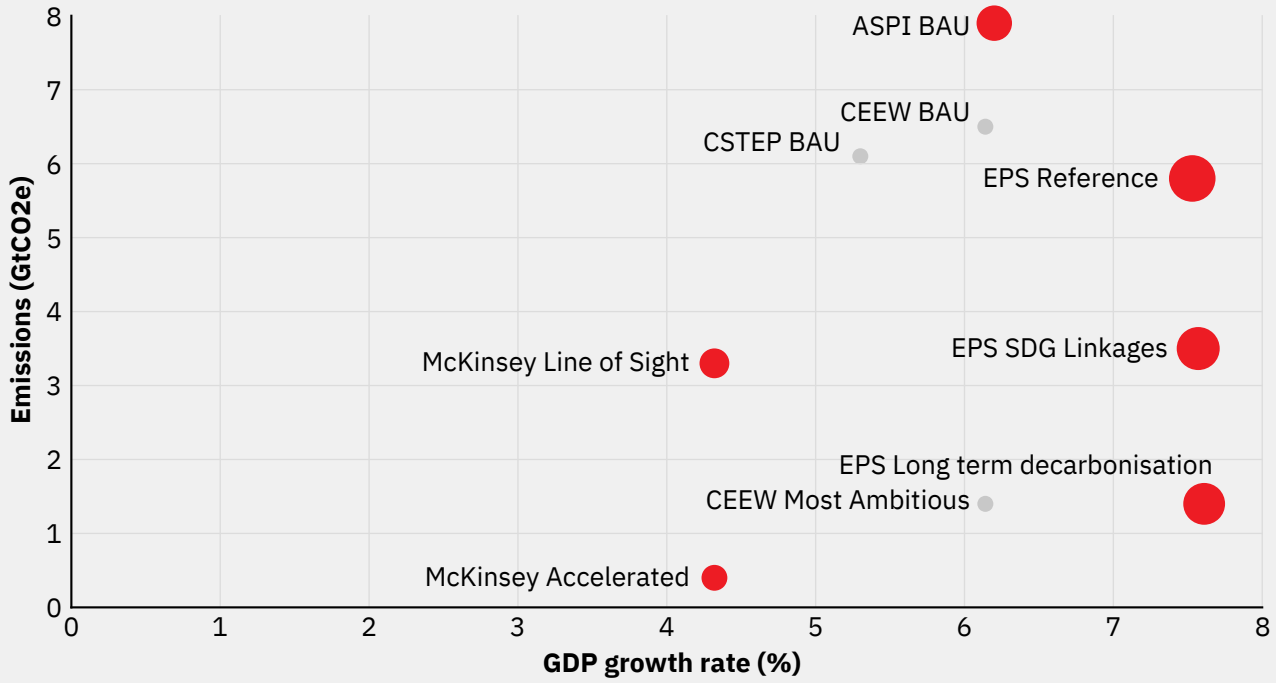
We summarise these results graphically across all studies assessed, and in tabular form for this study.

Figure 2: Annual GHG emissions in end-year vs. average GDP growth rate from base year

Notes: TERI-Shell and CEEW estimates are not adjusted for CCUS and carbon sinks, which are included in their scenarios to enable net-zero emissions; CEEW figures represent averages of four scenarios within respective net-zero years; Figures adjacent to the points represent primary energy demand in megatonnes of oil equivalent (Mtoe)



Emissions vs GDP Growth Rate (2050)



Emissions vs GDP Growth Rate (2070)

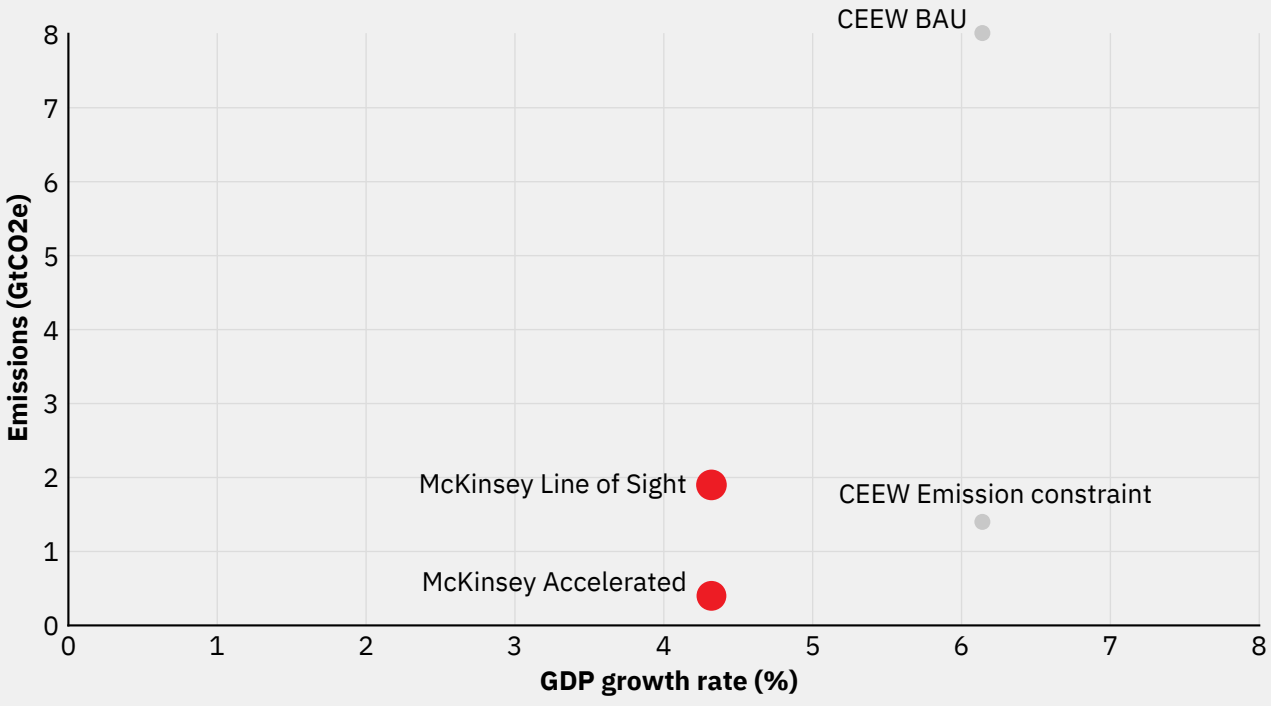


Figure 3: Final energy demand versus GDP growth rate in end-year faceted by end-use sector

Notes: 2019 data is sourced from IEA, in which building energy consumption includes traditional biomass use; Studies for which data was not available are not represented. IEA figures correspond to the 2040 year, the real data is from 2019, and CSTEP is 2050.

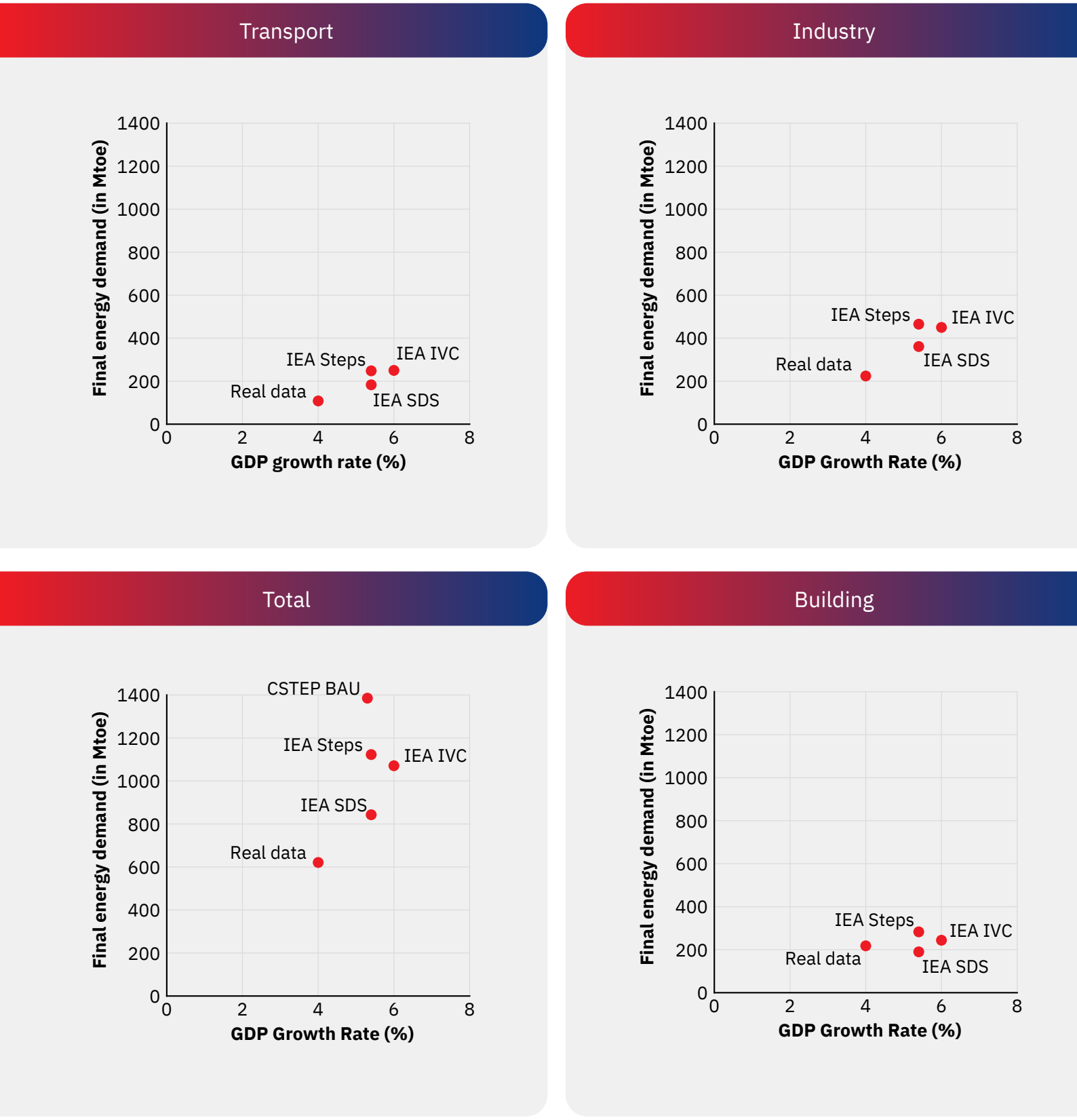
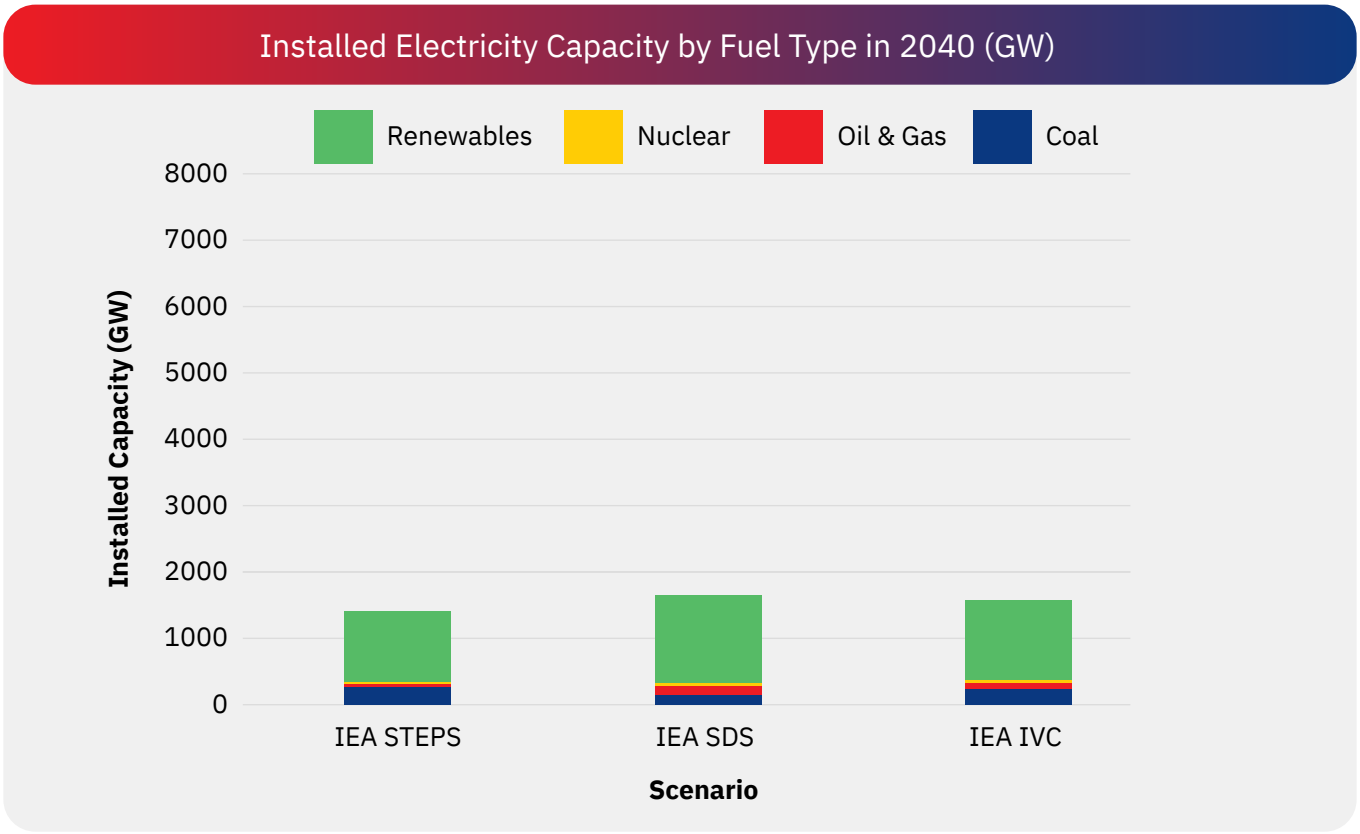
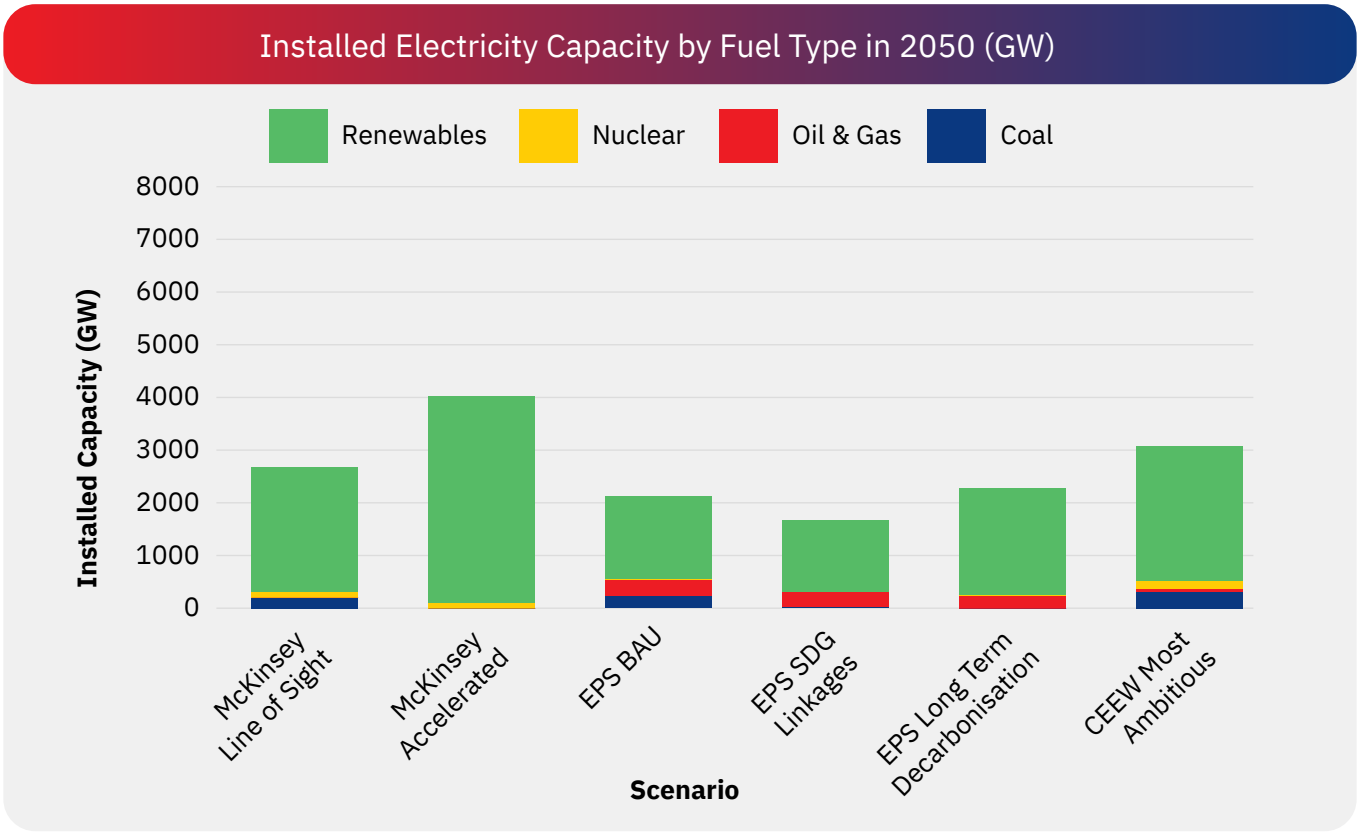


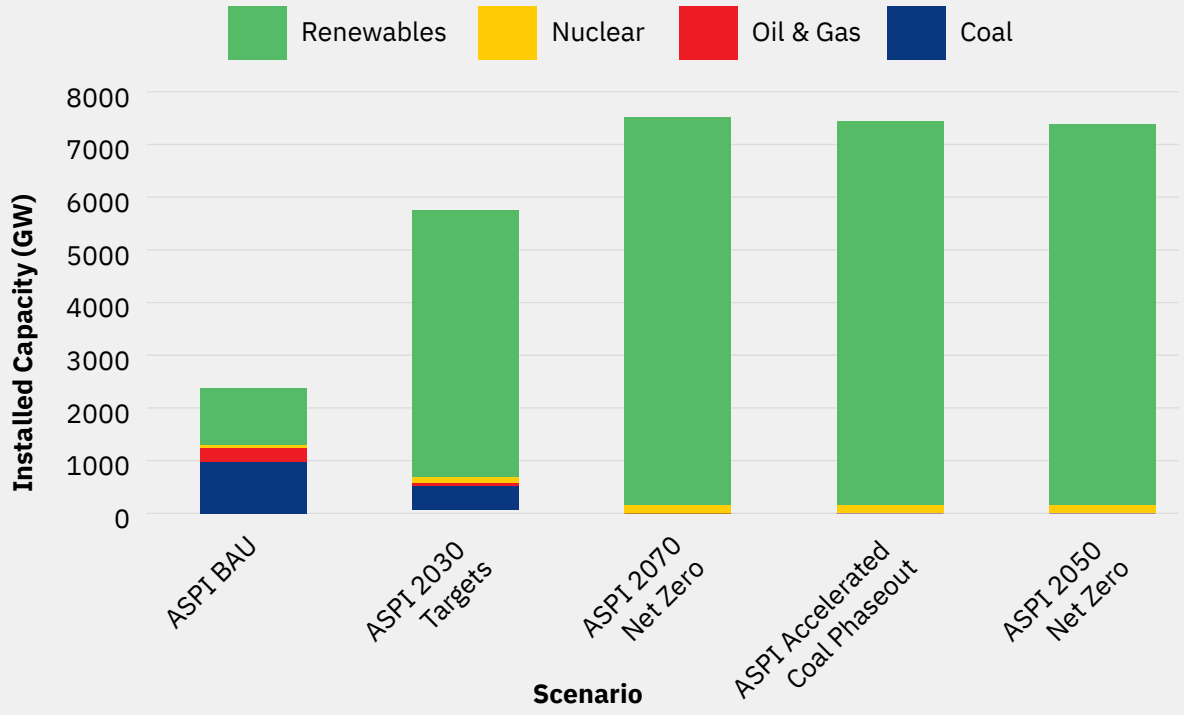
Figure 4: Installed electricity capacity (GW) in end-year

** Notes: Studies for which data was not available are not represented*





Installed Electricity Capacity by Fuel Type in 2060 (GW)



Installed Electricity Capacity by Fuel Type in 2070 (GW)

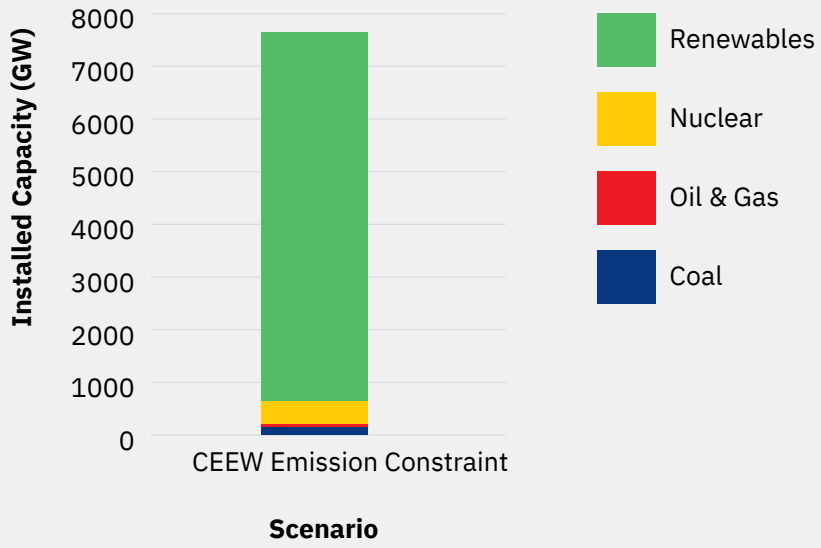
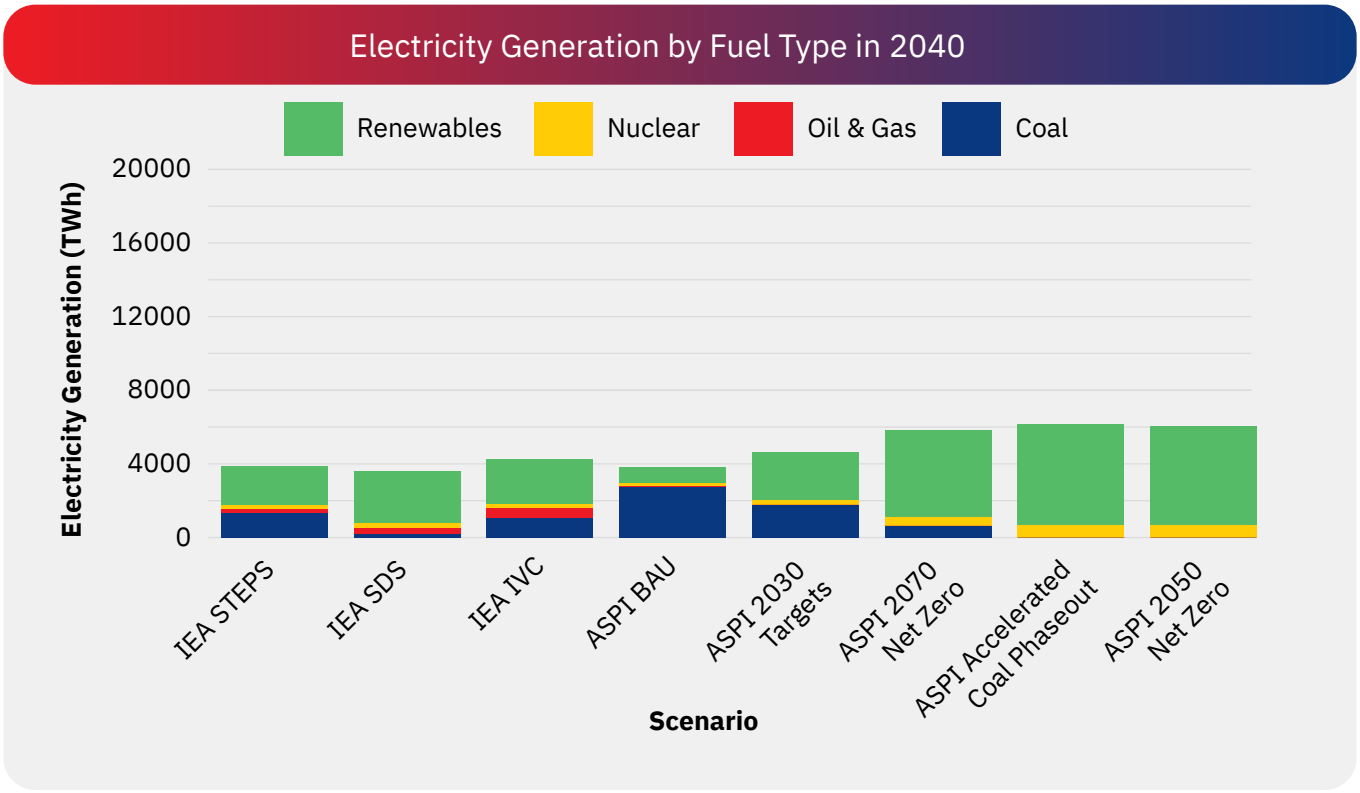
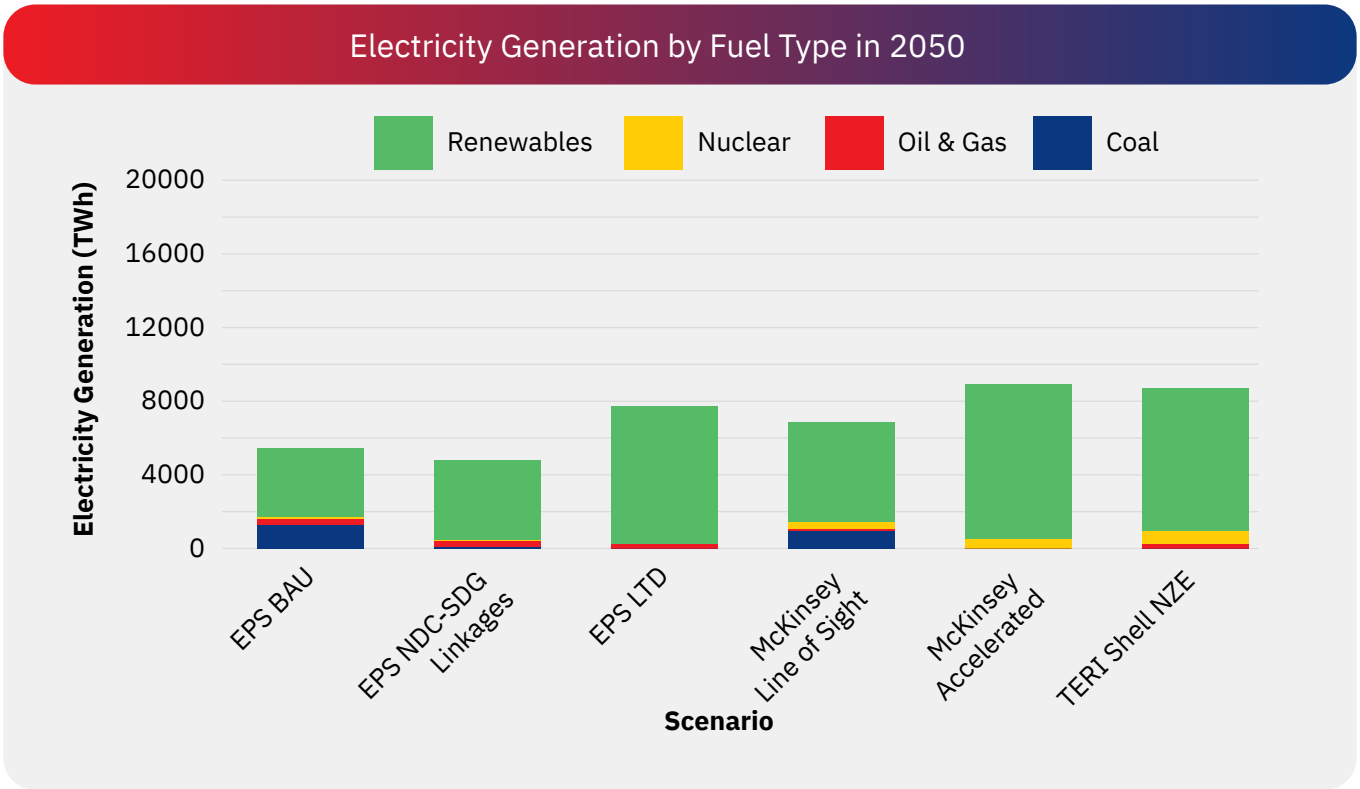
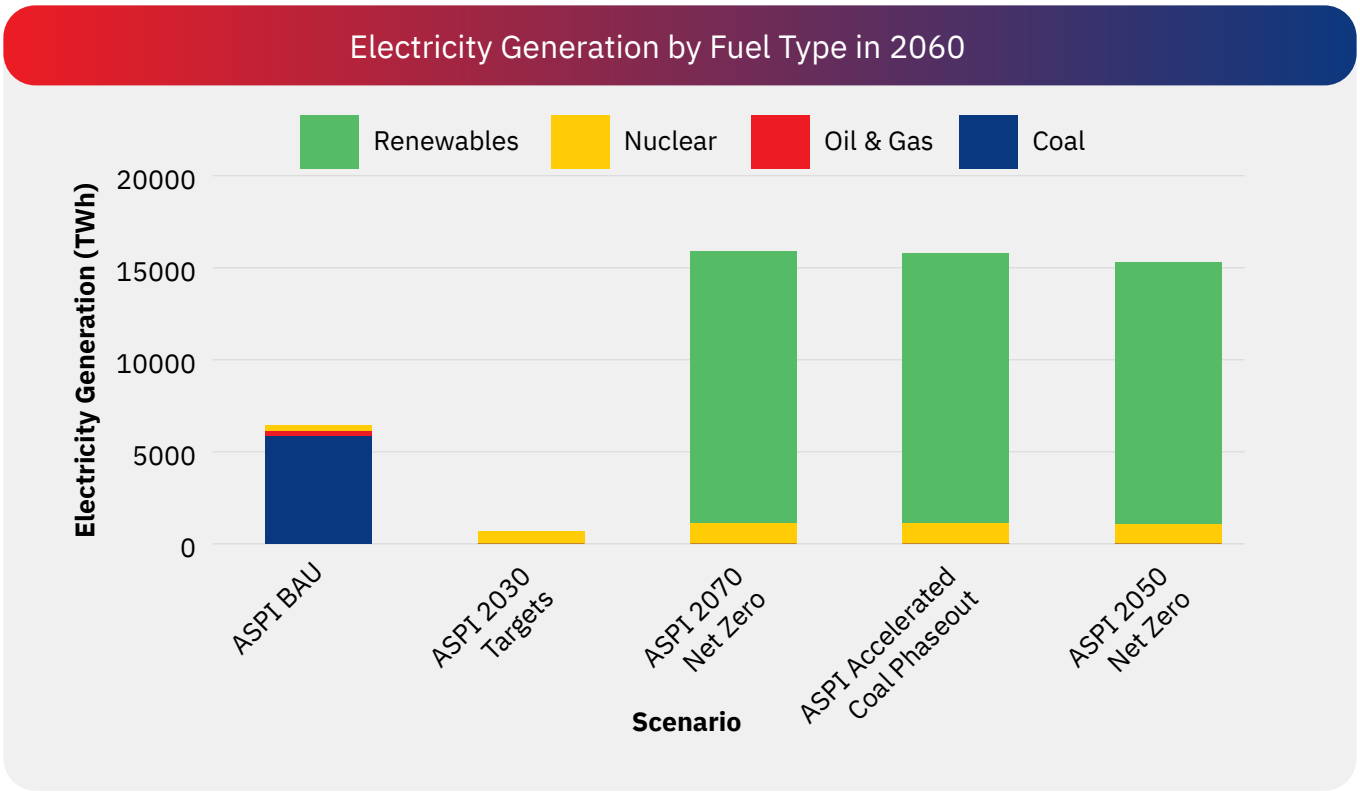


Figure 5: Electricity generation by fuel source in end-year

** Notes: Studies for which data was not available are not represented*
For ASPI, Renewables includes Biomass, Wind, Solar and Hydro
For IEA, Renewables includes Hydro, Bioenergy, Wind, Geothermal, Solar PV and CSP and Marine
For McKinsey, Nuclear includes hydro, biomass and nuclear (cannot be separated)







Key Results in Current Study

Scenario	Line of Sight	Accelerated
Macro-Structural Variables (2070)		
Annual GDP Growth (%)	4.23%[2]	4.23%[3]
GDP	$22 trillion economy in real 2010-dollar terms[4]	$22 trillion economy in real 2010-dollar terms[5]
Population	1.7 billion	1.7 billion
Urbanisation (%)	Data not listed[6]	Data not listed[7]

2 Gross domestic product (GDP) at constant market prices, rebased to 2010 constant prices and translated into US$ using the LCU:$ exchange rate in 2010 – from The Economist Intelligence Unit for 2020–50. Assumed 3% annual real GDP growth from 2050–70 (p. 43, 45, iii): 2020-2030: 5.8% ; 2030-2040: 5.1%; 2040-2050: 4.7%; 2050-2060: 3%; 2060-2070: 3%

3 Gross domestic product (GDP) at constant market prices, rebased to 2010 constant prices and translated into US$ using the LCU:$ exchange rate in 2010 – from The Economist Intelligence Unit for 2020–50. Assumed 3% annual real GDP growth from 2050–70 (p. 43, 45, iii): 2020-2030: 5.8% ; 2030-2040: 5.1%; 2040-2050: 4.7%; 2050-2060: 3%; 2060-2070: 3%

4 Based on Economist Intelligence Unit projection of $12.5 trillion by 2050 (Real GDP - USD at 2010 prices) and extrapolated to 2070 with 3 percent CAGR assumption. Real GDP growth rate assumption based on Economist Intelligence Unit (EIU) projection for 2020–30 is 5.8 percent, 2030–40 is 5.1 percent and 2040–50 is 4.7 percent. 2050–70 Real GDP growth rate has been assumed to be about 3 percent annually.

5 Based on Economist Intelligence Unit projection of $12.5 trillion by 2050 (Real GDP - USD at 2010 prices) and extrapolated to 2070 with 3 percent CAGR assumption. Real GDP growth rate assumption based on Economist Intelligence Unit (EIU) projection for 2020–30 is 5.8 percent, 2030–40 is 5.1 percent and 2040–50 is 4.7 percent. 2050–70 Real GDP growth rate has been assumed to be about 3 percent annually.

6 Note: India does not reach net-zero, “due to the residual emissions from agriculture and select industrial sectors (remaining emissions in 2070 of 1.8 and 0.4 GtCO2e in the LoS and Accelerated scenarios, respectively)”.However, coal emissions will reach net zero by 2070.

7 Note: India does not reach net-zero, “due to the residual emissions from agriculture and select industrial sectors (remaining emissions in 2070 of 1.8 and 0.4 GtCO2e in the LoS and Accelerated scenarios, respectively)”.However, coal emissions will reach net zero by 2050.

Scenario	Line of Sight	Accelerated
Job Growth Outcome	*Data not listed*	24 million new jobs could be created while six million of the existing jobs could be lost by 2050
Emissions		
Peaking Year	"Emissions peak in the early 2030s"	"Emissions peak in mid-2020s"
Emissions in Peaking Year (GtCO2e)	3.8 GtCO2e	3.4 GtCO2e
Net Zero Year	Data not listed	Data not listed
Energy Emissions in Net Zero Year (GtCO2e)	Power sector emissions are 1.27 GtCO2e in 2030	Power sector emissions are 1.30 GtCO2e in 2025
Energy and Electricity (2050)		
Primary Energy Demand (Mtoe)	1570 Mtoe[8]	1180 Mtoe[9]
Installed Generation Capacity (GW)	2675 GW	4019 GW
Electricity Demand (TWh)	6846 TWh[10]	8920 TWh[11]
RE Share in Electricity Generation (%)	79%	94%
RE Share in Primary Energy (%)	46% by 2050, and 85% by 2070[12]	86% by 2050, and 92% by 2070[13]
Costs and Investments		
Energy Investment Required	$2.5 trillion investment in renewable energy and storage required by 2050	$3.8 trillion investment in renewable energy and storage required by 2050

Table 1: Summary of key variables

8 This is the primary energy supply.
9 This is the primary energy supply.
10 Power sector generation.
11 Power sector generation.
12 Since it is green hydrogen, the RE share here also includes green hydrogen.
13 Since it is green hydrogen, the RE share here also includes green hydrogen.

IV: Interpretation of Results

This section comprises an interpretation of model outcomes along a set of parameters, in order to aid understanding of policy relevant insights.

Policy Parameter	Description
Development Pathway • **How does the model determine macro-structural assumptions (such as urbanisation, growth, jobs, total and sectoral energy demand, and electrification)?** • **What do macro-structural assumptions imply for patterns of development and how do they diverge from current trends?**	The study assumes steady growth in GDP and energy and materials demand driven by urbanisation. Alternative economic growth and urbanisation rates aren't explored. However, the model projects significant shifts in sectoral energy consumption, driven by growth in the industrial and transport sectors. Although the report estimates jobs created and lost, it does not explore their quality. The assumptions reflect an aspirational, forward-looking pathway that emphasises decarbonisation but does not explicitly test or present alternative macro-structural trends or their implications for development.
Energy Transition Pathway • **What does the study imply for sectoral energy needs, the composition of the energy mix, its adequacy, and other enabling considerations (e.g., complementary infrastructure, utilisation, resource adequacy)?** • **What are the technological implications of the study, and how are these expected to be realised?**	The study examines India's energy transition, focusing on sectoral energy needs, the evolving energy mix, and enablers like infrastructure, storage, and local manufacturing. It highlights energy demand drivers such as economic growth, industrial expansion, and efficiency improvements, with a strong emphasis on green technologies. While scenarios assume uniform urbanisation rates influencing energy use in construction, transport, and residential electrification, structural growth drivers and labor intensity implications are underexplored. The study details sectoral energy demand, the cost competitiveness of technologies like green hydrogen and batteries, and enabling measures such as grid expansion, storage, land adequacy, and domestic energy security. It underscores the importance of local manufacturing to scale solar panels, wind turbines, and batteries while reducing import dependency. Technological advancements, particularly in renewable technologies and electrolysers for hydrogen, are pivotal. However, the study overlooks the extensive infrastructure investments required for electrification and the challenges of transitioning from fossil fuels without economic or policy friction.

Policy Parameter	Description
Emissions • **Are emissions projected (to explore feasibility based on policies), or back-calculated (to assess policy needs) from an end-goal?** • **How complete is the coverage: are any sources of emissions not reflected?** • **What do technological and demand trends imply about robustness of emissions estimates, where projected?**	The report back-calculates emissions, starting from India's net-zero target and exploring pathways to meet this goal. Policies are evaluated based on their feasibility to achieve these emissions targets, lending credibility to the emissions estimates. But with shallow exploration of uncertainties, this robustness is somewhat limited. While the inclusion of key mitigation strategies such as renewable energy, green hydrogen, and CCUS enhances the robustness of emissions estimates, these projections depend heavily on optimistic assumptions about cost reductions and rapid technological deployment. The coverage of emissions sources is broad, including major contributors like power, automotive, and agriculture, with focus on GHG emissions more broadly and also CO2 specifically. However, certain smaller sources—like waste management and industrial by-products—are not extensively analysed. The integration of carbon sinks and land-use changes increases the scope for emissions reductions, but the feasibility of achieving projected outcomes depends on enabling policies and investments.
Investments • **What lessons does the study offer for investments, based on technological choices, cost assumptions, sectoral coverage, and avoided expenses?** • **Are investments factored as inputs or outputs within the modelling process?** • **How do investment estimates relate to cost and growth assumptions?**	The study highlights that India's transition to a low-carbon economy requires significant upfront investment, primarily in renewables, green hydrogen, and energy storage. The report provides different estimates for the LoS and Accelerated scenarios. These include investments in infrastructure and technology that are "in the money" (cost-effective in the long run) for sectors like power and agriculture. Investments are considered both inputs and outputs in the model. For example, certain investment levels are required to meet energy capacity and emissions targets. The report also calculates avoided costs, such as reduced energy imports, which yield economic savings. The investment estimates are aligned with GDP growth assumptions, strengthening the feasibility of estimates. The study offers broad insights but does not provide granular details on the financial structuring or specificity of investments.

Policy Parameter	Description
Equity and Resource Impacts • **If feasible, how does the study explore variations in economic outcomes across socioeconomic classes, sectors, or regions?** • **How do macro-structural inputs account for the roles of the informal economy and employment?** • **How does the study consider the natural resource implications of technology deployment? (ecosystem resources, land, water etc)**	The study acknowledges that India's energy transition will have diverse economic impacts, with 30 million jobs being transformed by 2050. However, it does not delve into how these impacts will vary across socioeconomic classes or regions. It touches on the need for reskilling and industrial redevelopment but lacks specific analyses of how different groups may be affected. The report does not analyse the role of the informal sector or how the transition will impact informal employment. The report considers the natural resource demands of decarbonisation, particularly land and water use for renewable energy and hydrogen production. It emphasises efficient land-use strategies and sustainable agricultural practices to avoid land competition, although it doesn't cover the ecosystem impacts of repurposing barren lands or trade-offs inherent in greater water use. The report discusses NCS, which involve conserving and restoring ecosystems to enhance carbon storage and reduce GHG emissions. It highlights the social and environmental co-benefits of an Accelerated NCS scenario, including biodiversity protection, improved air, water, and soil quality, and climate hazard mitigation and adaptation.
Energy Security • **Does the study factor fuel and material import dependence into its energy capacity and investment estimates?**	The study acknowledges India's reliance on fuel and material imports. By shifting to renewables and green hydrogen, it projects a significant reduction in energy imports, with savings in foreign exchange. However, it also highlights India's current dependence on imports for renewable technologies, and recommends localising manufacturing to improve energy security and reduce vulnerabilities. The study also addresses the risks of a disorderly transition if infrastructure and demand signals are not aligned, which could disrupt energy security and lead to resource shortages or import dependency in the short term.

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/sustainablefutures

/sustainablefuturescollab

hello@sustainablefutures.org

A-16, First Floor, Qutab Institutional Area
Aruna Asaf Ali Marg, New Delhi (110067)