Unpacking ‘Implications of a Net-Zero Target for India’s Sectoral Energy Transitions and Climate Policy’

The Climate Futures Project

Bridging Climate Policy and Models

CENTRE FOR POLICY RESEARCH

THE CLIMATE FUTURES PROJECT

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THE CLIMATE FUTURES PROJECT

Models are powerful analytical tools that shape policy priorities, targets, and international negotiations on climate change. The Climate Futures Project is an independent initiative co-developed by the Centre for Policy Research and the Indian Institute of Technology Delhi 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.
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THE CONSORTIUM

The Initiative on Climate, Energy and Environment at the Centre for Policy Research (CPR-ICEE) aims to stimulate an informed debate on the laws, policies and institutions shaping climate, energy and environmental governance in India. Our research focuses on an improved understanding of climate, development and environmental challenges – and pathways to improved outcomes – in three key areas: climate policy and institutions, the political economy of energy transition in India, and air quality governance. ***http://cprindia.org/projects/initiative-climate-energy-and-environment***

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Highlights

Purpose

- ***The stated purpose*** *of the study is to address the gap of '**informing the pathways and implications towards a net zero target**', across different net zero target and peaking years, and breakthrough technology costs.*

Key merits

- *With hydrogen and CCS technologies being amongst the most uncertain in terms of their commercial viability, this study contributes to our understanding by highlighting implications of their commercial viability (or lack thereof) on **the overall energy supply system under different net-zero pressures using a cost optimisation approach**.*

Scope for improvement

- *However, the study is limited by insufficient reflection on uncertainties from other key factors such as socio-economic drivers (E.g., GDP, urbanisation, energy demand), or uncertainties in costs of other emerging technologies such as storage, especially given the broad stated purpose of '**informing the pathways and implications towards a peaking year and net zero target**'.*
- ***The study does not clarify financial, equity, or energy security implications of the energy transition; or the trade-offs between developmental and mitigation choices**. Lastly, a discussion on pathways to overall net-zero would also benefit from explorations of non-energy emissions.*


NET
ZERO
CO_2

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 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: 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*
3. *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.*
4. *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

1.1. Purpose and Type

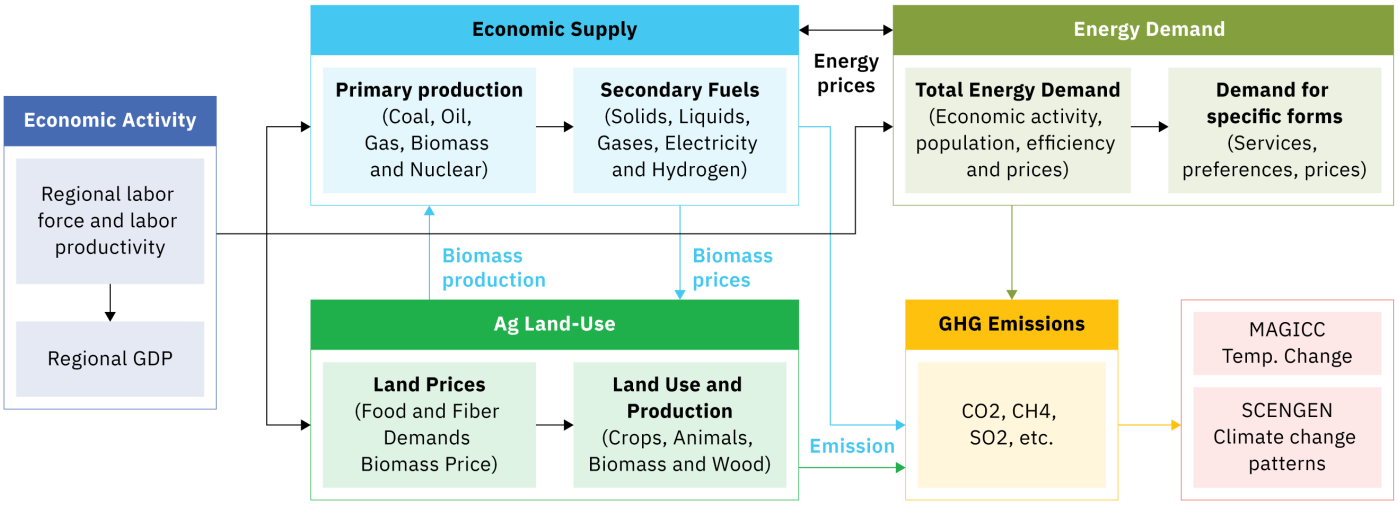
Purpose of Study: *This model seeks to inform India's net zero future by presenting a wide range of alternative scenarios and drawing out different policy options and technology configurations.*

Source: *Chaturvedi, V. and Malyan, A., 2021. Implications of a Net-Zero Target for India's Sectoral Energy Transitions and Climate Policy. Council on Energy, Environment and Water (CEEW). (**Link**, **Annexure link**)*

Model Type: *The model used is the Global Change Analysis Model (GCAM), an integrated assessment model, consisting of amongst others, economic, energy system, and land use modules. The implications of this model choice are explained further **here**.*

Model Structure:

Figure S1: Schematic representation of Global Change Analysis Model (GCAM)



*Source: Reproduced CEEW **Annexure**, based on Joint Global Change Research Institute / Pacific Northwest National Laboratory, USA*

Figure 1: Modelling structure | Source: Annexure

1.2. Key Scenarios

The CEEW study proposes 16 policy scenarios, along with 1 reference scenario. The policy scenarios are constructed according to peaking- and net-zero- years and the expected availability of technological breakthroughs. The combinations of peaking- and net-zero years studied are: 2030-2050, 2030-2060, 2040-2070, and 2050-2080. Each of these policy timeframes are further subdivided into 4 possible scenarios that account for combinations of CCS (yes or no) and hydrogen (high or low) availability.

1. Reference scenario (progress as usual scenario):

This scenario assumes continued increases in GDP and income that results in more demand for consumer goods, and continued lowering of costs of low carbon technology, leading to more penetration across sectors.

2. Most ambitious scenario:

Under this scenario, the peaking of emissions is expected to occur in 2030 with net zero achieved by 2050.

3. Emission constraint scenarios:

This is a lower ambition scenario that assumes the peaking- and net-zero occur beyond 2030-2050 respectively (i.e., 2030-2060, 2040-2070, and 2050-2080). The key assumption is emissions trends follow the reference scenario until the respective peak years, followed by linear declines up to the respective net zero years.

II: Assessment of Approach

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

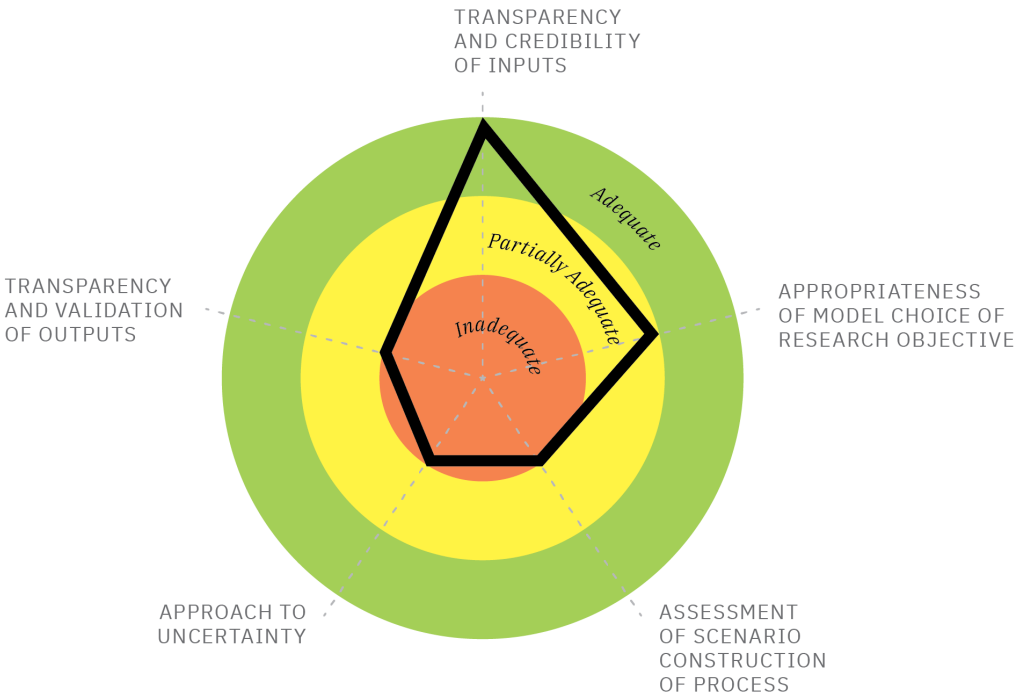
The framework for assessment employed in this section was developed based on studies of good practices for computational models which inform decision-making. A review of these papers indicated a few common themes: clarity of purpose, importance of model specification and the process involved, assessing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

CEEW



1. Transparency and credibility of inputs to the model

Overall Assessment Criteria	Overall Assessment Score
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	**Adequate** Input data is largely transparently described and justified. With regard to future projections, uncertainties are accounted for and justified mainly for technology cost and efficiency drivers, while increasing uncertainties in socio-economic drivers have not been accounted for in the inputs.

Sub-Criteria for Assessment	Sub-Criteria Scores
***Decision Rules to Aggregate Sub-criteria Scores**:* *For this assessment criterion, the study is rated 'Adequate' if all three sub-criteria are met, 'Partially adequate' if any two sub-criteria are met, and 'Inadequate' otherwise.*	
Are data and data sources transparently stated and, where possible, based on multiple corroborating sources?	**Yes** Most data for key inputs which drive outputs are stated in the Annexure. Key inputs include technology costs, GDP growth, energy efficiency assumptions. One key data point which is absent, however, is the demand growth, and final energy demand assumptions across sectors.
Are the data up-to-date, within the bounds of data availability constraints?	**Yes** Most data and assumptions are referenced with recently published sources.
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** Selected technology cost and energy efficiency inputs are justified through citations. However, one major limitation is the assumption of single projections for socio-economic drivers, and technology costs (except. hydrogen and CCS) across all scenarios.
• Is the basis for future projections explained and justified? For example reasonable justifications include expert interviews and validation includes consistency checks.	• **Yes** Selected future projections, such as technology costs are justified through citations of other studies. Socioeconomic projections have not been justified. Further explanation of the justification and reasoning behind the choice of projections would have bolstered transparency and credibility.
• Do inputs adequately reflect growing uncertainties over time?	• **No** Uncertainties are incorporated for hydrogen and CCS technology costs projections, but not other supply technology costs or demand trends driven by socio-economic drivers, such as GDP etc.

Response from authors: The approach tries to evaluate a specific analysis on the yardstick of a larger and complex problem that has many dimensions. Within one research study, we are trying to do specific analysis within the framework set by specific questions. A specific study can only be evaluated on the lines of 'claims' it makes, or if the conclusion derived is not defensible given the methodology and assumptions.

2. Appropriateness of model choice to research objective

Overall Assessment Criteria	Overall Assessment Score
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.	**Partially Adequate** The choice of model is aligned with the specific research objective of exploring technology cost options for achieving net zero, at different time frames. The model is, however, limited in addressing the broader objective of "informing pathways and implications towards net-zero", since the model is not capable of simulating social and governance processes which play a strong role in pathways towards net-zero.

Sub-Criteria for Assessment	Sub-Criteria Scores
***Decision Rules to Aggregate Sub-criteria Scores**:* *For this assessment criterion, the study is rated 'Adequate' if all three sub-criteria are met, 'Partially adequate' if any two sub-criteria are met, and 'Inadequate' otherwise.*	
Is the model structure transparent? (rated yes if at least 2 of the following are true)	**Yes** The model structure is transparent.
• Has the model structure been described adequately through text and/or figures?	• **Yes** Although the description of the model structure is brief, and likely insufficient to replicate the model, there are several references to peer reviewed literature which use the same model and have detailed model descriptions. This lends transparency and credibility to the model descriptions.
• Is the model itself open-source?	• **No** A different, but related version of the model developed by JGCRI institute is available for download. It is unclear, however, to what extent the model version used for this study is different from the open source version.
• Is there sufficient description and accessibility to data and model structure to enable replication of the model?	• **Yes** Key equations and overall model structure is described in the annexure of the study and in several peer reviewed publications However, it is likely to be very challenging and resource intensive to replicate the model solely on these descriptions.

Sub-Criteria for Assessment	Sub-Criteria Scores
Is there adequate discussion of the strengths and weaknesses of the model structure, with respect to its fitness for purpose?	**No** There is insufficient reflection on the specific implications of model assumptions on the intended purpose of the study. Some key assumptions include: emission trajectories are exogenously imposed and assumed to be successfully achieved, other countries do not emit beyond 2025, framing is primarily around costs, not benefits. The limitations of the model, are acknowledged briefly without touching upon such key assumptions, such as in the italicized excerpt below: *"Our modelling approach mainly represents the implications of economic choices... While we have discussed many issues related to the political economy of transition, issues related to just transition, as well as constraints related to land and water, are beyond the scope of our analytical framework. This can be regarded as a limitation of our approach."*
Are key conclusions drawn based on the strengths of the model structure, and qualified for limitations of the model structure? e.g., is the level of model detail appropriate for its conclusions? Is the model equipped to evaluate the impact of policy actions?	**Yes** Key conclusions are certainly all based on the strengths of the model, but the conclusions could have been qualified in greater depth for the limitations. For example, the logit model of the electricity sector may not be able to simulate the challenges involved in integrating intermittent renewables.

Response from authors: N/A

3. Assessment of scenario construction process

Overall Assessment Criteria	Overall Assessment Score
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. Scenarios provide a way to explore alternative policy-relevant futures. However, these have to be developed in a manner that clearly lays out the underlying rationale for the scenario, and transparently explains the drivers of change under each scenario.	**Inadequate** The stated purpose of the study is to address the gap of 'informing the pathways and implications towards a net zero target', across different net zero target years and breakthrough technology costs. Although the scenarios are well-designed to address the specific objective of informing net zero pathways across different net zero target years and breakthrough technology costs, we rate the scenario construction process inadequate in terms of the broader objective, for the following reasons: (i) alternatives in key socio-economic variables and technology cost (eg: storage)variables are not investigated within the scenarios (ii) the process through which the scenarios were developed is not explained (iii) the exclusive focus on long-term uncertainties of hydrogen and CCS leaves the study ill-equipped to comment on costs and trade-offs related to shorter term uncertainties (for example, a peaking year in 2030 or 2040).

Sub-Criteria for Assessment	Sub-Criteria Scores
***Decision Rules to Aggregate Sub-criteria Scores**:* *For this assessment criterion, the study is rated 'Adequate' if all three sub-criteria are met, 'Partially adequate' if any two sub-criteria are met, and 'Inadequate' otherwise.*	
Is the rationale for alternative scenario 'storylines', appropriate to study purpose, adequately discussed and explained (ranked adequate if both of the following are true)?	**Yes**
• Is there an explanation of the rationale for each scenario and how different scenarios relate to each other?	• **Yes**
• Are the scenarios well-designed to address the research question?	• **Yes** The scenarios are well-designed to address the specific objective of informing net zero pathways across different net zero target years and breakthrough technology costs.
Is the process through which these storylines were developed explained? (ranked adequate if at least2 of the following are true)	**No** Because there are no explanations regarding the process employed to arrive at the scenarios.
• Is the process transparent?	• **No**
• Did the process involve users, notably policy-makers?	• **No** Because insufficient information.
• Was the process iterative?	• **No** Because information is unavailable
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 uses a single trend for socio-economic growth rates across scenarios, while noting implications in a limited manner: "Mature economies that are already on a stable and lower economic growth path with declining emissions trajectory would find it comparatively easier to accelerate the transition to a net-zero future."

Response from authors: N/A

4. Approach to uncertainty

Overall Assessment Criteria	Overall Assessment Score
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?	**Inadequate** The study addresses uncertainties only for costs of hydrogen and CCS, and a temporal component, leaving out those related to demand growth, technological costs and so on. Furthermore, little attention is paid to uncertainties in model causal structures and possible implications on policy recommendations. Despite some exploration of uncertainties, the uncertainty bands don't reflect the full range of uncertainties required for an analysis of implications of peaking and net zero pathways.

Sub-Criteria for Assessment	Sub-Criteria Scores
***Decision Rules to Aggregate Sub-criteria Scores**:* *For this assessment criterion, the study is rated 'Adequate' if all three sub-criteria are met, 'Partially adequate' if any two sub-criteria are met, and 'Inadequate' otherwise.*	
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?)	**No** Some uncertainties are analysed and presented transparently, through quantified uncertainty bands. However, there is a notable absence of explorations of uncertainties in key inputs such as demand growth, and costs (related to generation technologies other than hydrogen and CCS).
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** Limitations related to model structure are listed (for e.g., how the model does not characterise feasibility – impacts of per capita income, political economy aspects etc.,). However, uncertainties related to model structure are not discussed explicitly. Furthermore, the implications of these limitations could have been discussed in greater detail, with greater references to alternative mechanisms and related underlying theories.
Do the model results analyse and represent how uncertainty may change with time?	**Yes** The model produces uncertainty bands for each scenario and timestep, even uncertainties are tested only for two variables (cost of hydrogen and CCS).

Response from authors: N/A

5. Transparency and validation of outputs

Overall Assessment Criteria	Overall Assessment Score
Transparency and validation of outputs Assessment of whether the key outputs are presented transparently and validated.	**Inadequate** Although the drivers of outputs are presented transparently, the study is limited in terms of uncertainty analyses, particularly in the context of the broader purpose of 'informing the pathways and implications towards a net zero target'. Additionally, the credibility of the study would have been strengthened through more rigorous forms of validation including peer review, and contextualisation with results of other decarbonisation studies.

Sub-Criteria for Assessment	Sub-Criteria Scores
***Decision Rules to Aggregate Sub-criteria Scores**:* *For this assessment criterion, the study is rated 'Adequate' if all three sub-criteria are met, 'Partially adequate' if any two sub-criteria are met, and 'Inadequate' otherwise.*	
Have outputs been presented in a manner that facilitates consideration of how they (outputs) are shaped by input assumptions, model mechanics, and scenarios?	**Yes** The drivers of outputs in the model are explained in detail.
Have the implications of uncertainties in inputs and model structure been considered in reporting of results and consequent policy implications?	**No** Key uncertainties in inputs (except hydrogen and CCS) and model structure are not thoroughly explored; in particular, uncertainties in socio-economic trends, alternative socio-economic pathways, and technology costs are not explored.
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** There are no explicit references or reflection on the validity of the outputs through any of the forms mentioned here.

Response from authors: N/A

III. Summary of Outputs

*In this section, we present **key mid-century projections related to emissions, GDP growth, final energy demand,** and **energy supply**, across studies*. We summarise these results graphically across all studies assessed, and in tabular form for this present study.*

3.1 Key Findings Across Studies

**Apart from IEA 2021, the other studies we include in the graphics below are*

***(i) International Energy Agency, 2021.** India Energy Outlook 2021. OECD.*

***(ii) TERI-Shell India, 2021.** India: Transforming to a Net-Zero Emissions Energy System.*

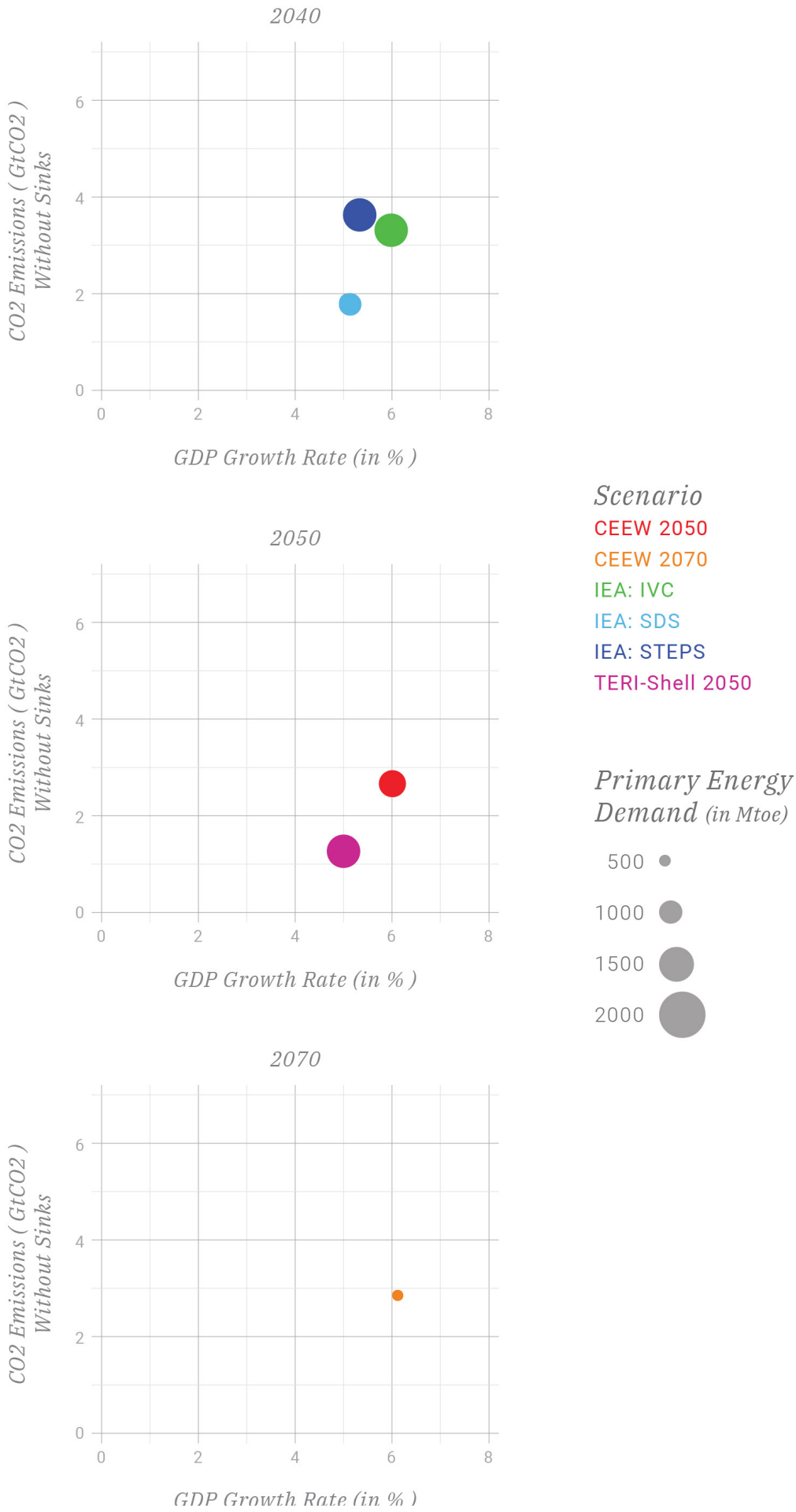


Figure 2: Annual CO2 emissions in end-year vs. average GDP growth rate from base year

** Notes: TERI-Shell and CEEW estimates are not adjusted for CCS 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)*

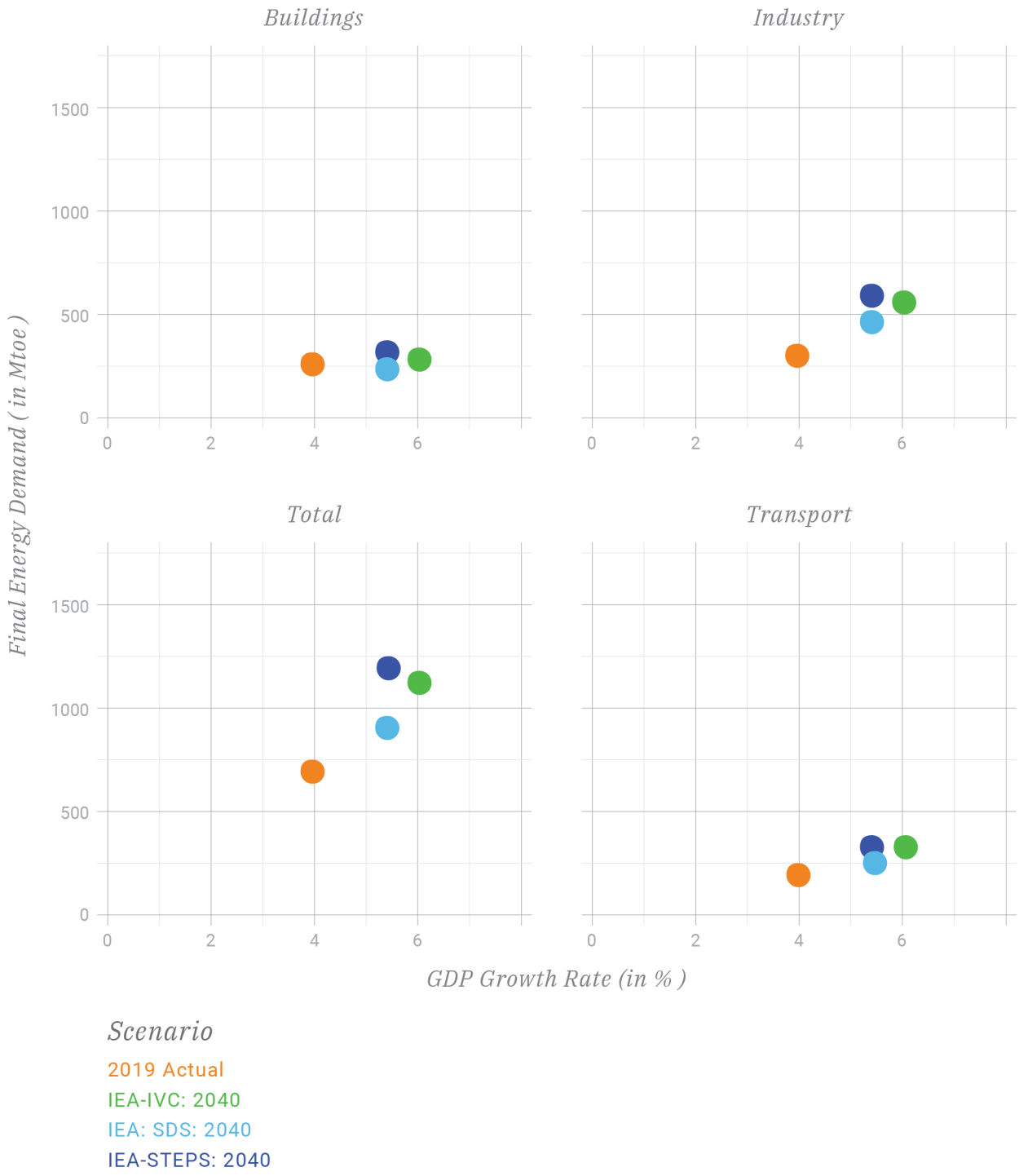


Figure 3: Final energy demand versus per capita GDP in end-year, facetted by end-use sector

** 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*

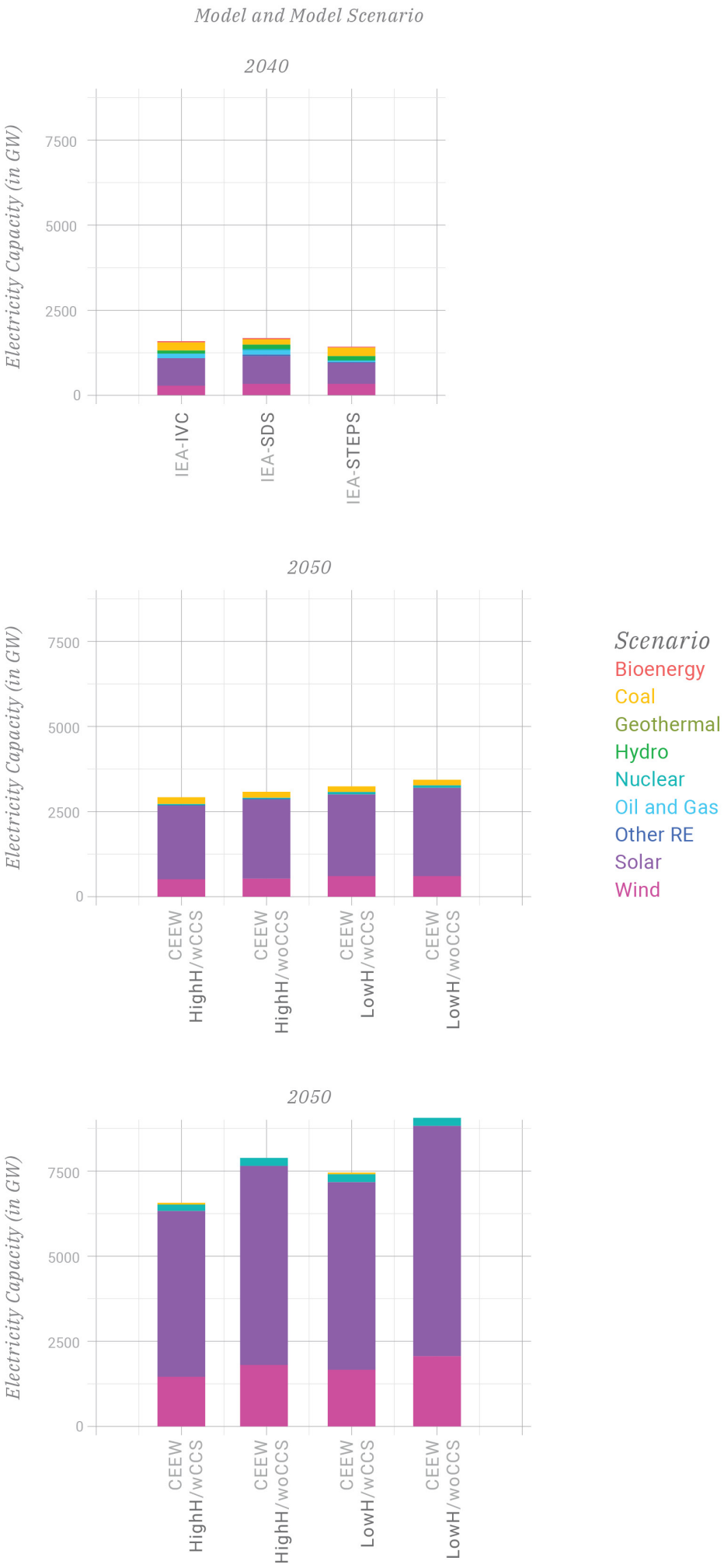


Figure 4: Installed electricity capacity (GW) in end-year

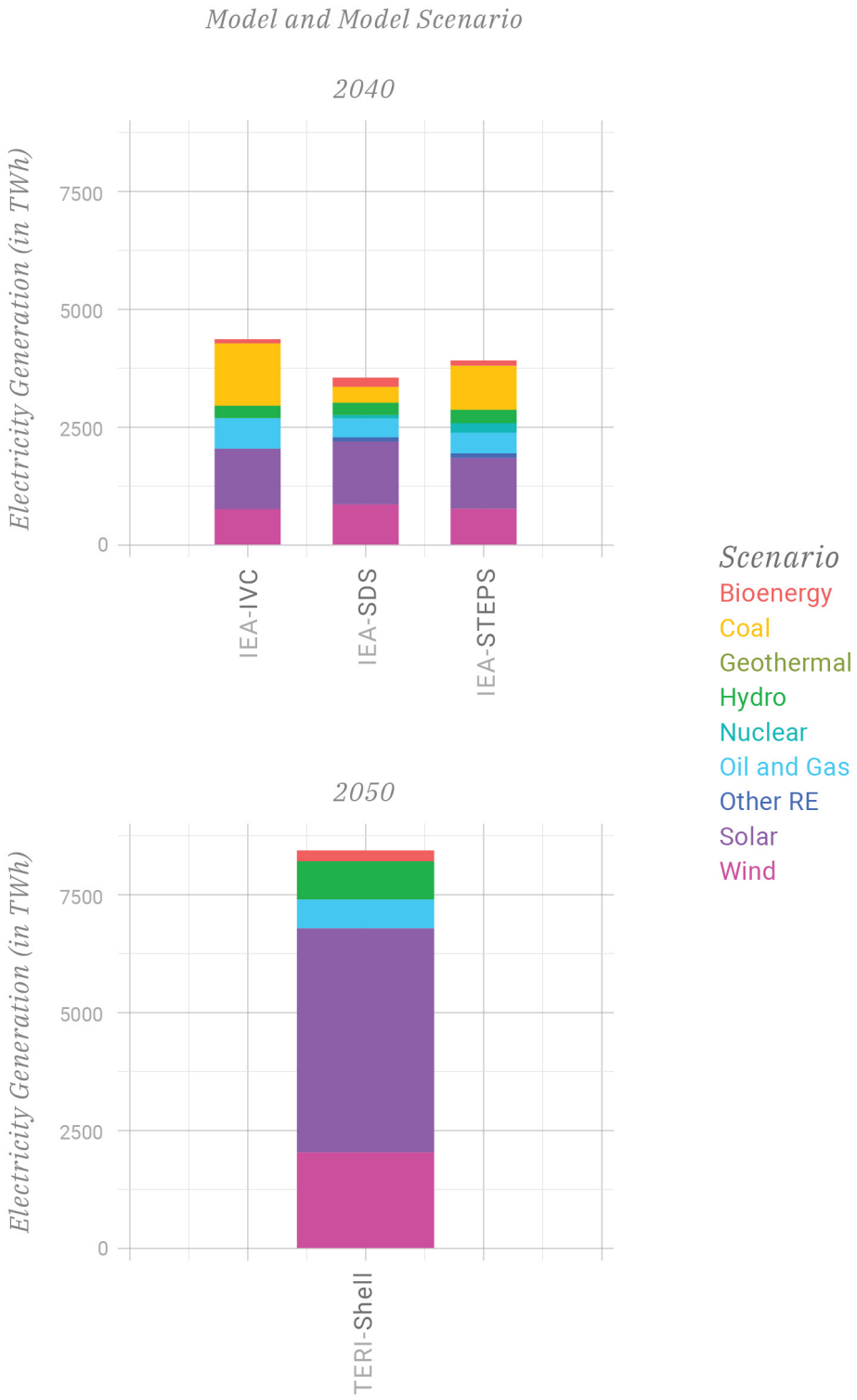


Figure 5: Electricity generation by fuel source in end-year
** Notes: Studies for which data was not available are not represented*

3.2
Key Results in Current Study

Scenario	Reference	Ambitious				Emission constraint			
		No CCS/ Low Hydrogen	CCS/Low Hydrogen	No CCS/ High Hydrogen	CCS/High Hydrogen	No CCS/ Low Hydrogen	CCS/Low Hydrogen	No CCS/ High Hydrogen	CCS/High Hydrogen
Structural Variables (2050)									
Annual GDP Growth (%)	6.14% (to 2050, CAGR)	Unclear (but appear to be the same assumption as the Reference scenario figures)							
GDP	17,143 (2015 Billion USD)								
Population	1,639 million	Data not listed							
Urbanisation (%)	50.7%	Unclear (but assumes to be corresponding with the growth rates. High-, medium- and low-growth rates lead to 55%, 50%, and 45% of urbanisation rate respectively)							
Job Growth Outcome	2 million	Unclear (estimate shown in range without specifying net zero year in Figure 5)				Approx. 2.2 million	Approx. 2.1 million	Approx. 2 million	2 million
Emissions									
Peaking Year	Endogenously determined	2030				2040			
Emissions (2050, MtCo2)	6,500 MtCo2	Approx. 1,500 MtCo2	Approx. 1,300 MtCo2	Approx. 1,300 MtCo2	Approx. 1,300 MtCo2	Approx. 3,600 MtCo2	Approx. 3,750 MtCo2	Approx. 3,800 MtCo2	Approx. 3,750 MtCo2
Emissions in Peaking Year (MtCo2)	N/A	Approx. 3,300 MtCo2	Approx. 3,300 MtCo2	Approx. 3,300 MtCo2	Approx. 3,300 MtCo2	Approx. 5,150 MtCo2	Approx. 5,200 MtCo2	Approx. 5,200 MtCo2	Approx. 5,100 MtCo2
Net Zero Year	Endogenously determined (2075)	2050				2070			
Energy Emissions in Net Zero Year (MtCO2)	Approx. 8,100 MtCO2	Approx. 1,500 MtCO2	Approx. 1,300 MtCO2	Approx. 1,300 MtCO2	Approx. 1,300 MtCO2	Approx. 1,300 MtCO2	Approx. 1,300 MtCO2	Approx. 1,500 MtCO2	Approx. 1,200 MtCO2

Scenario	Reference	Ambitious				Emission constraint			
		No CCS/ Low Hydrogen	CCS/Low Hydrogen	No CCS/ High Hydrogen	CCS/High Hydrogen	No CCS/ Low Hydrogen	CCS/Low Hydrogen	No CCS/ High Hydrogen	CCS/High Hydrogen
Per Capita Emissions (2050, tonnes/ capita)	Data not listed								
Energy and Electricity (2050)									
Primary Energy Demand (Mtoe)	Data not listed								
Installed Generation Capacity (GW)	Data not listed								
Electricity Demand (TWh)	5,500 TWh	Unclear (shown in range without specifying net zero year)				7,000 TWh	7,000 TWh	6,500 TWh	6,500 TWh
RE Share in Electricity Generation and in Primary Energy	Data not listed 20%	Data not listed Unclear (shown in range without specifying net zero year)				Data not listed 40%	Data not listed 35%	Data not listed 40%	Data not listed 35%
Costs and Investments (2050)									
Energy Investment Required	N/A (GCAM does not model to estimate)								

Table 1: Summary of key variables

Notes: (i) Emission constraints scenario presented in this Table is limited to 2040 peak-2070 net zero. (ii) Job growth is in power sector only. (iii) Energy emissions in net zero year (Gt) is taken from the sectoral emissions figure.

IV: Interpretation of Results

This section qualitatively interprets model outcomes along a set of parameters, in order to aid understanding of policy relevant insights. Through an ***iterative and consultative process, we have identified six policy priorities against which we interpret the outcomes****. These are:*

1. *Development pathway*
2. *Energy transition pathway*
3. *Emissions*
4. *Investments*
5. *Equity and resource impacts*
6. *Energy security*

For each parameter, ***the section offers a brief description and the justification for the assessment****. It also includes responses from the authors of the underlying study to the interpretation.*

Policy Parameter	Interpretation	Responses by Study Authors
Development Pathway • How does the model determine macro-structural assumptions (such as urbanization, 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 development pathway implicit in the study does not account for alternative patterns of urbanisation, demand, economic growth, and how these might affect emissions or be affected by climate policies. It instead assumes an extension of current development trends.** The study is based on a cost minimisation approach, assuming decarbonisation responses will be principally determined by the viability of two unproven technologies. The approach does not account for differences in patterns of urbanisation, construction, or consumption and energy demand. For instance, the study talks about shares of EV sales and the role of alternative fuels, without providing estimates of total vehicle sales, the composition of 2-wheelers and 3-wheelers in those sales, or shares of public transport. This approach does not enable a study of the bidirectional relationship between climate policies and economic growth trends. The industrial sector is assumed to see a small increase in its share of GDP; it is however not clear how or why that happens, or how other sectors evolve. This prevents a meaningful analysis of impacts of structural shifts on emissions or development indicators such as employment. The study does acknowledge that feasibility rests upon a number of factors including GDP, political economy, technology, international developments, resources, etc.	General response to assessment and interpretation: The approach tries to evaluate a specific analysis on the yardstick of a larger and complex problem that has many dimensions. Within one research study, we are trying to do specific analysis within the framework set by specific questions. A specific study can only be evaluated on the lines of 'claims' it makes, or if the conclusion derived is not defensible given the methodology and assumptions.

Policy Parameter	Interpretation	Responses by Study Authors
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 realized?	**The energy transition pathways explored in this study are driven primarily on the deployment of hydrogen and CCS, with other energy technologies only adjusted in response to their deployment, to minimize system costs, and are thus narrow in scope. Importantly, pathways do not respond to variances in demand factors, which aren't explored.** The study explores several scenarios optimising system costs based on either high or low costs of hydrogen and CCS uptake towards net-zero emissions, which impact shares of electricity and installed capacity. The energy transition pathway includes a role for gas in households and transport, and for nuclear power in base load generation across scenarios. Off-grid solar, which can have implications for energy access, isn't explicitly discussed. Although the setup indicates consideration of a range of diverse energy transition pathways towards various net-zero possibilities, these are primarily driven by the viability of two technologies. The study does not explicitly discuss the role of other energy technologies such as battery storage, and does not clarify how these pathways will affect associated infrastructure and financing needs. On the demand side, increases in electricity consumption are assumed to be driven by growth and urbanisation, coupled with increases in the manufacturing base and transport electrification. However, impacts of shifts in these drivers aren't discussed, and demand side measures focus on efficiency improvements in industry and buildings. The energy transition pathway thus appears to be largely supply-driven with focus on limited supply technologies	Refer to row 1 above.
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 study back-calculates technology needs for hydrogen and CCS under various peaking and net-zero emissions scenarios, and therefore isn't designed to explore feasible emissions pathways. It does not include non-energy and agricultural energy emissions.** Scenarios are based on various net-zero scenarios, and necessary policies and targets are identified working backwards from these goals. The study captures energy emissions - CO2, not overall GHG, from electricity, industry, transport, and buildings. This does not include agricultural energy use or non-energy emissions and thereby presents a partial picture of national emissions. Most scenarios assume trajectories follow the reference trajectory until their respective peaking years, and then linearly decline thereafter. This does not incorporate any bends in the emissions curve before peaking, or any potential snowball effects or disruptive impacts after peaking. Within each net-zero case, therefore, cumulative emissions are similar under different combinations of energy technology deployment. Notably, the study indicates 2010 as the base year. Subsequent and future shifts in technology and policy profiles of the two principal technology levers might affect the robustness of future estimates as well as the feasibility of realising them.	Refer to row 1 above.

Policy Parameter	Interpretation	Responses by Study Authors
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 bases investment implications primarily on two levels of feasibility (high or low) of two technologies; however, it does not explore uncertainties in the costs of any technologies, or explain assumed shifts in investment patterns and the distribution of economic co-benefits and co-costs.** Though the study doesn't quantify investment needs, it quantifies economic losses through 2100 due to shifts in investment patterns, noting that losses are heavily dependent on technology costs. The study does not however provide further details on these investment shifts, the uncertainties in the costs of the underlying technologies, or how the quantified economic losses will be distributed across sectors and what they include. It also does not explain whether these losses are net of other realised benefits. Additionally, losses are quantified in 2015 USD and the base year is stated to be 2010. These indicate a potential for variations based on fluctuations in exchange rates and advancements in technology. This limits the lessons that can be drawn for meaningfully planning the financial impacts of the transition.	Refer to row 1 above.
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?	**The study mentions elements of a just transition but does not address these in any detail, and does not discuss other distributive impacts, including those on vulnerable groups.** The study acknowledges the implications of solar power for land use, water use, and waste generation and management, and also mentions the importance of a just transition in the context of coal jobs, energy prices, fiscal revenue, and rail revenue. However, it mentions these elements without offering quantified estimates of impacts. Further, while these issues are acknowledged, they are not addressed. Discussions for instance on shares of EVs do not clarify total vehicle sales or their composition, or public transport usage, making equity and access implications difficult to infer. Skilling and education are not discussed in the context of technology development and deployment. The study does not offer a discussion on gender, the distribution of economic losses, or the role of the informal economy. Beyond the implications of solar power, the study does not explore other natural resource implications of the energy transition.	Refer to row 1 above.
Energy Security • Does the study factor fuel and material import dependence into its energy capacity and investment estimates?	**The study does not discuss implications of the energy transition pathway on energy security and import dependence.** Although coal and oil use declines in the scenarios, to be replaced by RE and potentially hydrogen, implications on fuel and component imports, and energy security, are not discussed. It is unclear how the expanded role of gas and biofuels - which constitute 15% of primary energy consumption across scenarios - will affect energy security.	Refer to row 1 above.