THE CLIMATE FUTURES PROJECT

Assessing Climate Mitigation Policy Models

A framework for model assessment, common limitations, and future avenues

The Climate Futures Project | October 2022

1. Introduction

Computational models, referred to simply as ‘models’, are increasingly playing crucial roles in decision-making across various sectors, including finance, economics, business, manufacturing, and government policy. When it comes to climate change in particular, models have enabled the scientific community to identify the causes of anthropogenic climatic changes, estimate their impacts on the physical and natural world, society, and the economy. As observed in the models assessed as part of this project, computational models also provide crucial information regarding design of mitigation policies, regarding commitments to particular levels of emission reduction. They inform climate negotiations with estimates of financing needs in developing countries.

Models, however, like technologies are neither good nor bad by themselves. Models can lead to both positive or negative consequences. For instance, the global financial crisis of 2008 has been partly attributed to models which ignore essential real-world features. Model results could therefore, be interpreted well or misinterpreted; used reliably or erroneously. Therefore, making the right decisions when using (or even commissioning) a model is perhaps more critical than the model itself.

The Climate Futures Project presents a framework and a review to help users of models – policy makers, scientists, journalists, and citizens – assess whether a model and its results can be credibly used for the purpose at hand. This document provides a brief description of the steps taken to develop an assessment framework, a detailed presentation of the framework itself, a summary of merits and limitations of commonly employed climate mitigation modelling approaches, and finally, future avenues for improvement.

2. Developing an Assessment Framework

Our assessment framework was developed based on the following steps. We conducted a review of literature on guiding the use, development, and deployment processes of computational models for public policy (Calder et al. 2018; Gilbert et al. 2018). 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 also reviewed recent literature discussing key pitfalls of computational models used for low-carbon transition related insights (Geels, Berkhout, and van Vuuren 2016; Peng et al. 2021; Süsser et al. 2022). Finally we were informed by own experiences interpreting diverse modelling results for policy recommendations in the Indian context (Dubash et al. 2018).

Once we identified the criteria for assessment, we our framework was reviewed by well-published scholars in the domain of climate and energy-economy models. Each modelling study review, which we call a ‘factsheet’, is also shared with the original study authors to elicit their comments, and allow a dialogue on the assessment.

3. The Assessment Framework

Based on the steps detailed above, we arrived at five main criteria, and three sub-criteria for each main criteria, to assess the credibility of the approach employed in a given modelling study. The five main criteria 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*

For each of the above main criteria, the evaluated study is rated either 'Adequate', 'Partially Adequate', or 'Inadequate' according to the following rules: 'Adequate' if all three sub-criteria are met, 'Partially adequate' if any two sub-criteria are met, and 'Inadequate' otherwise. The criteria are enumerated below.

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 (i) techno-economic data (demand trends, costs of technologies, fuel costs, technology options) (ii) socio-economic drivers, i.e., population, and economic growth. [Adequate/Partially Adequate/Inadequate]

The sub-criteria for this assessment criterion are the following:

a. *Are data and data sources transparently stated and, where possible, based on multiple corroborating sources? [Yes/No]*

b. *Are the data up-to-date, with the bounds of data availability constraints?*

c. *Are inputs justified sufficiently through clear reasoning, particularly when they are based on projections? In particular (rated yes if any one of the sub-criteria are rated yes):*

  - Is the basis for future projections explained and justified? For example, reasonable justifications include expert interviews and validation includes consistency checks. [Yes/No]
  - Do inputs adequately reflect growing uncertainties over time? [Yes/No]

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. [Adequate/Partially Adequate/Inadequate]

The sub-criteria for assessment are the following:

a. *Is the model structure transparent? [Yes/No] (rated yes if at least 2 of the following sub-criteria are met)*

   - Has the model structure been described adequately through text and/or figures?
   - Is the model itself open-source? [Yes/No]
   - Is there sufficient description and accessibility to data and model structure to enable replication of the model? [Yes/No]

b. *Is there adequate discussion of the strengths and weaknesses of the model structure, with respect to its fitness for purpose. [Yes/No]*

c. *Are key conclusions drawn based on the strengths of the model structure, and qualified for limitations of the model structure? For example, is the level of model detail appropriate for its conclusions? Is the model equipped to evaluate the impact of policy actions? [Yes/No]?*

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. 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. [Adequate/Partially Adequate/Inadequate]

The sub-criteria for assessment are the following:

a. *Is the rationale for alternative scenario 'storylines', appropriate to study purpose, adequately discussed and explained [Yes/No] (rated 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? [Yes/No]
   - Are the scenarios well-designed to address the research question?

b. *Is the process through which these storylines were developed explained? [Yes/No] (ranked adequate if at least2 of the following are true)*

   - Is the process transparent? [Yes/No]
   - Did the process involve users, notably policy-makers? [Yes/No]
   - Was the process iterative? [Yes/No]

c. *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? [Yes/No]*

4. *Approach to uncertainty*

Assessment of the study's approach to addressing and communicating uncertainty across the various criteria identified above, particularly, economic growth, technology options, cost trajectories, and any other uncertainties in input assumptions or model processes. [Adequate/Partially Adequate/Inadequate]

The sub-criteria for assessment are the following:

a. *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? [Yes/No] (For 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?)*

b. *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? [Yes/No]*

c. *Do the model results analyse and represent how uncertainty may change with time? [Yes/No]*

5. *Transparency and Validation of outputs*

Assessment of whether the key outputs are presented transparently and validated. [Adequate/Partially Adequate/Inadequate]

The sub-criteria for assessment are the following:

a. *Have outputs been presented in a manner that facilitates consideration of how they (outputs) are shaped by input assumptions, model mechanics, and scenarios? [Yes/No]*

b. *Have the implications of uncertainties in inputs and model structure been considered in reporting of results and consequent policy implications? [Yes/No]*

c. *Have results been validated with efforts at validation clearly presented? [Yes/No] Forms of validation include: expert validation, peer review, validation through literature, empirical validation.*

4. Merits and Limitations of Mainstream Modelling Approaches

Most models which inform climate mitigation policy are equilibrium-based constructs, which simulate individual, self interested actors operating within free market axioms. They highlight dimensions such as technologies, relative cost of low-carbon options; market competition, investments decisions and financial incentives. Fundamentally, they provide crucial knowledge regarding the magnitude of technological change required, and related financial implications; often asking two types of questions: (i) what technologies and costs can enable the achievement of certain emissions targets, or (ii) what emissions outcomes may be achieved under certain assumptions of technologies and costs.

The following table details some of the most commonly used modelling approaches, and their advantages and limitations. This table is based on the information presented in Pye and Bataille (2016).

Table A: Common modelling approaches and their merits and limitations.

Modelling type	Merits and Limitations
Accounting models are models which disaggregate all the major energy demand and supply sectors in a given region and simple balance energy supply and demand.	**Merits:** Transparent and easy to use **Limitations:** No theoretical or practical underpinning by which to forecast the effect of policy shocks on the economy or energy system in general.
Bottom-up models (**and their hybrids**) are detailed, often economy wide, linked maps of energy use from supply through end use demand, and their operating paradigm is minimization of life cycle costs for specific intermediate and end use energy demands through technology competitions, often in response to capital, labour, energy and emissions price changes.	**Merits:** Bottom-up based hybrids include elements of behavioural realism directly in investment, operation, and consumption (such as elasticity of demand) **Limitations:** Their weaknesses are their data intensiveness, behavioural simplicity (cost minimization based on financial discount rates does not completely describe firm and household behaviour), exogenous demands for energy services, lack of capacity to model the financial recycling effects of emissions charges, inability to model economic structural change.

Modelling type	Merits and Limitations
Top-down based hybrids are typically computable general equilibrium (CGE) full economy frameworks adapted for energy policy analysis. CGE models operate by maximizing household welfare subject to several operational constraints, including benchmarking of a starting equilibrium, zero windfall profits and all markets clearing.	**Merits:** Top-down hybrids have one key advantage over bottom-up hybrids, in their capacity to model the full impacts on GDP, employment and economy structural change by climate policies, and especially the capacity to accurately simulate the recycling method for carbon pricing, which has a large final effect on policy emissions and economic impact. **Limitations:** A weakness is their inability to accurately model detailed technology regulations.
Integrated Assessment models (IAMS) are full economy models that also include atmospheric GHG and energy balancing components to allow for temperature change targets, and in some cases include damage functions.	**Merits:** They incorporate attributes of both climate systems and economic systems in the same model, in a limited manner. **Limitations:** They are necessarily global, and national circumstances are often simplified to the point where they are not useful for national policy debates.
Mixed soft-linked and hard-linked models link established bottom-up and top-down frameworks, instead of directly incorporating their attributes in the other.	**Merits:** These models have the potential to incorporate both top down attributes such as the economic structure etc., and bottom up attributes such as detailed technological representations. **Limitations:** These frameworks, not having been designed together, will typically be challenged with boundary issues, i.e. overlapping coverage of systems and their dynamics.

5. Overarching limitations and future avenues for modelling approaches

Models are simplified representations of reality. The policy recommendations arising from models, therefore, are only as robust as the extent to which the real-world dynamics which influence those policy recommendations are captured in the model. This section presents a reflection on the correspondence between mainstream modelling approaches, and real-world dynamics. Gaps between the two have implications both for policy recommendations, as well as for desirable improvements in future modelling methods.

Uncertainties, Path Dependency, and Technological Innovation: Emissions projections decades into the future are abound with uncertainties, usually driven by factors such as costs of clean energy, structural relationships and assumptions, technological disruptions, and GDP. Clear elucidation of the key uncertainties, and how sensitive the model outputs are to such uncertainties and path dependencies, is essential to making policy recommendations more robust (Calder et al. 2018).

Despite their insights about the magnitude of transformations required, the models say little about whether the transformations are actually feasible. Transformations of technological systems also need socio-economic reorganisations, involving decisions across a wide range of actors with diverging interests, resources and capabilities, and their interactions. Similarly, innovation processes are characterised by complex, hard-to-predict, emergent non-linear dynamics. Mainstream energy-economy modelling approaches are ill-equipped to model innovation processes and technological disruptions, since the modelling approaches have limited ability to represent qualitatively different socio-technical structures and regimes. This limitation can impact indicators like “additional investments” and “emissions projections” significantly. Such models also offer limited insight into the process by which a transition to a different set of economically viable technologies is possible (Köhler et al. 2018).

Finally, the models implicitly make strong structural assumptions, for example, with respect to the relationship between urbanisation, economic growth and population growth, or regarding the suite of technologies which make energy efficiency possible. These structural assumptions are conjectural, with limited historical precedence, and may be expected to change in the future as development pathways evolve.

Economic Development and Poverty: The idea of development often relates to reducing poverty and inequality; yet, existing economic systems have contributed to significant economic inequalities within many countries (Piketty 2014). This is critical in the context of climate change, as poorer populations both within and across countries are most vulnerable to the impacts of climate change. However, mainstream energy-economy models often only represent aggregate wealth and do not unpack the impacts of different economic development pathways on the most vulnerable populations, under a changing climate. Incorporating such relationships is essential to clarify how development pathways (both socio-economic and technological) could impact the most vulnerable in society (Klinsky and Winkler 2018).

Furthermore, particularly in developing countries such as India, the informal economy contributes significantly to the overall economy. This implies that large parts of the workforce do not have income data accounted for, and do not have social protections either, making them far more vulnerable to both economic shocks and climate impacts. In future models, therefore, better representation of the vulnerabilities of the informal sector workforce will help policy makers design resilient development pathways for a given mitigation target.

Representing Real-World Macroeconomics: Although CGE modelling is the mainstream approach to analyse economic growth, it has limitations. It assumes a homogenous agent that maximizes utility with perfect foresight and rational expectations. It also assumes stable and linear economic growth trend under equilibrium, while neither path dependency nor cyclical trends (short- and long-term business cycles) are accounted for the model. While historical experiences demonstrate that recessions (e.g., from Covid-19) and financial crises are endogenous to the economic system, CGE models are ill-equipped to generate such effects. Therefore, projected and expected growth levels from the models until 2050-51 should be interpreted with caution, especially as GDP is a key factor influencing both economic growth and decarbonisation in the models.

Furthermore, structural macro-economic relationships for developing countries are also subject to several unknowns; for instance, limited historical precedence for service-sector-led growth. Future modelling exercises, in the process of updating India's LTS, should attempt to iteratively address some of these limitations (Spencer and Dubash 2022).

References

Calder, Muffy, Claire Craig, Dave Culley, Richard de Cani, Christl A. Donnelly, Rowan Douglas, Bruce Edmonds, et al. 2018. "Computational Modelling for Decision-Making: Where, Why, What, Who and How." Royal Society Open Science 5 (6): 172096. ***https://doi.org/10.1098/rsos.172096***.

Dubash, Navroz K, Radhika Khosla, Narasimha D Rao, and Ankit Bhardwaj. 2018. "India's Energy and Emissions Future: An Interpretive Analysis of Model Scenarios." Environmental Research Letters 13 (7): 074018. ***https://doi.org/10.1088/1748-9326/aacc74***.

Geels, Frank W., Frans Berkhout, and Detlef P. van Vuuren. 2016. "Bridging Analytical Approaches for Low-Carbon Transitions." Nature Climate Change 6 (6): 576–83. ***https://doi.org/10.1038/nclimate2980***.

Gilbert, Nigel, Petra Ahrweiler, Pete Barbrook-Johnson, Kavin Preethi Narasimhan, and Helen Wilkinson. 2018. "Computational Modelling of Public Policy: Reflections on Practice." Journal of Artificial Societies and Social Simulation 21 (1): 14. ***https://doi.org/10.18564/jasss.3669***.

Klinsky, Sonja, and Harald Winkler. 2018. "Building Equity in: Strategies for Integrating Equity into Modelling for a 1.5°C World." Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 376 (2119): 20160461. ***https://doi.org/10.1098/rsta.2016.0461***.

Köhler, Jonathan, Fjalar de Haan, Georg Holtz, Klaus Kubeczko, Enayat Moallemi, George Papachristos, and Emile Chappin. 2018. "Modelling Sustainability Transitions: An Assessment of Approaches and Challenges." Journal of Artificial Societies and Social Simulation 21 (1). ***https://doi.org/10.18564/jasss.3629***.

Peng, Wei, Gokul Iyer, Valentina Bosetti, Vaibhav Chaturvedi, James Edmonds, Allen A. Fawcett, Stéphane Hallegatte, David G. Victor, Detlef van Vuuren, and John Weyant. 2021. "Climate Policy Models Need to Get Real about People — Here's How." Nature 594 (7862): 174–76. ***https://doi.org/10.1038/d41586-021-01500-2***.

Pye, Steve, and Chris Bataille. 2016. "Improving Deep Decarbonization Modelling Capacity for Developed and Developing Country Contexts." Climate Policy 16 (sup1): S27–46. ***https://doi.org/10.1080/14693062.2016.1173004***.

Spencer, Thomas, and Navroz K. Dubash. 2022. "Scenarios for Different 'Future Indias': Sharpening Energy and Climate Modelling Tools." Climate Policy 22 (1): 30–47. ***https://doi.org/10.1080/14693062.2021.1973361***.

Süsser, Diana, Nick Martin, Vassilis Stavrakas, Hannes Gaschnig, Laura Talens-Peiró, Alexandros Flamos, Cristina Madrid-López, and Johan Lilliestam. 2022. "Why Energy Models Should Integrate Social and Environmental Factors: Assessing User Needs, Omission Impacts, and Real-Word Accuracy in the European Union." Energy Research & Social Science 92 (October): 102775. ***https://doi.org/10.1016/j.erss.2022.102775***.