HP 4 CORE SERIES

ECONOMIC ANALYSIS AND MODELING TOOLS TO ASSIST MINISTRIES OF FINANCE IN DRIVING GREEN AND RESILIENT TRANSITIONS

An overview of options and case studies of deployment

A report of the Coalition of Finance Ministers for Climate Action Helsinki Principle 4 initiative:

Economic Analysis for Green and Resilient Transitions

NOVEMBER 2025

About this report

This report is a product of the Helsinki Principle 4 (HP4) workstream of the Coalition of Finance Ministers for Climate Action (CFMCA). The workstream is designed to advance the overarching goal of integrating climate action into economic and fiscal policy. It is part of an initiative to enhance macroeconomic analysis and modeling tools for Ministries of Finance (MoFs) and equip them to assess the economic impacts of climate risks, mitigation efforts, and adaptation strategies. This is in recognition that many MoFs urgently need improved access to tools that will enable them to address the most pressing climate policy questions they face now, tailored to and appropriate for their context, and operating on timescales that meet the needs of decision-makers.

The report provides an overview of analytical tools available to MoFs to mainstream climate in their decision-making: it outlines different types of climate-enhanced macroeconomic and sectoral models, physical climate and disaster risk models and approaches, and decision-making frameworks and other analytical tools, along with specific examples and case studies drawn from the complementary Compendium of Practice (see below). The report maps various models and approaches to different climate policy questions, showcases ex-post case studies and evaluations, and discusses some cross-cutting analytical matters.

The Compendium of Practice that further details the tools included in this report is a global collaborative effort that consists of contributions from over 100 leading organizations and individuals gathered for this workstream. The author team would like to thank the numerous Coalition members, partners, and other individuals and organizations who directly contributed to the Compendium. The Compendium and complementary reports are available on a dedicated website, https://greenandresilienteconomics.org/. These include a survey of the world's Ministries of Finance, a report summarizing the Compendium, and thematic papers in areas related to Ministries' pressing climate policy needs. Further reports are under development.

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Acknowledgements

This report was led by Hannah Maier-Peveling with Nick Godfrey at the Grantham Research Institute on Climate Change and the Environment. The contributions drawn on were commissioned by Nick Godfrey and Moritz Baer and were subject to at least one round of comments and clarifications. The overall effort was guided by Mads Libergren (Danish Ministry of Finance) in partnership with Leon Clarke and Vanessa Ordoñez Padilla (Bezos Earth Fund), and Stephane Hallegatte, Camilla Knudsen, and Florent McIsaac (World Bank). This work benefitted enormously from the convening of stakeholders at the inaugural Forum on the Macroeconomics of Green and Resilient Transitions held in April 2024. All contributions were provided in-kind and voluntarily.

The author team wish to thank the following peer reviewers for their inputs and guidance: Saara Tamminen (Finland—Prime Minister's Office), Flavia Bottoni (Italy—Ministry of Economy and Finance), Janos Varga and Matthias Weitzel (European Commission), Edgar Cudmore, Bruce Calvert, and Samantha Goertz (Canada—Department of Finance), Benjamin Lerch (Switzerland—Federal Department of Finance), Diana Laura Jiménez Miranda (Mexico—Ministry of Finance), Emmanuel Tamba Gbondo (Sierra Leone—Ministry of Finance), Andrew Burns and Charl Jooste (World Bank), Sneha Thube and Benjamin Carton (International Monetary Fund), Filiz Unsal (Organisation for Economic Co-Operation and Development), David Anthony Raitzer, Lei Lei Song, and Abdul D. Abiad (Asian Development Bank), Anna Murphy (S-Curve Economics), Heinrich Bohlmann (Partnership for Economic Policy and University of Pretoria), Jane Mariara (Partnership for Economic Policy), Dimitri Zenghelis (University of Cambridge), Eric Beinhocker and Doyne Farmer (University of Oxford), and Aurélien Saussay (Grantham Research Institute on Climate Chance and the Environment).

The report was edited and production-managed by Georgina Kyriacou and designed by Joseph Adjei at the Grantham Research Institute.

Disclaimer

This report and the Compendium of Practice on which it builds were prepared at the request of, and with guidance from, the Ministry of Finance of Denmark as Lead of the Coalition's Helsinki Principle 4 initiative 'Economic Analysis for Green and Resilient Transitions' and its Steering Group, with input from its Technical Advisory Group. The views, findings, interpretations, and conclusions expressed are a synthesis of the diverse views of the authors, contributors, and reviewers. While many Coalition Members and partners may support the general thrust of the arguments, findings, and recommendations made in this report and the Compendium of Practice, the outputs do not necessarily reflect the views of the Coalition, its Members, or the affiliations of the authors, nor does the report or the Compendium of Practice represent an endorsement of any of the views expressed herein by any individual Member.

This report was first published in November 2025

Suggested citation: Coalition of Finance Ministers for Climate Action (2025) *Economic Analysis and Modeling Tools to Assist Ministries of Finance in Driving Green and Resilient Transitions: An overview of options and case studies of deployment*. Report for the HP4 initiative 'Economic Analysis for Green and Resilient Transitions'.

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Table A. Contributions to the Compendium of Practice used in this report

Institution	Authors	Title (and Compendium web link)
Canada—Department of Finance		Finance Canada's approach to climate–economy modeling
Ireland—Department of Finance/ Department of Public Expenditure, NDP Delivery and Reform (DPENDR)/Economic and Social Research Institute (ESRI)	Kelly De Bruin, Aykut Mert, David Owens, Ciara Morgan	Macroeconomic analytical tools: the Ireland Environment, Energy and Economy (I3E) model
European Commission	Francesco Ferioli, Derck Koolen, Janos Varga	Overview of the European Commission's energy and climate policy-related modeling suite
European Commission	Matthias Weitzel	Assessing the distributional consequences of the transition in the EU
Finland—Prime Minister's Office	Saara Tamminen, Kristiina Niikkonen	Improving the inclusion of nature and ecosystem service impacts in assessments of the economic impacts of climate risk by Ministries of Finance and economic decision-makers: the experience of Finland
Italy—Ministry of Economy and Finance		The Italian Ministry of Economy and Finance climate-related modeling tools: how to build a flexible suite of models serving different purposes
Morocco—Ministry of Economy and Finance		Computable general equilibrium model for the introduction of a carbon tax for the Moroccan economy
Sweden—National Institute of Economic Research (NIER)	Vincent Otto	Sweden's EMEC model, designed to study the long-term economic effects of energy and climate policies
Switzerland—Federal Department of Finance		Introduction of a replacement levy on electric vehicles
Switzerland—Federal Department of Finance	Benjamin Lerch, Thomas Brändle, Martin Baur	Modeling the fiscal impacts of the net zero target within fiscal sustainability analysis
Asian Development Bank (ADB)	Lei Lei Song	Navigating the trade-offs between investments for growth and climate action: the role of social discount rates
Cambridge Econometrics	Ha Bui, Simone Cooper-Searle, Richard Lewney	Macroeconomic modeling of climate change: the E3ME model
Coalition for Capacity on Climate Action (C3A)	Sebastian Valdecantos, Etienne Espagne	FSMAT: incorporating climate finance into a stock-flow-consistent disequilibrium framework
Council on Economic Policies	Patrick Lenain	It takes two to tango: the role of Ministries of Finance in pricing and non-pricing policies for a low-carbon economy
Danish Research Institute for Economic Analysis and Modelling (DREAM)		The GreenREFORM Model
Environment for Development Initiative		Facilitating socially responsible carbon pricing policies: the global Carbon Pricing Incidence Calculator (CPIC)
Environment for Development Initiative		Pricing carbon in the tropics: the CP+ model
ETH Zürich	Lint Barrage	Latest developments in upgrading DICE-2023: findings and implications for Ministries of Finance
French Economic Observatory (OFCE)—Sciences Po	Aurélien Saussay, Frédéric Reynès, Anissa Saumtally	The ThreeME model
Grantham Research Institute on Climate Change and the Environment/University of Warwick	David Stainforth	Climate tipping points

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Table A *cont*. Contributions to the Compendium of Practice used in this report

Institution	Authors	Title (and Compendium web link)
Green Macroeconomic Modeling Initiative (GMMI)		A community platform to accelerate innovation and progress in assessing green economic transitions
Harvard Growth Lab	Ketan Ahuja, Muhammed A. Yildirim	The Atlas of Economic Complexity: supporting strategic economic planning and green industrial policy in Ministries of Finance
International Monetary Fund (IMF)—Fiscal Affairs Department	Carolina Renteria, Tjeerd Tim	Fiscal risks of climate change: Quantitative Climate Change Risk Assessment Fiscal Tool (Q-CRAFT)
International Monetary Fund (IMF)—Fiscal Affairs Department	Emanuele Massetti	The critical role of Ministries of Finance for investment in adaptation and the analytical principles and tools available
International Monetary Fund (IMF)—Research Department		DIGNAD: Debt-Investment-Growth and Natural Disaster model
International Monetary Fund (IMF)—Research Department		GMMET: Global Macroeconomic Model for the Energy Transition
International Monetary Fund (IMF)—Research Department	Jean Chateau, Hugo Rojas-Romagosa, Sneha D. Thube, Dominique van der Mensbrugghe	IMF-ENV: integrating climate, energy, and trade policies in a general equilibrium framework
Inter-American Development Bank (IDB)/French Development Agency (AFD)/RAND Corporation	Nidhi Kalra, Adrien Vogt-Schilb, Edmundo Molina-Perez	SiSePuede: new approaches to assessing economic impacts of net zero pathways
Inter-American Development Bank (IDB)/French Development Agency (AFD)/University of Costa Rica	Jairo Quiros-Tortos, Adrien Vogt-Schilb, Marcela Jaramillo	Managing the fiscal impacts of electric vehicles, public transportation, and cycling
Inter-American Development Bank (IDB)/French Development Agency (AFD)/University of Costa Rica	Jairo Quiros-Tortos, Adrien Vogt-Schilb, Marcela Jaramillo	OSeMOSYS: Open Source Modeling System
Munich Climate Insurance Initiative (MCII)	Florian Waldschmidt, Sönke Kreft	Showcasing CLIMADA
Network for Greening the Financial System (NGFS)	Thomas Allen, Benjamin Alford, Léopold Gosset	The NGFS's approach to the macroeconomic assessment of physical risks
Network for Greening the Financial System (NGFS)	Thomas Allen, Benjamin Alford, Paul Champey	The NGFS's approach to modeling the short-term macroeconomic implications of climate change and the transition
Organisation for Economic Co-operation and Development (OECD)	Filiz Unsal	The new macro-structural climate adaptation and mitigation framework by the Economics Department of the OECD
Paul Watkiss Associates	Paul Watkiss	The analysis of climate impacts, adaptation costs, and adaptation benefits in the UK
S-Curve Economics	Simon Sharpe	Risk–opportunity analysis: policy appraisal in contexts of structural change, uncertainty, and diverse interests
S-Curve Economics/University of Exeter/University of Manchester	Simon Sharpe, Jean-Francois Mercure, Anna Murphy, Frank Geels	Policy packages for cost-effective transitions: learning from the past, simulating the future with the Future Technology Transformations models, and case studies from the Economics of Energy Innovation and System Transition project
S-Curve Economics/University of Manchester/University of Exeter	Simon Sharpe, Anna Murphy, Frank Geels, Jean-Francois Mercure	Low-carbon innovation and industrial strategy: analytical tools and frameworks for Ministries of Finance
SOAS University of London	Yannis Dafermos	Ecological stock-flow consistent modeling: an emerging tool for Ministries of Finance

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Table A *cont*. Contributions to the Compendium of Practice used in this report

Institution	Authors	Title (and Compendium web link)
United Nations Environment Programme (UNEP)	Alice Dauriach, Josephine Musango, Helena Arevalo, Luciana Fontes de Meira	IGEM's integrated approach to climate-smart economic decision-making
University College London	Paul Ekins	Analytical and policy approaches to the climate and economy
University of East Anglia	Rachel Warren	Methodological recommendations for Ministries of Finance on climate change risk assessment and the enhancement of damage functions
University of Oxford	Pete Barbrook-Johnson	The value of using systems mapping to help Ministries of Finance understand the impacts of transformative climate policy
University of Wisconsin–Madison	Gregory Nemet	How government actions have accelerated clean energy innovation: lessons for economic analysis and modeling by Ministries of Finance
World Bank	Camilla Knudsen, Stéphane Hallegatte	A new modeling approach combining bottom-up sectoral analyses with top-down macroeconomic models to understand the economic impacts of resilient and low-emissions development
World Bank		Strategic climate risk modeling for economic resilience: a guide for Ministries of Finance
World Bank		World Bank Group climate aware macroeconomic models available for use by Ministries of Finance
World Bank	Andrew Burns, Charl Jooste, Florent McIssac, Chung Gu Chee, Heather Ruberl, Thi Thanh Bui, Unnada Chewpreecha, Alex Haider, Baris Tercioglu	MFMod–CC: country-specific macrostructural models
World Bank	Lulit Mitik-Beyene, Martin Christiansen, Ragchaasuren Galindev, Noe Reidt, Mei Mei Lam, Alhassane Camarra	MANAGE-WB: a recursive-dynamic CGE model
World Bank		ENVISAGE: a global CGE model covering 160 regions
World Bank	Ira Dorband, Ulrike Lehr, Hector Pollitt, Bence Kiss-Dobronyi, Marco Capraro Brancher	MINDSET: an easy-to-use sectoral model covering 164 countries
World Bank—Finance, Competitiveness & Innovation Global Practice (FCI GP)	Michaela Dolk, Olivier Mahul	Stronger analytics for better financial resilience against climate shocks and disasters
World Bank/International Monetary Fund (IMF) Fiscal Affairs Department		The Climate Policy Assessment Tool (CPAT)
World Resources Institute (WRI)	Arpan Golechha, Apoorva R, Varun Agarwal	How system dynamic models can inform India's low-carbon pathways

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List of abbreviations

ABM	Agent-Based Model
AFD	Agence Française de Développement
ADB	Asian Development Bank
BAU	Business as usual
CAT	Catastrophe Model
CBAM	Carbon Border Adjustment Mechanism
CBA	Cost–Benefit Analysis
CEA	Cost–Effectiveness Analysis
CGE	Computable General Equilibrium
CLD	Causal Loop Diagram
DGE	Dynamic General Equilibrium
DICE	Dynamic Integrated model of Climate and the Economy
DSGE	Dynamic Stochastic General Equilibrium
ECB	European Central Bank
EEA	Extreme Event Attribution
ESM	Energy System Model
EU	European Union
HP4	Helsinki Principle 4
IAM	Integrated Assessment Model
IIASA	International Institute for Applied Systems Analysis
IMF	International Monetary Fund
IO	Input–Output
LULUCF	Land use, land-use change, and forestry
MoF	Ministry of Finance
NGFS	Network for Greening the Financial System
OECD	Organisation for Economic Co-operation and Development
PIOT	Physical Input–Output Table
RCP	Representative Concentration Pathway
RDM	Robust Decision-Making
ROA	Risk–Opportunity Analysis
SAM	Social Accounting Matrix
SCC	Social Cost of Carbon
SD	System Dynamics
SEM	Structural Econometric Model
SFC	Stock-Flow-Consistent
SSP	Shared Socioeconomic Pathway
UNEP	United Nations Environment Programme
WRI	World Resources Institute

Summary for policymakers

Key messages

Ministries of Finance (MoFs) urgently require fit-for-purpose analytical tools and credible results to inform the economic and fiscal decision-making needed to drive green and resilient transitions.

Different strategies can be used to integrate climate into analytical tools used by MoFs.

- MoFs already use models in economic analysis and forecasting, and these 'workhorse' models as well as existing decision-making frameworks can be adapted to incorporate elements of climate change and climate policies.
- MoFs can also use 'dedicated' climate–economy models and other analytical tools specifically designed to analyze climate impacts and policies.
- Depending on national circumstances, both approaches can help mainstream climate considerations into MoF decision-making.

No single tool can answer all relevant questions.

- Different climate policy questions require different tools that can capture the different variables and perspectives of the issues at hand.
- The suite of tools available typically includes: climate-enhanced macroeconomic and sectoral models; physical climate and disaster risk models and approaches; decision-making frameworks and other analytical tools; and ex-post case studies and evaluations.
- Where capacity allows, using multiple tools can provide a range of analytical perspectives and complementary insights, and can prevent critical factors from being overlooked.
- Comparing results across tools and conducting sensitivity analyses can help assess the robustness of results against model choices and assumptions.

Tools can be linked in hybrid approaches for more comprehensive analysis.

- The boundaries between tool categories are not rigid, and different tools can be linked or used in conjunction to leverage their strengths and contribute to more comprehensive analyses.
- Physical climate impact assessments can inform macroeconomic models, while sectoral models can enhance the representation of critical sectors for the transition, such as the energy or agricultural sector.

Continuous learning and development are crucial.

- Mainstreaming climate within MoFs' analytical tools and decision-making is an evolving process that requires continuous learning by analytical teams within MoFs.
- Investing in monitoring, evaluation, and refinement of policies, and improving data and models to advance relevant and useful analysis is essential. Peer learning within and across countries and institutions, and working with insights from scientists, investors, and academics, is a critical part of this.

Active leadership on climate from Ministries of Finance requires support in the use of tools and models

Ministries of Finance (MoFs) are at the forefront of coordinating economic, fiscal, and financial policy, and collectively they oversee more than US$30 trillion in public spending annually (Coalition of Finance Ministers for Climate Action, 2023). Their active leadership is essential for driving climate action. To provide this leadership they need to address several challenging policy questions regarding the direct and indirect impacts of climate change, and evaluate the trade-offs and policy implications of the transition to a green and resilient economy.

Summary for policymakers

These questions range from how to manage the fiscal challenges of investing in green energy, cope with climate risks, fund resilience measures, and support green manufacturing, to how to manage and overcome the impacts of declining activity in high-carbon sectors on workers and communities and plan for and spur improvements in the cost and performance of new technologies. There is also a mismatch between the scope, uncertainty, and timelines associated with the costs and benefits of action. The costs are mostly upfront and knowable with a degree of confidence, whereas the benefits are often more uncertain and longer term, but potentially far greater. MoFs and other economic ministries urgently need credible evidence and approaches to navigate these emerging challenges and opportunities.

Different analytical tools can support MoFs in answering these questions, but navigating the wide range of available tools can be difficult. This is compounded by MoFs having to navigate the landscape of analytical tools and models they already use to support economic decision-making—from macroeconomic modeling and budget forecasting to cost–benefit analyses of spending programs. While these existing models were not originally designed for climate-related policy, they can often be built upon and expanded to examine climate-related questions, and knowledge capital from developing and working with existing models can be transferred to new applications.

Categories of available tools and their policy applications

To provide a systematic overview of analytical tools used by and available to MoFs for integrating climate considerations into economic analysis, in this report we classify tools into four main categories:

1. **Climate-enhanced macroeconomic and sectoral models.** These provide quantitative analysis of the macroeconomic, sectoral, and distributional impacts of selected elements of climate change and the transition to a low-carbon and climate-resilient economy. These models often build on existing macroeconomic models used by MoFs but incorporate climate-related factors.
2. **Physical climate and disaster risk models and approaches.** These are tools specifically designed to assess climate damages and risks. They can help MoFs identify the economic and fiscal impacts of physical climate risks and inform effective fiscal risk management strategies and adaptation investments in both the short and long run.
3. **Decision-making frameworks and other analytical tools.** These include cost–benefit analysis and a wide range of other approaches and tools, including Robust Decision-Making, and can provide important qualitative and quantitative complements to other modeling approaches. Some of the tools covered here can be especially helpful to inform decision-making in the context of uncertainty and risk.
4. **Ex-post case studies and evaluations.** These analyze the ex-post impacts of climate policies and technology transitions, providing insights for policymakers into what has worked, what challenges have arisen, and how policies have influenced the economic and technological change needed for effective climate action.

We categorize 23 different tools using the above framework (named in Table S1 below) and clarify their use cases, strengths, and limitations, providing case studies of their deployment and drawing out important analytical considerations across the board. Additionally, we map tool types to key policy questions to help MoFs identify the most relevant tools for their needs. No single analytical approach is right; we recognize that different approaches have different strengths and weaknesses, and that drawing insights from a range of analytical tools is often useful. The analysis is informed by contributions to the online Compendium of Practice from MoFs, international organizations, and the academic community. The Compendium mentions over 60 examples of analytical tools, and showcases more than 15 case studies of deployment.

Summary for policymakers

In order to choose the right analytical tools, decision-makers within MoFs must start with a clear understanding of the policy and research questions they aim to address. There are key analytical considerations to keep in mind when determining the most appropriate suite of analytical tools to use, in particular: the representation of technological change, structural change, distributional consequences, multiple policy levers, climate science, the choice of social discount rate, uncertainty, sensitivity analysis, model performance, and data availability.

Table S1. Analytical tools considered in the report

Categories	Tools
Climate-enhanced macroeconomic and sectoral models	Computable General Equilibrium (CGE) models
	Dynamic Stochastic General Equilibrium (DSGE) models
	Structural Econometric Models (SEMs)
	Sectoral and technology cost models
	Process-based Integrated Assessment Models (IAMs)
	Cost–benefit Integrated Assessment Models (IAMs)
	Input–Output (IO) models
	Gravity models
	Demand-led models
	System Dynamics (SD) models
	Agent-Based Models (ABMs)
Physical climate and disaster risk models and approaches	Damage functions
	Loss and damage assessments and asset-level analyses
	Catastrophe models
	Extreme Event Attribution (EEA)
Decision-making frameworks and other analytical tools	Cost–Benefit Analysis (CBA)
	Cost-Effectiveness Analysis (CEA)
	Risk–Opportunity Analysis (ROA)
	Real options theory and Robust Decision-Making (RDM)
	Multi-Criteria Decision Analysis (MCDA)
	Systems mapping
	Complexity analysis
Ex-post case studies and evaluations	Large-scale, aggregate studies
	Sector- or technology-specific case studies
	National or policy-specific case studies

By leveraging the strengths of various analytical tools and fostering an environment of continuous engagement, MoFs can better navigate the complexities of climate-related economic policy and drive meaningful climate action.

1. Introduction

Green and resilient transitions demand far-reaching structural transformations and investment in all sectors, from power generation to transportation, buildings, industry, and agriculture, and at all levels of government and society. Active leadership by Ministries of Finance (MoFs) will be critical to driving the economic transformation and investment needed, given their important role in macroeconomic and fiscal policy—in the context of a US$100 trillion global economy, MoFs collectively oversee US$30 trillion in public financing annually (Coalition of Finance Ministers for Climate Action, 2023).

MoFs are used to doing robust analysis for sectors that require significant investment from the budget, such as health, education, and state pensions, but still face new challenges in relation to climate action given the scale, complexity, and uncertainties involved in the low-carbon, climate-resilient transition. Traditional economic models used by MoFs for forecasting and fiscal planning were not originally designed to assess climate change risks or evaluate climate policy and there is a clear information gap when it comes to integrating climate considerations into economic analysis.

A major obstacle to accelerated action is thus the lack of suitable tools and capacity in MoFs to answer many of the most daunting economic questions they face in driving green and resilient transitions. These include:

- How much investment is needed for a green transition, and how can it be financed?
- What are the costs of climate action versus inaction, and how will chronic and acute climate risks impact public budgets?
- What policy combinations will be most effective in reducing emissions and supporting development, and who is affected by these policies?
- How can climate policy drive economic transformation while safeguarding jobs and competitiveness?

This report provides an overview of analytical tools available to MoFs for addressing these and other pressing climate policy questions. It aims to help a range of audiences in MoFs—particularly those new to climate policy analysis or familiar with only a subset of tools—better understand the landscape of available models and approaches. While it is not exhaustive, it presents a variety of analytical approaches with different theoretical underpinnings, strengths, limitations, and use cases.

Scope of the report and target audience

To support MoFs in tackling these challenges, the report categorizes available analytical tools and clarifies their uses, strengths, and limitations. This is accompanied by high-level descriptions of the available tools, specific examples and case studies, and an indicative mapping of tools to policy questions they are well-suited to address. Not all included case studies necessarily reflect analysis typically undertaken within MoFs, yet these are retained to represent potentially fruitful areas for further exploration. The report also outlines key factors that MoFs may wish to consider in more detail when selecting and designing analytical tools for addressing climate policy questions more generally.

The report does not recommend any specific analytical tool or approach; the suitability of different approaches is context- and implementation-dependent and to be determined by MoFs and other users themselves.

The report is aimed at interested audiences primarily within MoFs that have some familiarity with economic analysis and modeling and want to learn more about how to apply approaches to climate-specific questions. This could include those familiar with macroeconomic models in general but not climate-specific applications, including modeling teams in MoFs at the beginning of their work to integrate climate into their economic analysis. It may also include those familiar with one specific type of analytical tool who are seeking to expand their knowledge of other available approaches. As such, the report does address some technical aspects but does not give all the technical detail required to effectively implement a specific approach. This would require additional context- and country-specific work. While references to more technical information and detailed applications are provided, highly technical audiences may wish to consult the applied literature directly.[1]

The report does not consider the large literature on tools to support public financial management or the design of specific financial instruments in the context of climate policy, such as green budgeting tools, green taxonomies, or debt-for-nature swaps. For more details on these tools, see the Coalition's *Guide to Strengthening the Role of Finance Ministries in Driving Climate Action* (2023: 108–113; 205). The report does not focus, either, on the fact that a lack of capacity to do the associated work is often a key barrier to integrating climate in economic analysis, going beyond the information gap. The capacity issue is instead addressed in two other forthcoming reports in the HP4 Capability Series: *How Ministries of Finance Can Build Capabilities for Analysis and Modeling to Drive Green and Resilient Transitions: Taking Stock of Challenges, Strategies and Lessons Learned* [henceforth described as the 'HP4 Capabilities Report'] and *How Ministries of Finance Can Address Pressing Climate Policy Questions to Drive Green and Resilient Transitions: A Step-by-Step Guide to Using Analytical Tools* [henceforth described as the 'HP4 Step-by-Step Guide'].

Finally, there is a clear need for further work to examine how economic analyses of climate policy questions can be systematically integrated into broader analytical, policy, and decision-making processes. While this is not discussed further in this report, it is a critical issue: analytical insights can only add value if they are actively used to inform real-world decisions.

The report draws on contributions from MoFs, international financial institutions (IFIs), academic researchers, and think tanks, which are contained in an online Compendium of Practice. The Compendium includes inputs from, among others, the World Bank, International Monetary Fund (IMF), Organisation for Economic Co-operation and Development (OECD), Inter-American Development Bank (IDB), United Nations Environment Programme (UNEP), European Commission, and leading research institutions such as the University of Oxford, University of Wisconsin–Madison, SOAS University of London, Harvard Growth Lab, and the Danish Research Institute for Economic Analysis and Modelling (DREAM). Additionally, the academic literature, in particular Nikas et al. (2019) and Dietz (2024), has informed the categorization and characterization of analytical tools (see below). Overview tables in the report provide specific examples of the models discussed, while Appendix A details model descriptions and links to documentation, where available.

Important considerations for the design of any analytical toolbox

The range of tools available to MoFs to address pressing climate policy questions presents a confusing and complex landscape. It is important for Ministries to keep in mind three key considerations when designing their analytical toolbox:

1. **No one tool can effectively address all climate-related policy questions.** Different questions demand analytical tools with different perspectives that capture alternative output variables and insights. Provided that sufficient capacity exists, multiple tools can be useful to answer different aspects of a single overarching policy question or can help indicate the sensitivity of results to the analytical tool and assumptions employed. With access to a diverse suite of tools, decision-makers in MoFs can draw on a more robust foundation for evidence-based policymaking.
2. **There are different strategies for mainstreaming climate into analytical tools.** As outlined further in Section 3, MoFs already use models and analytical tools in day-to-day economic analysis and forecasting which are likely designed to be a good representation of the national economy. These can be termed macroeconomic

[1] Appendix A provides references to documentation and papers describing specific models and may be a useful starting point.

'workhorse' models. Although not originally built for analyzing climate policies but rather to inform overall macroeconomic and fiscal policy and to evaluate the trade-offs across various policy priorities, these tools can be and have been retrofitted to incorporate climate change impacts and climate policy. Another approach is for MoFs to make use of models developed specifically for the purpose of analyzing climate impacts and climate policies, including with particular application to the local and regional context. These can be thought of as 'dedicated' climate–economy models. Depending on how they were developed, they may not initially be tailored to the national economy to the degree existing 'workhorse' models are. Although augmented workhorse models and dedicated climate–economy models differ in their initial motivation and purpose, both approaches can lead to similar models, and the boundaries between them are often blurred. Either approach can offer fertile opportunities to mainstream climate within MoF decision-making, depending on specific circumstances. In any case, it is critical that MoFs understand tools in detail so they can identify tools that meet their needs and circumstances before expanding existing or adopting new approaches.[2]

3. **The tools overlap and can be linked.** The categories of tools outlined in this report are not exhaustive or rigid, as many tools interact and can be linked. For instance, physical climate models provide inputs for macroeconomic models, and decision-making frameworks can shape model design or utilize model results. Soft-coupling models can help leverage the strengths of different tools to provide more comprehensive insights.

Four categories of analytical tools

The report groups analytical tools into four broad categories:

1. **Climate-enhanced macroeconomic and sectoral models.** These include both **retrofitted 'workhorse' models**, which are traditional macroeconomic models adapted to incorporate climate-related variables, and **dedicated climate–economy models**, which are specifically designed to assess climate impacts.
   i) Workhorse models, such as Computable General Equilibrium (CGE) models and Structural Econometric Models (SEMs), were originally built for macroeconomic and fiscal policy analysis. They can be retrofitted for climate-related applications by, for example, implementing the tracking of greenhouse gas emissions associated with economic activities, improving energy sector representation, or incorporating damage coefficients to reflect climate impacts.
   ii) Dedicated climate–economy models, such as Integrated Assessment Models (IAMs), are designed to explicitly analyze the economic impacts of climate change and climate policy. These include cost–benefit IAMs, which assess optimal emission pathways, and process-based IAMs, which focus on sector-specific decarbonization strategies.
2. **Physical climate and disaster risk models.** These models assess the economic impacts of acute and chronic climate risks, such as extreme weather events and long-term environmental change. Examples include catastrophe models, loss and damage assessments, and asset-level analyses. While typically they do not capture economy-wide effects, their outputs are often used as inputs for macroeconomic models.
3. **Decision-making frameworks and other analytical tools.** These approaches include tools typically well known to many MoFs and adapted to consider climate policy-related factors such as cost–benefit and cost-effectiveness analysis, as well as a wide range of other approaches and tools such as robust decision-making, systems mapping, and complexity analysis. These can provide important qualitative and quantitative complements to other modeling approaches, and some of the tools covered here can be especially helpful to inform decision-making in the context of uncertainty and risk.
4. **Ex-post case studies and evaluations.** Learning ex-post from the effectiveness of climate policies that have been implemented and from past economic transitions can provide valuable insights for policymakers. Case studies may focus on the average effect of multiple policy interventions on outcomes such as economic and emissions impacts, a specific sector or technology, or a single national policy to provide evidence on what has worked, what challenges have arisen, and how policies have influenced economic and technological change.

[2] See also the HP4 Capabilities Report.

Figure 1.1 illustrates this categorization of analytical tools and Table 1.1 further outlines which specific models and analytical frameworks are included in each category.

Figure 1.1. Categorization of analytical tools considered

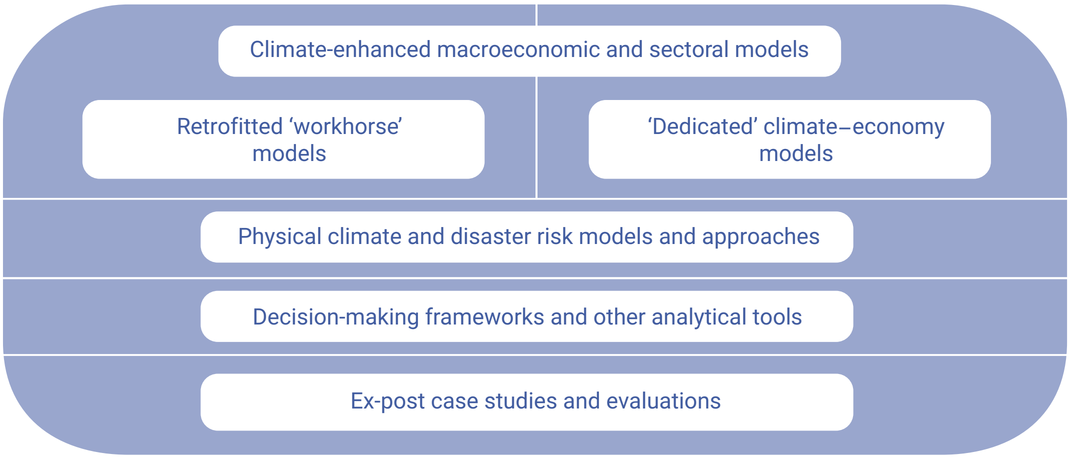


Table 1.1. Analytical tools considered in the report

Categories	Tools
Climate-enhanced macroeconomic and sectoral models	Computable General Equilibrium (CGE) models
	Dynamic Stochastic General Equilibrium (DSGE) models
	Structural Econometric Models (SEMs)
	Sectoral and technology cost models
	Process-based Integrated Assessment Models (IAMs)
	Cost–benefit Integrated Assessment Models (IAMs)
	Input–Output (IO) models
	Gravity models
	Demand-led models
	System Dynamics (SD) models
	Agent-Based Models (ABMs)
Physical climate and disaster risk models and approaches	Damage functions
	Loss and damage assessments and asset-level analyses
	Catastrophe models
	Extreme Event Attribution (EEA)
Decision-making frameworks and other analytical tools	Cost–Benefit Analysis (CBA)
	Cost-Effectiveness Analysis (CEA)
	Risk–Opportunity Analysis (ROA)
	Real options theory and Robust Decision-Making (RDM)
	Multi-Criteria Decision Analysis (MCDA)
	Systems mapping
	Complexity analysis
Ex-post case studies and evaluations	Large-scale, aggregate studies
	Sector- or technology-specific case studies
	National or policy-specific case studies

The categorization of tools

The peer review process for this report has demonstrated that there is no clear consensus on how to categorize analytical tools for MoFs in relation to climate. This is not entirely surprising, given that such a categorization has not been widely attempted before. Our approach to categorizing tools has been based on an extensive consultation process, review of the literature, and review of the multiple contributions from MoFs and beyond as part of the overall program of work within which this report sits. The starting point is some of the most common macro-modeling tools that MoFs are already familiar with and that are frequently adapted to incorporate climate. We then supplement these with a broader range of methods commonly used within MoFs and other departments or institutions. While we acknowledge that this approach is not perfect, we believe that it provides a practical starting point that can be refined over time.

Some peer reviewers suggested alternative categorizations. One possibility might, for example, begin with physical climate risk models as inputs into national macro-modeling, which could offer a more integrated approach to analyzing both mitigation and adaptation policies. We have not taken this step due to the current reality that many MoFs primarily focus on assessing transition impacts rather than physical climate risks, though we hope that this balance changes over time. Another possibility might also aggregate the first two categories as ‘modeling tools’ while considering the latter two as ‘non-modeling approaches’. A further approach could be to categorize tools based on their relevance to different stages of policymaking and day-to-day MoF analysis; we are currently producing a step-by-step guide that may partially address this need (due to be published in spring 2026). Alternatively, the discussion could be framed in terms of impact channels that need to be represented for different policy questions, and how these map onto various analytical approaches (see, for instance, Mitra et al., 2025 for a useful review focusing on this approach).

We therefore recognize that further work is likely necessary and that the most appropriate categorization of tools is likely to vary for each MoF, depending on its specific context. This would then also include a more detailed discussion of the impact channels that should or can be represented in any analytical approach. Our intent at this stage is to provide a broad and flexible overview of available tools rather than state how they should be deployed at different stages of decision-making or to provide a more sophisticated categorization method. Overall, this report is designed to serve as a practical resource for MoFs, helping them navigate the landscape of climate-related analytical tools, build analytical capacity, and integrate climate considerations into economic decision-making.

The suitability of tools

Within the climate economics community there are differing views about the suitability of different types of modeling tools to inform the most effective climate policy measures. One approach has prominently relied on equilibrium models such as CGE models and IAMs for informing climate policy, with their genesis in policies that address market failures that take the market away from an optimal allocation of resources. Another approach has placed a greater emphasis on disequilibrium analysis and frictions, drawing on a wider set of tools such as structural econometric models to better capture the response of the economy to climate shocks and transitions from one equilibrium to another. Other analytical tools such as sectoral technology models, system dynamics models, and risk–opportunity analysis focus on climate action as a process of driving structural transformation through the phase-down and phase-up of different sectors and catalyzing innovation.

In this report, we do not take a view on the merits of each approach. Instead, we seek to point readers to engage in understanding the various strengths and limitations of different analytical tools and ensure that the ones selected are suitable for the task at hand. We equally hope that the Community of Practice will utilize this report to galvanize a constructive debate about how to enhance consensus on the tools most appropriate for tackling the most pressing climate policy questions facing MoFs. In general, we encourage the use of a plurality of approaches and diverse set of analytical perspectives and guard against the disproportionate reliance on one or two model types.

Structure of the report

The remainder of the report is structured as follows:

- **Section 2** outlines key aspects MoFs can consider when selecting and using analytical tools to ensure climate–economy interactions are sufficiently well captured for the question at hand.
- **Section 3** describes the characteristics and applications of different models, decision-making frameworks, case studies, and other analytical tools.
- **Section 4** maps analytical tools to climate policy questions.
- **Section 5** lists real-world examples of the analytical tools discussed and provides case studies of how these have been applied in policymaking.
- **Section 6** concludes.
- **Appendix A** provides an at-a-glance overview of the modeling tools discussed in Section 5.
- **Appendix B** lists further resources that might be valuable to MoFs.

2. Tool selection and designing the analytical toolbox

2.1. Introduction

The models, decision-making frameworks, and other analytical tools covered in this report are useful for providing quantitative and qualitative evidence on key climate policy questions in domains where theory and data are sufficiently developed to enable systematic analysis. This is incredibly valuable for supporting evidence-based policymaking and contributes to advancing the understanding of climate change, mitigation, adaptation, and associated policy options.

Before examining the various types of analytical tools and specific examples of each, we take a step back to consider which elements of using an analytical tool need to be considered before deployment, to ensure the output is relevant and useful. In this context, it is important to remember that even though the following discussion highlights some difficulties in deploying and using analytical tools with confidence, these tools can still be helpful in exploring the questions at hand. Despite their limitations, analytical tools can provide valuable insights and contribute to informed decision-making.

This section is not an authoritative or comprehensive discussion of the topics addressed. Rather, it seeks to highlight a few of the issues at hand and associated developments and insights that Ministries of Finance might find helpful to consider upfront when identifying and designing analytical tools to drive climate action. This approach, described in further detail below, includes:

- Starting the analysis from the questions to be answered, to ensure analytical outputs are relevant and useful.
- Understanding the strengths and limitations of different tools or tool combinations.
- Learning from the experiences of others, MoFs and otherwise, in answering similar questions.
- Considering how various critical factors, such as structural and technological change, are integrated.
- Keeping in mind important caveats, also to ensure they are communicated alongside results.

2.2. Starting with the questions to answer

The driving motivation for MoFs using analytical tools in the context of climate policy is usually because MoFs are considering pressing climate policy questions for informed decision-making. Identifying clear research questions from broader policy questions is essential for MoFs to effectively use analytical tools and ensure that the analysis is focused, relevant, and actionable. This is because these questions guide the analytical teams in their modeling and broader analytical efforts, ensuring that the results are relevant and useful for evidence-based policymaking. Clear policy and research questions help determine the necessary analytical outputs, including the variables of interest, relevant time frames, and the minimum level of sectoral and technological granularity required.

When considering how to best answer a question, it is important to remember that there is no one-size-fits-all approach and no single model or analytical tool is likely to be able to answer all relevant questions. It can often be useful for MoFs to leverage multiple, complementary tools for a more informative analysis than each could provide individually, as each tool has its own set of strengths and weaknesses. If capacity allows and the resourcing is proportionate to the task at hand, it can be very beneficial to consider the same question with different models or tools that are able to serve similar purposes to assess how the results depend on the tool and assumptions employed (in addition to sensitivity analysis performed for each model being used). By considering the same question with different tools, MoFs can better understand the robustness of their findings and make more informed decisions.

Narrowing down and defining clear research questions can be challenging, in part due to the complex and multifaceted nature of climate policy issues. Climate change affects various sectors and stakeholders, each with their own perspectives and priorities. Additionally, the challenge of "not knowing what you do not know" can hinder the process of defining clear research questions. However, this is an important task, as broad questions like "What are the macroeconomic impacts of natural disasters?" are impossible to answer comprehensively and may be interpreted differently by different analysts. More focused questions such as "How do disruptions to economic activities and supply chains impact GDP in the 20 years following a severe flood event?" are clearer and easier to action. A further challenge is the identification of a business-as-usual baseline against which various policy and climate scenarios can be compared. While it may not be immediately clear or easy to determine what the long-term BAU scenario is, this does need to be clearly defined and communicated for an informed interpretation of policy simulations.

A set of policy questions MoFs may be facing is provided in Section 4, linked to analytical tools that may be useful to help answer the question at hand. The overarching structure of the policy questions is taken from the HP4 Compendium, though the questions are slightly altered and consolidated here. These questions are indicative and point toward topic areas a tool may be helpful for assessing. For specific applications, more focused research questions are needed.

2.3. Understanding model characteristics and linking tools

A decision on which tools to draw on for answering key policy questions needs to be informed by tool characteristics. This can include the level of sectoral granularity, heterogeneity between agents and integration of distributional impacts, time frames, consideration of general equilibrium effects, and the output variables of interest, including beyond standard macroeconomic indicators such as GDP. Considering such factors can help ensure the tools employed provide relevant outputs that address the heart of the questions at hand and may indicate how drawing on a range of complementary tools may be useful.

Particularly useful complementarities exist between models with high sectoral detail and more aggregate models that maintain a general equilibrium framework. These different strengths can often be exploited via the use of a hybrid approach, which typically involves using the results of more granular sector-level analysis as an input into higher-level macroeconomic models. More advanced applications would also consider significant feedback loops between the sectoral models and the macroeconomic framework. By integrating detailed sectoral strategies within a consistent, general equilibrium macroeconomic framework, a hybrid modeling approach is well-placed to help MoFs unify perspectives across ministries and agencies into a coherent strategy. The approach allows line ministries (in energy, transportation, agriculture, and so on) to develop their own detailed strategies and policies (including non-pricing policies) using technical models specific to their sectors. From the MoF perspective, these pathways can be challenging to appraise and finance due to potential differences in assumptions and methodologies and unclear economic interactions and financial implications across sectoral models. Integrating the various inputs via the hybrid approach can help combine different sectoral policies and pathways into a consistent macroeconomic framework, enabling MoFs to manage trade-offs across sectors, optimize the sequencing of interventions, and develop consistent economy-wide strategies that consider economic and financial feasibility constraints. The World Bank Country Climate and Development Reports (CCDRs) use the hybrid approach,[3] among many others; examples are discussed in detail in Section 5 below.

[3] See 'A new modeling approach combining bottom-up sectoral analyses with top-down macroeconomic models to understand the economic impacts of resilient and low-emissions development' and 'World Bank Group climate aware macroeconomic models available for use by Ministries of Finance', contributions by the World Bank to the HP4 Compendium of Practice.

For the hybrid approach to be useful, the MoF should have confidence in the modeling undertaken by the line ministry. While inputs coming from the line ministry may be challenging to appraise if the sectoral expertise is in the line ministry, it nonetheless remains important that the MoF does so if it uses the data as an input into its modeling. MoFs might also prepare their own analysis and thereby stress-test the line ministry's results, but this may not always be feasible given capacity constraints.

2.4. Learning from the experience of others

The range of analytical tools available to address climate policy questions is vast and expanding rapidly. This means a range of actors, including MoFs, are gaining valuable experience in utilizing these tools. Given the capacity constraints of MoFs, learning from the experience of others can be an efficient way to access and improve modeling capabilities. The case studies and examples in Section 5 provide tangible examples of how analytical tools have been useful and contribute to knowledge-sharing in this space. The selection draws primarily on the HP4 Compendium, which can be consulted for additional examples.

2.5. Critical factors to consider in climate–economy modeling and other forms of analysis

When deciding on a suite of analytical tools on which to draw to inform climate policy, there are several factors to consider to help ensure the analysis yields relevant and useful outputs. What makes outputs relevant and useful is largely determined by the policy question at hand. Nonetheless, some dimensions are generally useful to consider across the board. These factors, outlined below, are particularly pertinent to climate policy analysis yet are often overlooked in analytical approaches.

Technological change

Technological change and technology diffusion are fundamental to the transition to a decarbonized economy. Endogenously representing processes of technological change in analytical tools is important for analyzing how and when this change should be incentivized and the associated consequences, though this remains difficult and uncertain (Zenghelis et al., 2024). It is critical to consider whether modeling technological change is necessary for the policy question at hand, and what the implications for the analysis are if this is not included. The mechanisms and parameters chosen to drive endogenous change materially impact results and are thus important to consider carefully (Coppens et al., 2025).

Structural change

Large-scale decarbonization is about economic transformation: the growth of new sectors and the transition of existing sectors. This structural change includes sectoral reallocation as well as changes in production within sectors. It is critical for MoFs to consider how to capture this process in analytical approaches, as this process of dynamic change can impact the tax base, employment, and income and regional inequality. Tools that model the transition do not necessarily offer sufficient detail for analyzing structural change, especially if they have a highly aggregate representation of the economy. Even when sectoral disaggregation is sufficient, many tools are better at considering marginal changes around an equilibrium rather than substantial shifts within and between sectors. It can therefore be important to recognize these limitations and look for approaches that can complement the analysis.

Distributional consequences

Economic models vary in their ability to reflect distributional impacts. Many rely on a single representative agent, which makes it difficult to represent income inequality and the heterogeneous effects of climate change or climate policy. Additionally, not all output metrics are equally informative on distributional impacts. This means that disproportionate effects on different income groups or regions may be masked. Given that some climate policies can have regressive impacts if not well designed or complemented by other measures, and already vulnerable households are more vulnerable to extreme events, it is of interest for MoFs to consider whether a model adequately accounts for distributional impacts. Selecting models that incorporate household-level data and labor market effects can help design more targeted, equitable, and politically feasible policies. While distributional consequences are typically associated with consequences across income groups, heterogeneous impacts across sectors are sometimes also considered distributional consequences.

Multiple policy levers

The need for green and resilient transitions comes with a range of challenges and typically requires multiple policy levers to be pulled simultaneously. This may include pricing emissions, fossil fuel subsidy reform, incentivizing research into and deployment of green technologies, and managing the distributional consequences and ensuring a just transition through policies that dampen the impacts for adversely affected sectors and groups. Moreover, MoFs already operate in an environment of policy mixes, whether or not they were initially designed as coherent packages.[4] Given the need to use a range of policy levers, it should be considered whether the analytical tools applied reflect relevant levers and the interactions between them in a manner that is adequate for the questions at hand or whether the tools need to be enhanced or complemented. Analysis of the fiscal impacts of such policy combinations and potential financing options can help assess whether policy packages are fiscally viable and inform strategies to make them so. Tools that reflect public finances—including revenues, expenditures, and debt dynamics—can support this.

Climate science

Recent revisions to damage functions have consistently increased estimates of climate-related economic impacts,[5] yet there remains no clear convergence. Even newer work on damage functions that rely on historical data and are estimated econometrically may fail to capture unprecedented impacts that may occur at higher temperatures. A key area of concern in terms of physical climate change is the deep uncertainty around what the consequences could be and the limited information about the occurrence and impacts of climate tipping points. Tipping points can lead to sudden and irreversible (on timescales relevant to human societies) changes, with potentially severe economic consequences, including cascading effects through trade, migration, and conflict.[6] Even when tipping points are expected, assigning probabilities to them for use in economic models is often not feasible. Additionally, deep uncertainty about climate trajectories poses challenges; the possibility of catastrophic consequences cannot be ruled out. The presence of such extreme possibilities can undermine standard economic models, particularly those based on utility maximization, and result in paradoxical results such as infinite willingness to pay to avoid catastrophic outcomes (Stern et al., 2022; Weitzman, 2007, 2009, 2011). Where analysis considers climate damages, it is important to consider and communicate whether acute as well as chronic impacts are considered and whether damages are known to be underestimated with the method chosen (which is likely to be the case even with state-of-the-art approaches).[7] If these limitations are not considered, this can lead to underestimated benefits to mitigation and adaptation, and insufficient climate action. It is therefore crucial for their short- and long-term fiscal planning that MoFs draw on tools that are realistic about the expected damages and the extent of uncertainty associated with them.

Social discount rate

In cost–benefit analysis, including that conducted via cost–benefit IAMs seeking to optimize emissions trajectories over time, a discount rate is used to express future costs and benefits in present value terms. It is

[4] See 'It takes two to tango: the role of Ministries of Finance in pricing and non-pricing policies for a low-carbon economy', contribution from the Council on Economic Policies to the HP4 Compendium of Practice; and 'Analytical and policy approaches to the climate and economy', contribution from University College London to the HP4 Compendium of Practice. This topic will be expanded upon in the forthcoming HP4 report *How Ministries of Finance can Design Coherent Climate Policy Packages*, due to be published in spring 2026.
[5] See 'The NGFS's approach to the macroeconomic assessment of physical risks', contribution from the Network for Greening the Financial System (NGFS) to the HP4 Compendium of Practice.
[6] See 'Climate tipping points', contribution from the Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science, and University of Warwick to the HP4 Compendium of Practice.
[7] See 'Methodological recommendations for Ministries of Finance on climate change risk assessment and the enhancement of damage functions', contribution from the University of East Anglia to the HP4 Compendium of Practice.

usually based on the Ramsey rule[8] and has two key components: time preference, which captures the degree to which value is preferred now rather than later, and a wealth effect, which captures that additional consumption brings less satisfaction (utility) as consumption increases (this is also referred to as 'inequality aversion'). More formally, the discount rate usually reflects expectations of future economic growth and inequality aversion (the 'wealth effect'), and the rate of pure time preference. Additionally, some applications reflect unpredictable catastrophic or systemic risks that could lead to obsolescence or are not otherwise considered in appraisal by adding a small factor to the rate of pure time preference (HM Treasury, 2022; Stern, 2007).

The degree of inequality aversion (i.e., how fast the utility of additional consumption declines as consumption increases) and the rate of pure time preference lack clear empirical counterparts, and normative judgement is typically required. Many argue that a rate of time preference at or very close to zero is the only defensible option because the welfare of future generations should not be given less weight than that of present generations (Dasgupta, 2008; Stern et al., 2022). Nonetheless, there remain a wide variety of views on which parameter values are appropriate for the different components of the discount rate and the extent to which these choices can be informed by empirical evidence versus normative judgement (Drupp et al., 2018). The Stern Review (2007) applied a discount rate of 1.4% (Weitzman, 2007), while typical public sector discount rates can be closer to 5% (e.g., the rate for UK government appraisal is set at 3.5% [HM Treasury, 2022] and is higher still in the private sector). It is therefore crucial for MoFs to consider the appropriate discount rate to use for climate policy analysis and potentially consider using a range of options.

Uncertainty, sensitivity analysis, and model performance

All analytical tools need to make simplifying assumptions. It is important to test the assumptions made and the parameter values chosen to learn how assumptions affect the results, and which assumptions are critical and possibly drive the results. Running many simulations with model variables drawn from one or multiple distributions can help explore sensitivity with regard to uncertainty in variables. This is especially valuable for variables that are difficult to estimate empirically. It can also be valuable to explore which courses of action retain valuable options to adapt in the future, as more information becomes available, or lead to an acceptable outcome under many different assumptions and possible futures.

Such optionality and vulnerability assessments can feed into the design of robust strategies. Analyzing the same or similar issues with multiple models and systematically comparing results can help establish the extent and in which direction the choice of model drives the results.[9] Additionally, it is important to assess the historical track-record of different tools in terms of the usefulness for policy advice or predictive accuracy, and to quantify uncertainty in model results, where possible. Some cases of implementing models covered in this report have not necessarily had strong predictive accuracy, for instance in relation to technology cost projections. Assessing the track record upfront can help MoFs develop an understanding of tool suitability and the potential robustness of results and contribute to more informed decisions.

Data availability

Many of the analytical tools available for the context of climate change and climate policy analysis are highly quantitative. This means applications may have extensive data requirements, including across time and for detailed disaggregation of sectors or production possibilities. This type of data is not always available. While improving data availability and access is an area of ongoing work, considering which data is reliable and feasible to access in relevant timeframes is also an important consideration to bear in mind when selecting analytical tools.[10]

[8] The Ramsey Rule is applied in social discounting and can be derived from a simple standard welfare function under specific assumptions. See Drupp et al. (2018, section I.A) for a conceptual background on the Ramsey Rule and further references. The application of this simple rule is not without issues, and some provide reasons for moving beyond it (see, for instance, Venmans and Groom, 2021).

[9] Model intercomparison projects can be useful here. For one example, see 'A community platform to accelerate innovation and progress in assessing green economic transitions', contribution by the Green Macroeconomic Modeling Initiative (GMMI) to the HP4 Compendium of Practice.

[10] Many tools rely on socioeconomic and climate scenarios as data inputs. The Shared Socioeconomic Pathways (SSPs) used by the Intergovernmental Panel on Climate Change (IPCC) are described in Riahi et al. (2017) and made available by the International Institute for Applied Systems Analysis (IIASA) at https://iiasa.ac.at/models-tools-data/ssp. The SSPs are used in conjunction with Representative Concentration Pathways (RCPs) by models participating in the Coupled Model Intercomparison Project 6 (CMIP) to generate climate scenarios. Data from these climate scenarios is made available by the Copernicus Climate Change Service (2021) or the World Bank Climate Change Knowledge Portal at https://climateknowledgeportal.worldbank.org/

2.6. Appropriate level of detail and matching tools to capabilities

Models are designed to simplify reality, but some assumptions can be especially unrealistic in the context of the transition. While it can be of benefit to enhance models to reflect additional variables and greater detail, a balance between simplicity, which ensures tractability and transparency, and incorporating key variables necessary for answering policy questions may be desirable to pursue.

In practice, MoFs also need to consider their capability and capacity to develop and maintain tools, as well as whether necessary data is available. Many methods are powerful and versatile, yet the quality of the analysis critically depends on the specific application and the technical capabilities of the modelers conducting it. Even when analysis is outsourced or performed by line ministries, in-house experts are required to understand and interpret the technical outputs produced by others. This means that investments in human capital are important to consider and that staff turnover may be costly.

Some tools require specialized software and coding skills, while others, such as the Climate Policy Assessment Tool (CPAT) and Quantitative Climate Change Risk Assessment Fiscal Tool (Q-CRAFT), run in spreadsheet software like Excel. These tools are user-friendly, pre-loaded with country-level data, and enable quick scenario testing. However, reliance on global data where country-level information is unavailable can lead to misleading results if not properly checked. Additionally, the partial equilibrium nature of these Excel-based tools limits the consideration of second- and third-order effects.

To improve accessibility, some developers offer Excel dashboards for more complex models. In academia, analytical IAMs have emerged as a response to the criticism that traditional IAMs and climate-macro models function as 'black boxes' (Dietz, 2024). These simplified models offer closed-form solutions, making them easier to interpret and analyze.[11]

Usually, a balanced approach is needed, combining investment in model development, simpler complementary analytical methods, and in-house expertise to evaluate model results obtained from elsewhere. Complexity should not come at the cost of transparency, as clear model interpretation is key to identifying effective policy levers.

2.7. Communicating model results

Quantitative results clearly aid understanding of the relative importance of various climate and climate policy impacts and contribute to informed decision-making. However, it is important to remember that models can create a false sense of precision and certainty if their results are presented as facts. To avoid making decisions based on potentially incomplete information and overinterpretation of results, it is especially helpful to clearly communicate critical assumptions and uncertainties alongside model results. This can include communicating which assumptions drive model results and illustrating how results vary under different assumptions based on the results of sensitivity analysis. The data sources used, and associated limitations and gaps, are also useful to highlight.

While the purpose of such transparency is informed decision-making, highlighting contingencies and gaps can indicate areas for future research. As a result, integrity in communication can lead to improved and more informative results down the line. Complementary analytical perspectives that consider elements not reflected in the model(s) used can further corroborate results or flag areas for further analysis.

[11] Note too that while complex models can be more accurate, they need not be; there is no *a priori* positive correlation between complexity and precision.

3. The different categories of analytical tools

3.1. Introduction

Ministries of Finance already use a wide range of analytical tools and models to support economic decision-making, from macroeconomic and budget forecasting approaches to providing guidance to other ministries on cost–benefit analyses of major spending programs and investments. These tools provide structured and objective frameworks for policymakers to understand the macroeconomic consequences and other impacts of major policy and investment decisions. The physical impacts of climate change and the policies devised to mitigate and adapt to it are all material to a country's welfare, finances, and macroeconomic stability and thus need to be evaluated by MoFs.

This section aims to outline the range of analytical tools available and showcase the purpose they can serve in economic and climate policy analysis within MoFs. The following sub-sections consider each of our four identified categories of analytical tools in turn: climate-enhanced macroeconomic and sectoral models, physical climate and disaster risk models and approaches, decision-making frameworks and other analytical tools, and ex-post case studies and evaluations.[12]

3.2. Climate-enhanced macroeconomic and sectoral models

There are many possible ways to group and categorize macroeconomic models that are being used to address climate policy questions, and different authors have adopted different approaches. Here, we distinguish models by general setup and important assumptions. We do not provide a higher-level organizing structure for the different model types. The nuances that inform such higher-level groupings are important, and interested readers may consult this literature (see for instance Mercure et al., 2019). The critical message is that it is important to disclose underlying theoretical frameworks and critical assumptions, regardless of the model type or analytical approach. We discuss some of these nuances within individual model-type descriptions but do not start from a comprehensive theoretical framework for different model types here.[13]

The climate-enhanced macroeconomic and sectoral models covered here tend to focus more on mitigation, that is, assessing how climate policies focused on decarbonization impact the macroeconomy and how to achieve emissions reduction targets. However, some such models incorporate physical climate impacts through damage functions or coefficients, thereby also capturing elements of adaptation. Dedicated physical climate and disaster risk models (covered in Section 3.3. are more explicitly focused on adaptation because adaptation benefits are closely tied to avoided physical risks and associated co-benefits.[14]

[12] Sharpe et al. (2025) consider a similar range of analytical tools in the context of innovation and competitiveness in the low-carbon transition and provide a table illustrating the ease-of-use of these models in terms of skills and data required and how available they are. This can be useful to consider in conjunction with the overview of tools provided here.

[13] A further distinction between models can be their geographical scope, for instance whether they are global or focus on a single country. While Table 5.1 and Appendix A in later sections indicate the geographical scope of the models listed, the implications of this scope are not discussed here. This is nonetheless important to consider in practice.

[14] Models do not often capture migration as a margin of climate change impact or explicit adaptation strategy well, and other market-driven mechanisms such as trade and sectoral relocation can also be useful to consider. These facets are endogenous channels that support climate risk response and could be strengthened. See Chapter 4 in Bilal and Stock (2025) for a discussion and references.

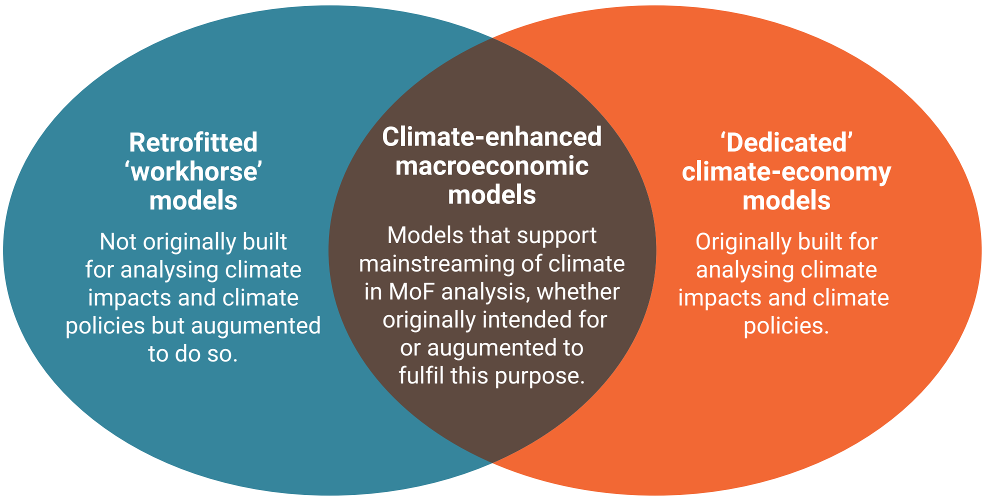
We consider two types of IAMs—cost–benefit IAMs and process-based IAMs—in line with the Integrated Assessment Modeling Consortium (IAMC, 2025). (Note that there is a growing literature on spatially explicit IAMs, but these are not discussed here; see Desmet and Rossi-Hansberg [2024] for a review.) Recent reports by the Network for Greening the Financial System (NGFS, 2024) and S-Curve Economics (Sharpe et al., 2025) consider IAMs to also refer to CGE and DSGE models that incorporate climate through emissions or damages. Here, we treat each of these models in turn, while acknowledging that the boundaries can be indistinct.

It is important to re-emphasize a key distinction between two types of approaches in this category:

- Macroeconomic 'workhorse' models: standard macroeconomic models used by MoFs that have been adapted for climate-related applications.
- 'Dedicated' climate–economy models: purpose-built models designed specifically to analyze climate change and climate policy.

This distinction is based on the process of model development rather than their inherent characteristics. In practice, both approaches can lead to similar models and the boundaries between them often overlap (see Figure 3.1). However, these alternative development processes outline different ways of integrating and mainstreaming climate in MoF analyses. Workhorse models build on existing tools familiar to MoFs, potentially making it easier to mainstream climate considerations within established workflows. Dedicated climate–economy models may use analytical processes that are new to MoFs and can thus require additional capacity-building.[15] In each case, models are likely better suited to answering questions within their original focus, with more limited capacity to touch on fields into which they have been expanded.

Figure 3.1. Overlap between macroeconomic 'workhorse' and 'dedicated' climate–economy models



Due to the overlaps in categories and the often complex history of models in use today, this report does not strictly categorize models as 'workhorse' or 'dedicated'. Rather, it treats all macroeconomic models that integrate climate as 'climate-enhanced macroeconomic models'. This broader category also includes sectoral and partial equilibrium models, particularly Energy System Models (ESMs), which are often incorporated as sub-models in climate-enhanced macroeconomic frameworks.

It is worth noting that multiple terms are often used by different organizations to describe the same modeling approach. For example, Structural Econometric Models (SEMs) are also referred to as macrostructural models, New Keynesian macroeconometric models, or policy models, hence, where needed, we have sought to clarify key terms.

Box 3.1, later in this section, provides a brief history of the evolution of some of the standard macroeconomic models used to analyze climate impacts and climate policy today.

[15] For a more detailed discussion of the process of developing analytical capabilities, see the HP4 Capabilities Report.

3.2.1. Computable General Equilibrium (CGE) models

Computable General Equilibrium (CGE) models: summary

Typical features: optimization-driven; general equilibrium; potential for detail, e.g., sectoral disaggregation, granular tax types, and heterogeneous agents; flexibility to apply different assumptions; exogenous technological change; can be static or dynamic, though often dynamic for climate applications.

Example policy questions typically seen as most helpful for CGE models to address:

- What is the best way to design carbon pricing policies? How can carbon pricing revenue best be recycled?
- What are the impacts of other large-scale green fiscal policies (e.g., taxes and subsidies)? How will consumer and producer behavior change in response?
- What are the high-level macroeconomic effects of the transition?
- How is the tax base projected to change, especially as fossil fuels are phased out?
- What are the investment requirements for the transition (e.g., of reaching targets in nationally determined contributions [NDCs])?
- What are the current and expected future impacts of physical climate change on productivity and output across sectors?
- Which sectors are most impacted by decarbonization?
- What are the labor market implications of structural change as a result of the transition?
- What are the distributional impacts of the transition?

Further examples are listed in Table 4.1.

Commonly cited limitations:

- Standard CGE models using nested constant elasticity of substitution (CES) functions are quite rigid, which limits the analysis of non-marginal, structural change. To address this limitation, key parameters can be updated manually over time.
- These models are usually solved by finding an equilibrium at each time step rather than a continuous adjustment being modeled. This means the state of the economy in short-run disequilibrium, e.g., shortly after a policy or climate shock, is not reflected.
- Building detailed custom databases with high levels of disaggregation can be challenging.
- CGE models, alongside other model types, are often considered 'black boxes' as the indirect impacts are not necessarily tractable.

Commonly used software: GAMS/MPSGE (requires license), GEMPACK (requires license)

CGE models represent the market economy algebraically, disaggregated by sectors and products, and regions in the case of global or nationally disaggregated models, and are one of the most common modeling types in use in MoFs. They represent sectoral interlinkages, numerous tax types, and, depending on the implementation, various households and regions. Through this detail, CGE models can capture the higher-order, general equilibrium effects of a range of policies, including policies with various degrees of enforcement and intensity across sectors, and compare these with a business-as-usual baseline.

Standard CGE models are typically driven by neo-classical assumptions of producers and consumers maximizing profits and utility, respectively, which determines demand and supply. The price mechanism brings about general equilibrium in each timestep of the model. Detailed national accounts data for a point in time are used to form a social accounting matrix (SAM) that is used to calibrate the model to reproduce the economy in question in that base year.[16] For dynamic models, parameters and variables are then calibrated to produce a time path for the projection period (Ziesmer et al., 2023). The demand and supply elasticities and substitutability between different factors of production are often estimated empirically, which also means that these models are data-intensive to run without a closed-form solution and rely on parameterization. This setup captures how shocks propagate through the economy, i.e., general equilibrium effects, by modeling the interlinkages between sectors

[16] Many global CGE models rely on the GTAP database (Aguiar et al., 2023) as their primary source of information. Models implemented in GEMPACK often use Input–Output or Supply–Use tables as their key dataset, which may have more detail than SAMs.

explicitly. Generating sector-specific outputs and accounting for general equilibrium effects are advantages CGE models have over models that use more aggregated, reduced-form functions to represent the economy.[17]

For policy analysis, a policy proposal is translated into exogenous shocks to model parameters with which a new equilibrium is computed and compared with the equilibrium in the absence of the shock. The difference provides the estimated policy impact.

A similar approach can be used to analyze the impacts of climate change and climate change policy via CGE models.[18] CGE models track economic activities and those used for climate policy analysis also attach emission coefficients to these activities. Thus, CGE models can track how emissions change as economic activity changes. Pricing policy can be reflected as a shock to relative prices and can be directly integrated. Non-pricing policy can also be reflected, for instance via (distortionary) shadow prices and (non-distortionary) revenue return,[19] or via coupling, e.g. with energy system models (Hallegatte et al., 2023; Weitzel et al., 2023). CGE models can simultaneously represent a range of pricing and non-pricing policies, which allows analysis of their trade-offs. Energy, climate, and trade policies can also be considered in conjunction, which is helpful especially because the lines between the three are increasingly blurred, as in the case of the EU Carbon Border Adjustment Mechanism (CBAM). Regional and especially global CGE models can also help analyze the cross-border spillovers of climate policy (see e.g., Fournier et al., 2024), competitiveness, carbon leakage, the economic impacts of international cooperation and coordination (see e.g., Thube et al., 2021), and trade.

Climate damages can be reflected as shocks to, for instance, the availability or productivity of factors of production or to demand (Dietz, 2024). Shocks from the impacts of physical climate risks can be considered by linking CGE models to biophysical models (Roson, 2004). Biophysical models can indicate the magnitude of shocks to, e.g., labor productivity or limits or reductions to the endowment of capital due to climate change, which can be input into a CGE model to elicit macroeconomic consequences. While such linkages between models are possible, they are often not straightforward, as biophysical models are seldom created with this purpose in mind.

Sectoral models are often linked to CGE models to augment the resolution of sectors that are key to decarbonization, such as the energy sector.[20] This can enable a more accurate representation of available technologies and substitution between them. Setting sectoral models to one side, technological change is typically assumed to be exogenous in CGE models, although technological change can be endogenized (Chewpreecha et al., 2024; Mercure et al., 2016; Witajewski-Baltvilks, 2023).

CGE models can incorporate features from overlapping generation models (OGMs), which helps relax the assumption of a single representative agent on the demand side by accounting for how people behave at different stages in their lives. Additionally, some CGE models have multiple representative agents distinguished by income decile, which means distributional implications and potential regressivity of policies can be identified without the use of additional data from household surveys. Such models include the Finnish FINAGE and VATTAGE models (Honkatukia, 2009; Tamminen et al., 2019), IRENCGE-DF and MANAGE-WB.[21]

In most CGE models, the economy is in general equilibrium at each point in time, meaning supply equals demand in all markets, including the labor market (Castellanos and Heutel, 2024). This means the state of the economy in the long run, in successive equilibria, can be analyzed with these models, but the state of the economy in the very short run when it is transitioning between equilibria is not readily elicited. In theory, this means CGE models can represent structural change. However, as the state of the economy after a policy shock depends on consumption

[17] For further details the *Handbook of CGE Modelling* (Dixon and Jorgenson, 2013a) is a key reference.
[18] In addition to work cited in the remainder of this section, ongoing work on climate and the environment by the GTAP group at Purdue University, the Centre of Policy Studies (CoPS) at Victoria University, and the International Food Policy Research Institute (IFPRI) is also at the forefront of the discipline and may be useful to consult.
[19] See 'Finance Canada CGE model', contribution from Canada's Department of Finance to the HP4 Compendium of Practice.
[20] See also 'The Italian Ministry of Economy and Finance climate-related modeling tools: how to build a flexible suite of models serving different purposes', contribution from the Italian Ministry of Economy and Finance, and 'Overview of the European Commission's energy and climate policy-related modeling suite', contribution from the European Commission to the HP4 Compendium of Practice.
[21] See 'The Italian Ministry of Economy and Finance climate-related modeling tools: how to build a flexible suite of models serving different purposes' (op. cit.); and 'MANAGE-WB: a recursive-dynamic CGE model', contribution from the World Bank to the HP4 Compendium of Practice.

and production elasticities and substitution possibilities that are typically assumed to remain constant, results following a large shock and in the long run may not be realistic, as elasticities and substitution possibilities may indeed change. This is especially the case where technological evolutions change the production possibilities. However, this critique is not unique to CGE models and can affect model parameters across the range of tools.

The impact of a policy shock also depends on the baseline economy, meaning that these models are best suited to analyzing marginal changes around this baseline. Given that climate action is likely to elicit a degree of disruptive non-marginal change between and within sectors, this can often be seen as a constraint. Nonetheless, key coefficients and elasticities that are expected to change in the context of large shocks or the transition may be updated throughout model runs via exogenous shocks and thereby aid a more realistic representation of structural change in the medium to long term.

Model results also critically depend on the equilibrium assumptions applied and potential frictions integrated into the model. Some CGE models include 'disequilibrium' aspects, such as frictions in labor and capital markets, which can help to adjust the market equilibrium assumption. Frictions in capital markets can be incorporated via vintages, which influence the estimated cost of large structural shifts.[22] Labor can be differentiated by skill level, which can provide another dimension to labor mobility. Even where alternative assumptions about labor market frictions indicate similar effects of climate policy on aggregate outcomes such as the employment rate, there may be important underlying differences, for instance in employment in the fossil fuel-driven electricity sector (Castellanos and Heutel, 2024). Decisions about the specification of the labor market also depend on the specific country context.

CGE models can be single-country or global models and either static or dynamic. Global models are usually maintained by international organizations, while individual MoFs tend to have models that represent their own economy. The latter nonetheless usually represent the 'rest of the world', to support representation of the economy as an open one. Dynamic models can be solved recursively, which is to say sequentially, with agents assumed to be myopic, or via inter-temporal optimization, such that all time-steps are solved simultaneously and agents take their expectations of the future into account when making decisions. Recursive models are especially well suited for the short- and medium-term analysis of, say, five to ten years, as these models can represent shorter-term dynamics of economies well. Models solved via inter-temporal optimization smooth over shorter-term dynamics but have forward-looking agents, which makes them less well suited for the short term and better suited for longer-term analysis.

3.2.2. Dynamic Stochastic General Equilibrium (DSGE) models

Dynamic Stochastic General Equilibrium (DSGE) models: summary

Typical tool features: short-term; optimization-driven; capture disruptions around general equilibrium; some sectoral disaggregation; technological change is typically exogenous, but endogenous is possible.

Example policy questions typically seen as most helpful for DSGE models to address:

- What are the high-level macroeconomic effects of the transition?
- How might financial stability be impacted by the transition, including a disorderly transition?
- What are the monetary policy implications of the transition?
- What are the current and expected future impacts of physical climate change on productivity and output across sectors?
- What is the best way to design carbon pricing policies? How can carbon pricing revenue best be recycled?
- What are the impacts of other large-scale green fiscal policies (e.g., taxes and subsidies)? How will consumer and producer behavior change in response?

[22] The 'vintage' of capital refers to the year the capital was first committed or deployed. Differentiating between vintages can help assess the ageing of the capital stock and its time-dependent characteristics, such as emissions intensities, how easily different inputs can be substituted in production (factor substitution elasticities), or resale value on secondary markets. The IMF-ENV model integrates this form of friction into capital markets. See Appendix A and 'IMF-ENV: integrating climate, energy, and trade policies in a general equilibrium framework', contribution from the IMF Research Department to the HP4 Compendium of Practice, for more details on this model.

Commonly cited limitations:

- DSGE models often have limited sectoral disaggregation and limited heterogeneity across agents due to high computational demands and tractability.
- These models are less suited for modeling large-scale, longer-term economic transformation for decarbonization, especially because they are usually solved around a steady state.

Commonly used software: MATLAB (requires license), Dynare (open source if run on Octave but can also run on MATLAB)

DSGE models are another common model type for studying the dynamics of an economy in a general equilibrium setting, primarily used in central banks and academia but also by Ministries of Finance. Modeled macroeconomic shocks are stochastic (i.e., random-sampled from a given distribution) and the models are normally run on a quarterly frequency. As a result, DSGE models are usually well suited for quantitative analysis of the short and medium term, usually in the context of monetary and fiscal policy, and macroeconomic shocks.

As in CGE models, DSGE models characterize households and firms as utility and profit maximizers, respectively. In contrast to most CGE models, however, DSGE models take uncertainty into account and focus on the short and medium term.[23] Agent expectations are usually forward-looking and behavior is thus sensitive to expected future developments. This behavior is typically specified based on microfoundations and is model-consistent in the sense that agents make decisions based on expectations formed using the same assumptions and relationships that underpin the model itself. Real, nominal, and financial frictions (i.e., barriers to immediate adjustment of relative prices or other market imperfections) are also often represented, which addresses the criticism that DSGE models that do not incorporate such frictions do not record real-economy effects from nominal shocks even though empirical evidence suggests there are real-economy effects (Dietz, 2024). They also usually have a monetary authority that sets the interest rate according to a reaction function. As solving DSGE models is complex, they often represent a more stylized economy with fewer sectors. In contrast to long(er)-term macroeconomic models, the long-run macroeconomic equilibrium is often assumed, with perturbations around this being the focus of analysis. This makes them more suited for short-term analysis.[24]

DSGE models can represent macroeconomic frictions such as sticky prices or unemployment in the equilibrium computed. Incorporating such frictions may be of particular interest to developing economies, where low wages and high unemployment, or high inflation and thus pricing frictions, may be important features of economic analysis. The frictions especially worth incorporating will vary by country context, which also means that, within the model type, not all models are equally suited for different countries.

There are multiple ways in which variables such as greenhouse gas emissions or pollution more generally, which are relevant for climate change impacts and climate policy, have been integrated into DSGE models. The overview that follows is based on Annicchiarico et al. (2022). Emissions can be integrated as an input to production, or by specifying emissions as a byproduct of production. Both can be influenced: emissions as an input is a choice variable, meaning the degree of reliance on it is endogenous to the model, and emissions can be reduced by spending on abatement, which is akin to how emissions are reflected in standard IAMs such as DICE, described in Section 3.2.6 below. The impact of emissions can be modeled either via direct (negative) impacts on welfare or via an indirect impact on welfare mediated by negative impacts on output or productivity. If output or productivity are affected, a damage function is required to translate the stock of emissions (and implied warming) to associated economic impacts.

This setup enables DSGE models to provide insights into the response of a decentralized economy and what an optimal (either centrally planned or individually optimal general equilibrium) reaction would be to random macroeconomic shocks in terms of emissions and abatement spending, in addition to other macroeconomic

[23] Some CGE models treat uncertainty explicitly (see, for instance, Pratt et al., 2013).

[24] Note that some approaches close to the DSGE framework relax the assumption of a steady state. These include the forthcoming OECD Macrostructural Framework, see 'The new macro-structural climate adaptation and mitigation framework by the Economics Department of the OECD', contribution from the OECD to the HP4 Compendium of Practice, for a short summary.

indicators such as output. By implementing policy measures, such as a constraint on emissions (e.g., an Emissions Trading System [ETS]), a price on emissions (e.g., a carbon tax), or an emissions intensity standard (e.g., an efficiency standard for production) in a DSGE model, the impact of policy measures when the economy faces macroeconomic shocks can be studied (Annicchiarico et al., 2022). This can help provide insights into different features of policy options and their robustness when the economy is out of equilibrium.

As DSGE models typically represent relatively few sectors (fewer than CGE models, for instance), conducting practical policy assessments can be challenging if the policy in question applies only to specific sectors or to different sectors in varying ways. Nonetheless, DSGE models are being utilized in the context of climate policy assessments. For instance, analysis conducted with the EU's E-QUEST model contributed to the EU's 2030 and 2040 Climate Target Plan assessments, focusing on the impacts of carbon tax revenue recycling and the optimal timing of mitigation policies, respectively.[25]

Additionally, DSGE models are usually considered useful for studying the interactions between climate change impacts, especially acute climate risks that cause a short-term shock, and economic vulnerability. In this sense, climate change can itself be the source of the (random) macroeconomic shock, the economic response to which is to be analyzed via the DSGE model. This also requires a translation of the physical shock into economic impacts that can be input into the DSGE model. If the financial sector and associated financial frictions are integrated into the model, the risk to financial stability from a climate shock can also be analyzed (Dietz, 2024). Nonetheless, the limited sectoral detail in DSGE models can limit the specificity of climate shocks that can be accounted for. As many acute climate shocks impact specific assets, this can be a limitation to consider.

DSGE models are also increasingly incorporating heterogeneity across agents—either firms or households—to assess distributional consequences, as well as sectors to capture sectoral interdependencies. However, this is difficult to implement, thus limiting the granularity that can be achieved. Although the field is expanding rapidly with increased computational power, this requires modeling expertise that is not yet widely available.

Modeling the economic transformation and transition required for decarbonization can be more challenging with DSGE models, given that macroeconomic equilibrium, subject to perturbations, is typically assumed. Additionally, the reliance on detrended data makes accounting for the influence of climate change on potential output via productivity effects and capital accumulation very difficult. However, as DSGE models integrate forward-looking expectations, they have the potential to be useful for considering endogenous technological change and R&D investment, though these areas remain in development.[26] Examples to build on start with the seminal article by Acemoglu et al. (2012) and, more recently, include Baldwin et al. (2020) and Casey (2024).

To indicate that DSGE models can be used to study climate change impacts and change policy, they are sometimes referred to as 'E-DSGE' models, i.e., Energy-DSGE or Environment-DSGE models. Such models extend DSGE models with a more detailed representation of energy generation, trade, and use, which provides multiple avenues for decarbonization in the model.

[25] See 'Overview of the European Commission's energy and climate policy-related modeling suite' (op. cit.).
[26] See 'Overview of the European Commission's energy and climate policy-related modeling suite' (op. cit.).

3.2.3. Structural Econometric Models (SEMs)

Structural Econometric Models (SEMs): summary

Typical tool features: short-, medium-, and long-term; data-driven; disequilibrium features; granular sectoral disaggregation; exogenous and endogenous technological change.

Example policy questions typically seen as most helpful for SEMs to address:

- What are the high-level macroeconomic effects of the transition?
- What are the budget impacts of climate change in the long term and what are the implications for debt sustainability?
- Which policy mixes are needed to reach net zero goals?
- How does uncertainty concerning the transition impact the economy?
- How could a disorderly transition impact the economy?
- What are the labor market implications of structural change as a result of the transition?

Further examples are listed in Table 4.1.

Commonly cited limitations:

- SEMs may have less sectoral detail than other model types as time series data may not be available. However, they can be linked to sectoral models to provide granularity on key sectors.
- Their reliance on historical data to estimate behavioral equations assumes historical relationships hold in the future and in the context of shocks and transformations modeled.

Commonly used software: Python (open source), R (open source), EViews (license required)

SEMs are commonly used within MoFs for short-term forecasting and fiscal planning. Equations in these models are estimated using time series econometrics, with long-term behavior usually guided by efficient use of resources and such that economic variables follow a balanced growth path. While these models have fallen out of favor in large parts of academia, they continue to be used and developed in international and government institutions. They are motivated and informed by theory but also seek to reflect existing data well. This external consistency (with data and with the real world) is considered to make them useful for policy analysis (Blanchard, 2018; Wren-Lewis, 2018).

In comparison with SEMs, DSGE models are more focused on theory and internal model consistency, even if this means the model can explain less of the data, i.e., it has less external consistency. DSGE models often assume the long run and operate based on detrended data, while SEMs usually incorporate a time-varying long-run equilibrium. SEMs navigate the trade-off between more theoretical and empirical modeling. Ideally, theory and data would coincide, but this is not always the case. There is no objective way to determine the ideal trade-off, which may well contribute to models in this class being diverse. SEMs typically have more sectoral and spatial granularity than DSGE models, but less than CGE models. The limit to granularity is usually due to a lack of time series data that is sufficiently disaggregated by products or within countries.

Although models in this category are diverse, they are anchored in common ground that is shared by neo-classical and New Keynesian approaches. This includes frictions in the short term (in particular, nominal rigidities), imperfect competition between firms, equilibrium analysis, and a focus on stability and growth in the long term. The representation of the short term can therefore be considered to be in the New Keynesian tradition and the focus on long-term equilibrium and balanced growth is associated with neo-classical approaches (Murphy, 2017).

Multiple terms are used for these models in practice. Structural Econometric Models (SEMs) (Wren-Lewis, 2018) is one term, but macrostructural models (Burns et al., 2019),[27] (New Keynesian) macroeconometric models, and policy models (Blanchard, 2018) are also used. They are also more generally referred to as econometric models,

[27] See also 'MFMod-CC: country-specific macrostructural models', contribution from the World Bank to the HP4 Compendium of Practice.

including in conjunction with the prior terms, given their reliance on data and econometric investigation to specify individual or systems of equations that are part of these models (Wren-Lewis, 2018).[28]

Disequilibrium in the short and medium term coupled with an endogenous supply-side makes macrostructural models especially suitable for analyzing both long-lasting shocks and transitions and more event-driven shocks (such as a natural disaster), as they can capture the transient dynamics of markets and prices, and the resulting underutilization of resources (including labor and physical capital). It enables these models to capture benefits from climate policies from their impact on existing market failures and imperfections that feature in macrostructural models but not necessarily in CGE or DSGE models. Tackling pre-existing market imperfections (e.g., capital market constraints or rigidities in the labor market) can give rise to double dividends in the form of emission reductions and net economic benefits.[29] Productivity is usually exogenous but can be endogenized (Chewpreecha et al., 2024).

While these models are designed to capture short- and medium-run dynamics, they require specific adjustments to capture some of the impacts of climate change. Unlike DSGE models, which are driven more by theory and require internal consistency in a rigorous mathematical framework, SEMs, though also informed by theory, are more flexible. They can readily be adjusted to incorporate additional features, data, or modeling output from other models, e.g., via soft linking. For instance, capturing the full cost of disasters requires an explicit representation of the role of infrastructure and a realistic representation of the post-disaster reconstruction process (Hallegatte et al., 2024). Similarly, land needs to be explicitly represented as a factor of production to assess the impacts of climate policies through land use.

Due to their flexible design, SEMs also offer a useful framework to test various modeling assumptions that influence the estimated macroeconomic impacts of climate investment. This is an important exercise, because estimated impacts can differ significantly between models (Hallegatte et al., 2023; Mercure et al., 2016). Relevant factors include modeling assumptions about the crowding in or crowding out of additional investment, the inclusion of co-benefits (e.g., pollution reduction from mitigation investment that increases labor productivity), uncertainty in the assessments of co-benefits, and the risk of double counting.

The concepts of the crowding in and crowding out of climate investment are crucial for understanding the potential impacts of government spending on private sector investment, and SEMs are particularly well-equipped to analyze these dynamics.[30] These concepts help policymakers to anticipate the broader economic effects of their fiscal decisions.

The crowding out assumption is based on the idea that spending in an economy is limited by income. In a closed economy, an increase in government spending typically leads to increased borrowing, which must come from the private sector. When the private sector lends money to the government, it reduces its spending on other activities such as consumption, investment, or savings. In an open economy, the savings of the rest of the world (capital inflows) are added to the equation, but the fundamental accounting logic remains the same.

The extent to which crowding out occurs depends on how households perceive the implications of increased government debt. At one extreme, the concept of 'Ricardian equivalence,' at the heart of some DSGE models, suggests that households anticipate higher future taxes to repay the debt and therefore save an amount equal to the increase in government spending. In such models, there is total and immediate crowding out, with no spending multipliers, implying no role for government intervention as the private sector offsets government actions.

Conversely, the crowding in assumption posits that government spending, particularly on infrastructure and public goods, can stimulate private investment. This can occur through improved business conditions, increased demand for goods and services, and enhanced investor confidence. In models where endogenous money creation is

[28] They are nonetheless distinct from data-driven non-structural models that have little theoretical foundation and are used for forecasting, such as Vector Auto-Regression (VAR) models. These are not covered in this report.
[29] Note that double dividends understood as net benefits from carbon taxes can be captured in other models, such as CGE models, as well, as these depend on how revenues are recycled.
[30] The remainder of this section on crowding in and crowding out greatly benefitted from the input of Florent McIsaac.

considered (discussed in Section 3.2.7.3.), increased government spending generates additional demand, leading to more private sector investment and economic activity, effectively removing the savings constraint.

Most mainstream models used by MoFs adopt a middle-ground approach. In the long run, there will be full crowding out if government spending does not increase the capital stock, productivity, or labor supply. In the intermediate period some crowding in may occur as incomes rise with higher demand, leading to increased individual savings. However, due to capacity constraints in the economy, higher demand can generate inflation, eventually bringing the economy back to its equilibrium level of output (again, if capital stock, productivity, and labor supply are unaffected). The mechanism through which crowding out and crowding in occur is the interest rate, which effectively represents the price of savings.

Different economic models incorporate the concepts of crowding in and crowding out to varying degrees. For example, CGE models may use simplifying assumptions that align with either full crowding out or full crowding in, depending on the model's closures. SEMs employ an endogenous interest rate response to increased demand, resulting in less-than-total crowding out. These models help provide nuanced perspectives on the interplay between government and private sector investment and can help policymakers understand the potential economic impacts of their fiscal decisions.

Understanding these assumptions is essential for MoFs when designing and implementing fiscal policies. By considering the potential crowding in or crowding out effects, policymakers can better anticipate the broader economic impacts of their decisions. For instance, during an economic downturn, adopting policies that assume crowding in may justify increased government spending to stimulate growth. Conversely, in a context of high debt levels and inflationary pressures, concerns about crowding out may lead to more cautious fiscal strategies.

Box 3.1. A short history of SEM, DSGE, and CGE models

Structural Econometric Models (SEMs) can be considered Keynesian models prevalent before the Lucas critique introduced micro-foundations and rational, forward-looking agents into macroeconomics. These models "are structural in the sense of incorporating a good deal of theory [and t]hey are econometric because this is how the equations are typically parameterized […] Consistency with microeconomic theory was nice to have, but it was not an admissibility criteria" (Wren-Lewis, 2018: 57).

Through the Lucas critique (Lucas and Sargent, 1979), macroeconomics moved towards microfoundations and rational expectations, which, via Real Business Cycle (RBC) models, led to the development of New Keynesian Dynamic Stochastic General Equilibrium (DSGE) models. These incorporate forward-looking agents and rigorous microfoundations to address the Lucas critique but also incorporate factors including short-term frictions and imperfect competition that makes them New Keynesian rather than neo-classical.

While SEMs fell out of favor in many parts of academia as DSGE models became standard, SEMs remained in use in government institutions and some central banks, such as the U.S. Federal Reserve. By being data-driven, they match the data well and can be effectively used for forecasting and policy analysis, and hence have a particular use-case for policymaking (Blanchard, 2018). Over time, these older-form models have nonetheless continued to be developed, such that current SEMs are not the same as earlier SEMs that were the subject of the Lucas critique. Some, for instance, have incorporated rational expectations (Wren-Lewis, 2018). Nonetheless, some models of this kind do still have behavioral equations that are based on time-series analysis and are thus backward-looking, at least in the short term.

CGE models[31] were developed largely in parallel with DSGE models. The first CGE model was described by Leif Johansen in the 1960s. It marked a departure from Input–Output models as conceptualized by Leontief, which represent the economy as a single agent and assume linear production relationships such that inputs and outputs change proportionally. CGE models allow for more flexible production with substitution between inputs and additionally explicitly represent the optimizing behavior of separate agents. Coordination is facilitated by the price mechanism, which ensures demand equals supply.

[31] This paragraph is based on Dixon and Jorgenson (2013b).

3.2.4. Sectoral and technology cost models

Sectoral models: summary

Typical tool features: short-, medium-, and long-term; optimization- or simulation-driven; partial equilibrium; detailed disaggregation in select sectors; multiple technologies reflected and focus on technological change.

Example policy questions typically seen as most helpful for sectoral and technology cost models to address:

- What are the current and expected future impacts of physical climate change on productivity and output across sectors?
- Which technologies have the most potential for cost reductions and deployment at scale?
- Which policies should be used to support technology development and deployment?
- What are the possible decarbonization pathways in different sectors? Given cost projections, what are the decarbonization costs in different sectors?
- What are the investment requirements for the transition (e.g., of reaching NDC targets)?

Further examples are listed in Table 4.1.

Commonly cited limitations:

- Sectoral models disregard general equilibrium effects and may provide misleading results if considered in isolation.
- If a sectoral model is driven by optimization and lacks micro-foundations, results may not be realistic.
- Sectoral models focusing on technology, such as Future Technology Transformation (FTT) models, need to be continuously updated, in part because they do not account for possible future technologies.
- Estimating learning curves to assess technology costs requires a substantial amount of historical data, which means the curves and the models that use them are backward-looking in this respect.

Commonly used software: GAMS (requires license), Python (open source)

Granular, sector-specific models are often used in isolation to assess the impacts of the transition and technological change. Additionally, results from sectoral models can be integrated into macroeconomic models to provide further detail for sectors especially relevant for climate policy questions. Chief among these are Energy System Models (ESMs), which consider the power sector but can also incorporate sectors material to the energy system more generally, such as transportation and heavy industry. These sectors are especially important to consider in the context of climate policy due to their substantial contribution to emissions and because technological change within them influences transition costs and benefits, as well as emissions in other sectors that depend on their outputs.

In policy analysis, these models can be especially useful to help consider cost-effective pathways to comply with emission targets, compare the costs of different mitigation pathways, identify technologies with good prospects, and estimate the potential for energy efficiency improvements. Nikas et al. (2019) consider optimization and simulation ESMs. Optimization models identify optimal technology, usually based on the lowest cost given a set of constraints such as emission targets. Simulation models seek to replicate the real world rather than operating according to an optimization framework. They simulate the most probable outcomes in response to a policy shock in a context where economic agents do not necessarily have to be optimizers themselves.

On their own, the limitations of ESMs include that they do not capture feedback effects (or other general equilibrium effects) from policy measures, and they may lack theoretical (microeconomic) foundations. Notably, these models typically omit economy-wide capacity constraints and may therefore overstate the benefits of interventions by not taking into account where re-allocated resources come from. In the context of macroeconomic analysis, ESMs are mainly sub-models for macroeconomic models where general equilibrium effects and agent behavior are reflected, which mitigates some of these concerns. Moreover, ESMs such as POLES and PRIMES, have started to incorporate behavior informed by microeconomic foundations.[32] While

[32] Note that POLES is sometimes characterized as a process-based IAM, as it captures economy-wide emissions. Indeed, process-based IAMs are often developed from ESMs (Wilson et al., 2021).

ESMs are characterized as sectoral models here, as the emphasis is on increasing the resolution at which especially the energy sector is reflected in macroeconomic models, they can sometimes also be considered partial equilibrium models (Nikas et al., 2019).

The energy transition hinges on technological change and for planning purposes it is important to know what the cost of technologies is likely to be in the future, and to know how quickly these technologies can be deployed. Efforts are underway to integrate endogenous technological change into some sectoral models by simulating technology diffusion and dynamic returns associated with technology choice (Behrens et al., 2024; Gillingham et al., 2008). One such model is the Future Technology Transformation (FTT) model, which uses S-shaped diffusion curves to depict technological progress. FTT models currently exist for the power, road transportation, and household heating sectors (Knobloch et al., 2019; Mercure, 2012; Mercure et al., 2014, 2018). Technology costs are endogenous, with technologies benefitting from increasing returns to scale and cost reductions driven by deployment via learning-by-doing effects. By positing a mechanism to represent investment decisions, technological progress, and technology adoption, this introduces a degree of path dependency in technological change. Using endogenous costs and the impact of policies on relative prices, models that integrate technological change can then estimate the technology mix and implications for investment and prices.[33]

Technology-cost time series models, in the same family as the FTT model, are constructed using historical data from technology transitions and can be used to make predictions, again based on learning-by-doing, and Moore's Law (Nagy et al., 2013).[34] Methods to predict the accuracy of predictions from such time series models have been developed and shown to be reliable (Farmer and Lafond, 2016; Lafond et al., 2018). These methods have been used to compare scenarios for the energy transition, with the conclusion that a rapid green transition is likely to be substantially cheaper than business as usual, and cheaper than a slow transition (Way et al., 2022). Renewables, especially solar, are likely to continue to see cost reductions, which drives these results. This analysis has been extended to predict costs at the national level (Baumgärtner and Farmer, 2025), and new methods have been developed to predict technology deployment as well as costs (Wagenwoort et al., forthcoming), also with error estimates for the predictions.

Such technology cost time series models are limited in their ability to take policies into account. While they can be used to evaluate investment scenarios (e.g., investment in solar versus nuclear) and to inform long-term planning (e.g., whether to build infrastructure to support renewables), they are not useful for questions concerning how future deployment of a specific technology depends on a country's policies. Their advantage is that so far these models have predicted future costs and deployment of renewable technologies well.

Sectoral models covering the LULUCF (land-use, land-use change, and forestry) sectors are also often integrated into macroeconomic models. This is motivated at least in part by the significant proportion of emissions contributed by these sectors, hence including them in some detail can give a better account of associated policy impacts. This integration can also shed light on ecosystem risks in various transition scenarios.[35] However, given data limitations and a lack of feedback loops between nature and the economy in many macroeconomic models (e.g., CGE and DSGE models), integrating systemic risks is difficult, and alternative approaches may be warranted to aid analysis.

Sectoral models are also used to estimate the damage caused by climate change to specific sectors. This is covered in more detail in Section 3.3.1. on damage functions below.

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[33] See 'Macroeconomic modeling of climate change: the E3ME model' (op. cit.) and 'Policy packages for cost-effective transitions: learning from the past, simulating the future with the Future Technology Transformations models, and case studies from the Economics of Energy Innovation and System Transition project', contribution from S-Curve Economics, University of Exeter, and University of Manchester to the HP4 Compendium of Practice.

[34] This and the following paragraph on technology cost time series models greatly benefitted from the input of Doyne Farmer.

[35] See 'Improving the inclusion of nature and ecosystem service impacts in assessments of the economic impacts of climate risk by Ministries of Finance and economic decision-makers: the experience of Finland', contribution from Finland's Prime Minister's Office to the HP4 Compendium of Practice.

3.2.5. Process-based Integrated Assessment Models (IAMs)

Process-based Integrated Assessment Models (IAMs): summary

Typical tool features: long-term; optimization-driven; detailed representation of select sectors; biophysical processes incorporated.

Example policy questions typically seen as most helpful for process-based IAMs to address:

- What are the possible decarbonization pathways in different sectors?
- Given cost projections, what are the decarbonization costs in different sectors?
- How could a disorderly transition impact the economy?

Commonly cited limitations:

- Process-based IAMs may overstate emission abatement costs if feedback effects are not considered, such as learning-by-doing which drives down the costs of green technology as deployment becomes more widespread.
- The high level of detail and integration of multiple processes means the models can be 'black-boxes' with results that are not very tractable or transparent.

Commonly used software: GAMS (requires license), Python (open source), R (open source)

Process-based IAMs represent biophysical and socioeconomic activities, or 'processes', that cause emissions. This primarily includes an explicit account of how emissions are generated in energy and land-use systems, and, increasingly, water supply and demand. Process-based IAMs represent these processes and technologies at a high level of detail, especially in the energy sector. In the context of climate policy analysis, detailed process-based IAMs are used to develop mitigation pathways and evaluate their relative efficiency. The Intergovernmental Panel on Climate Change (IPCC) uses a range of process-based IAMs to develop its transformation pathways (Van Beek et al., 2020).

Process-based IAMs generally do not account for economy-wide damages caused by climate change (Wilson et al., 2021). This reflects their focus on developing cost-effective mitigation pathways in response to exogenous targets, such as limiting warming to 2°C (or well below), or other national goals. This contrasts with cost–benefit IAMs, discussed in the next sub-section, which consider economy-wide damages from climate change in conjunction with emission abatement costs to determine an 'optimal' level of warming through cost–benefit analysis and are also used to calculate the social cost of carbon.

While process-based IAMs draw on a range of disciplines to represent economic and biophysical processes, decision-making in such models tends to follow economic principles (Clarke et al., 2014). When determining mitigation pathways, this usually involves minimizing the cost of reaching an emissions target. Usually, these are partial equilibrium models that only represent sectors that are particularly important for decarbonization or models that have a highly aggregate, reduced-form representation of the remainder of the economy that is not as critical to decarbonization.

Maintaining interpretability and transparency can be particularly challenging with process-based IAMs (Wilson et al., 2021). The high level of detail and integration of different systems makes them 'black boxes', meaning how results are generated is not necessarily tractable. Additionally, there are substantial barriers to entry, given that these models require specialized tools to run. This does not mean these models should not be used or are not useful: they have a wide range of useful applications, but the complications make model evaluation all the more important (ibid.).

3.2.6. Cost–benefit Integrated Assessment Models (IAMs)

Cost–benefit Integrated Assessment Models (IAMs): summary

Typical tool features: long-term; optimization-driven; growth model; very limited sectoral disaggregation, if at all; exogenous technological change.

Example policy questions typically seen as most helpful for cost–benefit IAMs to address:

- What are the current and expected future impacts of physical climate change on high-level macroeconomic outcomes?
- What is the best way to design carbon pricing policies?
- What are the high-level macroeconomic effects of the transition?

Commonly cited limitations:

- Cost–benefit IAMs may overstate abatement costs if feedback effects are not considered, such as learning-by-doing which drives down the costs of green technology as deployment becomes more widespread.
- The models' damage functions may understate damages, and, if based on historical data alone, may not be a reliable guide to future damages.
- Limited sectoral disaggregation may limit their usefulness for fiscal policy analysis.
- Choice of parameter values can strongly determine results. Where these parameters lack empirical counterparts, results can be substantially influenced by choices of the modeler.

Commonly used software: MATLAB (requires license), GAMS (requires license), Microsoft Excel

Cost–benefit IAMs integrate climate modules with an economic module that is relatively simpler than in the macroeconomic models described above: usually a neoclassical growth model with one aggregate sector. Rather than representing the processes through which emissions are generated, these models adopt a reduced-form approach with simplified representation of the energy and land-use systems (Wilson et al., 2021). The paradigmatic example of cost–benefit IAMs is the widely used DICE model.

Cost–benefit IAMs[36] typically feature optimal growth or welfare optimization as their organizing principle, where welfare is the utility of a representative agent to be maximized over time. The trade-offs between emission trajectories are considered, where higher emissions today translate to higher present consumption and higher future damages from climate change. Hence, the intertemporal nature of the trade-off as well as the magnitude of the damages play a crucial role. Damages are usually translated to monetized economic impacts via a damage function that relates temperature rise to economy-wide damages. How damage functions are specified is an active area of academic debate, and Section 3.3.1. considers them in more detail.

Intertemporal welfare maximization is subject to ethical debates also because it involves discounting future welfare to arrive at its present value via the Social Discount Rate (SDR). The SDR depends positively on the pure rate of time preference, the elasticity of the marginal utility of consumption (a measure of inequality aversion and risk in consumption), and the growth rate of per-capita real consumption. There is no simple, objective way to determine the values the first two parameters should take, which is one cause for debate (Dasgupta, 2008; Tarsney, 2017). The concept of 'intergenerational justice', which is subjective and may differ between political systems and cultures, matters for both. The growth rate of per-capita real consumption differs between economies; from 1961 to 2023, annual growth in real GDP per capita was 3.0% in low- and middle-income economies on average, compared with a global average of 1.9% (World Bank, 2025). Discount rates in lower-income economies are therefore higher, all else being equal. This reduces the relative attractiveness of mitigation investments that provide benefits in the long term while increasing the relative attractiveness of more immediate growth-enhancing investments. As climate change mitigation is globally optimal, additional incentives may be needed to make tackling climate change locally optimal in different country contexts.[37]

[36] For the remainder of this section, 'IAMs' refers to cost–benefit IAMs unless otherwise specified.
[37] See 'Navigating the trade-offs between investments for growth and climate action: the role of the social discount rate', contribution from the Asian Development Bank (ADB) to the HP4 Compendium of Practice.

IAMs have a climate module that integrates physical relationships that affect climate change and facilitates the link between the economy and the physical climate system via the damage function. This typically includes a representation of the carbon cycle, a radiative forcing equation, climate change equations (relating radiative forcing to global mean surface temperature change), and a damage function relating climate stressors to economic outcomes, which closes the loop and completes the integration. They also include estimates of abatement costs, which are required to make the trade-offs between mitigation and damages.

As cost–benefit IAMs tend to deploy highly aggregated climate and economic modules and aggregated damage functions with relatively simple functional forms, their design principles are more straightforward to grasp, and the deployment of these models is relatively accessible, compared with large CGE models, for instance. Some IAMs, especially those that can be solved analytically, can be effectively deployed as diagnostic tools: they can help understand parameters at work in climate–economy interactions and can be used to "apply new ideas from economic theory, for example, welfare and decision theory" (Dietz, 2024: 35). Nonetheless, one ought to keep in mind that such IAMs have limitations as prognostic tools (Dietz, 2024). More complex, process-based IAMs with detailed climate, land-use, and energy modules or greater spatial resolution have been developed (as described in Section 3.2.5. above).

MoFs can use cost–benefit IAMs to analyze the economic impact of climate change and weigh the costs and benefits of action/inaction. These IAMs can also be used to calculate the social cost of carbon (SCC), which reflects the present value of all future damages expected to be caused by one tonne of carbon dioxide emitted today. This quantifies the externality emitters usually do not consider and can be used in public appraisal and to inform carbon tax rates.[38] They can also be used for cost-effectiveness analysis, where the least-cost mitigation path in line with high-level targets, such as a temperature goal or emissions targets, is sought. Such analysis crucially depends on the abatement options integrated into the IAM in question. While such analysis can be influential, it may not constitute mainstreaming of climate considerations into the operations of MoFs *per se*, as these IAMs do not generally replace the more detailed workhorse models Ministries already rely upon for economic forecasting.

3.2.7. Other model types

3.2.7.1. Input–Output (IO) models

Input–Output (IO) models: summary

Typical tool features: short-term; partial equilibrium; granular sectoral disaggregation; exogenous technological change.

Example policy questions typically seen as most helpful for IO models to address:

- What are the current and expected future impacts of physical climate change on high-level macroeconomic outcomes?
- What are the domestic impacts of other countries' carbon border adjustment mechanisms, green subsidies, or investments in critical technologies?

Commonly cited limitations:

- Their results may be unrealistic when large shocks or impacts over multiple years are modeled, as elasticities are assumed to remain constant. This means structural change (including within sectors) can be reflected well only up to the point where, for instance, substitutability between factors of production remains unchanged.

Commonly used software: R (open source), Python (open source)

IO models leverage tables that represent production in detail by mapping the interlinkages between sectors in the economy through their production inputs and outputs, drawing on the principles of double-entry bookkeeping.

[38] For more detailed discussions of the SCC see, for instance, Metcalf and Stock (2017), Pindyck (2019), Ricke et al. (2018), and van der Ploeg et al. (2023), and see Chapter 2 in Bilal and Stock (2025) for further references.

Unlike CGE models, which embed the same input–output tables in their Social Accounting Matrices (SAMs), IO models assume linear production relationships based on the data in the IO table. This means inputs and outputs change proportionally. While CGE models have the same starting point, they incorporate mechanisms to adjust production and resource allocations as economic incentives, technology, and resources change. Despite being more rigid, IO models are still in use, also because they are more easily implemented and can generate results quickly. Additionally, like partial equilibrium models, IO models do not normally consider supply constraints. While they do consider direct and first-round effects of a policy or climate shock on other sectors, they do not consider impacts on other sectors that give up resources or that benefit from resources being made available, depending on the intervention.

Due to their reliance on accounting matrices that represent sectoral inputs and outputs, IO models have been linked to environmental assessment methods, such as footprint methods, flow analysis, and Life-Cycle Assessment (LCA), and ESMs to assess the environmental impacts of both production and consumption (Beaussier et al., 2019; Budzinski et al., 2024; Wiedmann et al., 2007). For such applications, transactions may be reported as physical units of commodity flows, including primary inputs, rather than the usual denomination in economic value terms (Miller and Blair, 2022). Here, waste and emissions, not usually captured as part of a sectoral output, can also be reported. Such tables are referred to as physical input–output tables (PIOT).

Multi-regional input–output (MRIO) tables and models in the environmental domain are also applied to understand the environmental implications of trade, including embedded emissions. Such analysis is often underpinned by the environmentally extended input–output database EXIOBASE (Miller and Blair, 2022; Stadler et al., 2018).

For policy analysis, IO models are useful for measuring how impacts propagate across the economy due to sectoral interlinkages, which can be represented in great detail.[39] However, IO tables capture the interlinkages at a single point in time and are thus static. Additionally, as there are usually no behavioral equations, prices are assumed to be fixed, and supply perfectly elastic, IO models can overestimate policy impacts (Beaussier et al., 2019; Partridge and Rickman, 2010). Numerous extensions to IO models have been devised to address some of these limitations, including letting production coefficients change to reflect factors such as technological change or changing relative prices (Miller and Blair, 2022).

3.2.7.2. Gravity models

Gravity models: summary

Typical tool features: typically static; appraisal of actual and potential trade flows.

Example policy question typically seen as most helpful for gravity models to address:

- What are the domestic impacts of other countries' carbon border adjustment mechanisms, green subsidies, or investments in critical technologies?

Commonly cited limitations:

- There is generally limited accounting within these models for important differences between countries, such as variation in industrial composition and technological capabilities.
- They are often static, thereby overlooking important changes over time of, for instance, comparative advantage and supply chains. The potential future actions of competitors are not generally considered either.

Commonly used software: R (open source), Python (open source)

Gravity models of international trade predict trade flows between countries based on the size of their economies and the distance between them. Comparing a predicted trade flow with an actual trade flow can indicate, to a first approximation, whether there is potential for trade to be increased. This analysis can be done at the product or sector level by aggregating exports of specific products or product categories. This can provide some

[39] See 'How system dynamics models can inform India's low-carbon pathways', contribution from World Resources Institute (WRI) to the HP4 Compendium of Practice.

indication of the sectors in which a country may have the opportunity to increase its exports and which countries could be viable as destination markets.

In the context of the green transition, gravity models can be used to analyze the trade and diffusion of environmental goods, as classified by bodies such as the OECD. Cantore and Cheng (2018), for instance, use a gravity model to analyze the impact of the stringency of environmental regulation of the importer on the trade of environmental goods. These types of analysis require highly disaggregated trade data that facilitates the isolation of the trade of environmental goods in particular.

Gravity models often assume countries are similar without accounting for variations in economic structures, industrial compositions, or technological capabilities. In that context, the quality of analysis conducted with gravity models is highly dependent on the degree to which such variations are integrated or controlled for (Borges Aguiar and Cossu, 2019). Gravity models typically assume static relationships between countries, overlooking changes in comparative advantage, technologies, and global supply chains over time. A limitation that gravity models share with economic complexity analysis (discussed in Section 3.4.7) is that they generally do not consider the future actions of competitors, whereas such consideration is vital when aiming to develop new areas of competitiveness.

3.2.7.3. Demand-led models

Demand-led models: summary

Typical tool features: medium-term; data-driven; disequilibrium features; sectoral disaggregation.

Example policy questions typically seen as most helpful for demand-led models to address:

- What are the current and expected future impacts of physical climate change on productivity and output across sectors?
- What are the benefits to adaptation, given the physical risks, across sectors and regions?
- Which policy mixes are needed to reach net zero goals?
- Which sectors are most impacted by decarbonization?
- What are the labor market implications of structural change as a result of the transition?
- What are the distributional impacts of the transition?
- How does climate policy affect other domestic policy priorities? How can it align with maintaining price stability, energy security, economic growth, and other policy priorities?

Commonly cited limitations:

- The behavioral equations used are sometimes considered to be relatively arbitrary, as decision-making is not formulated as profit or utility maximization. Improved justifications for the behavioral assumptions and more transparency around the sensitivity of results to these assumptions are needed.
- Reliance on historical data to estimate behavioral equations assumes historical relationships hold in the future and in the context of shocks and transformations modeled.
- Stock-flow-consistent (SFC) models typically have specific medium-run time frames of five to ten years, which may curtail versatility.

Commonly used software: Python (open source), Fortran (open source)

Demand-led macroeconomic models are characterized by effective demand driving output rather than supply-side factors. Typically, such models are in the post-Keynesian tradition and emphasize uncertainty and the role of institutions. The focus on demand means that there is greater emphasis on quantity adjustments (i.e., supply adjustments) rather than price adjustments (i.e., reallocation in response to changing relative prices) for reconciling supply and demand. This is supported by spare capacity in the economy, which is often a feature of such models. However, supply constraints are not irrelevant. Labor supply, for instance, is naturally bounded by the size of the working-age population, and existing industrial capacity can be featured in the output equations of such models (Dwesar et al., 2022).

Demand-led, post-Keynesian models are not currently a tool commonly used within MoFs, although a prominent model of this type, the E3ME model, is used by the European Commission as a complement to other models.

Behavioral equations in these models are derived empirically, based on historical data. This historical, data-driven specification of behavior is subject to the Lucas critique for being backward-looking and behavior not changing over time or in the face of changed incentives. This is a concern for models in this tradition.[40] One approach is to adjust the behavioral equations where such changes are plausible or likely.

Another difference between post-Keynesian models and other models discussed above (e.g., CGE models, SEMs, and DSGE models), is their treatment of money and finance. In post-Keynesian approaches, money is created endogenously. This means that banks can provide finance for investments using their balance sheets. In models with exogenous money, the stock of money is determined by the central bank. The focus then is on balancing savings and investments, which can lead to trade-offs in investment. While a detailed discussion of these alternate theories of money is beyond the scope here, this is an area of active academic debate.

The sectoral representation in this model class varies but can be quite detailed. E3ME, for instance, includes 43 products, 28 types of household expenditure, and, particularly relevant in the context of climate policy, 12 different types of fuel.[41] In terms of detail, this puts them between CGE models, which have highly granular representation, and more stylized DSGE models.

In the context of climate policy, the modeling assumptions of demand-led models may lead to alternative estimated economic impacts to the models discussed above. Spare capacity and a demand-led approach mean that climate policies can boost economic as well as environmental performance and need not divert resources from other activities. For instance, investment in green technologies or infrastructure need not necessarily crowd out private investment and may instead stimulate higher spending, output, and employment.

Within the demand-led post-Keynesian tradition, ecological stock-flow-consistent (E-SFC) models are emerging, but are also not yet common within the toolkits of MoFs. E-SFC models can be considered part of the present class of demand-led models given their theoretical foundations in the demand-led post-Keynesian tradition, as described above. They integrate endogenous money theory and behavioral equations that may deviate from strict profit and utility maximization, and demand plays an important role in long-term economic outcomes in the short to the long term.

E-SFC models in particular are built on explicit representations of the dynamic interactions between monetary and physical stocks and flows.[42] Monetary stocks and flows include debt, investment, and interest payments, while physical stocks and flows include carbon emissions, waste, and water. SFC models use an accounting approach combining national and physical accounting data with macro-econometric approaches, meaning the development of the model structure is data-driven.

E-SFC models are used to analyze the macrofinancial and environmental implications of different policy scenarios in the subsequent five to ten years. Longer time horizons require additional assumptions, and the approach is not suitable for short-run forecasting. To analyze the green transition, country-specific scenarios are required. Scenarios provided by the NGFS can be a starting point but would need to be adapted to the domestic, country-specific context.

In recent years, general equilibrium models have been modified to incorporate some of these modeling assumptions, such as more detail about the financial system and endogenous money theory. Nonetheless, it remains challenging to do so, especially if multiple of the above characteristics are to be integrated simultaneously.

[40] It is also not a given that the rational expectations and optimization in other types of models, e.g., DSGE models, fully address the Lucas critique (Haldane and Turrell, 2018).

[41] See 'Macroeconomic modeling of climate change: the E3ME model' (op. cit.).

[42] See 'Ecological stock-flow consistent modeling: an emerging tool for Ministries of Finance', contribution from SOAS University of London to the HP4 Compendium of Practice.

3.2.7.4. System Dynamics (SD) models

System Dynamics (SD) models: summary

Typical tool features: medium- to long-term; simulation-driven; sectoral disaggregation; endogenous technological change possible.

Example policy questions typically seen as most helpful for SD models to address:

- What are the current and expected future impacts of physical climate change on productivity and output across sectors?
- What are the current and expected future impacts of physical climate change on high-level macroeconomic outcomes?
- What are the economic impacts from nature- and ecosystem-related risks to the economy?
- How does climate policy affect other domestic policy priorities? How can it align with maintaining price stability, energy security, economic growth, and other policy priorities?

Commonly cited limitations:

- SD models contain only small amounts of within-sector detail, and endogenizing variables such as technological change can limit the number of sectors covered.
- Labor market frictions and details are usually only represented in a limited manner.

Commonly used software: MATLAB (requires license), Stella (requires license)

SD models are simulation-based models that provide a holistic view of the dynamic interactions between sectors of the economy and the environment and simulate the economic, social, and environmental impacts of different policy scenarios (Bassi, 2015). By representing the stocks and flows of natural resources, they can estimate ecological scarcities, which helps identify environmental risks and vulnerabilities and sheds light on how the degradation of natural capital impacts productivity over time. The holistic scope of SD models means they are often seen as especially suitable for analyzing trade-offs between different policy objectives, and they can help understand complex and dynamic interactions and feedback loops (ibid.). Applications include the analysis of long-term benefits and trade-offs from measures such as investing in renewable energy, energy efficiency, or sustainable infrastructure.

The aim of SD models is not to make precise predictions of the outcomes of different policy alternatives but rather to explore which scenarios may lead to better outcomes in dimensions considered material to a range of policy objectives (Bassi, 2015). While SD models can represent the economy in a disaggregated manner, integrating endogenous change in technology, energy prices, and improvements in human capital supports fewer sectors. Labor market frictions and wage–employment interactions tend to be included, but only in a limited manner. The focus on dynamic interactions between sectors is usually prioritized over large amounts of vertical, within-sector detail. However, SD models can be linked to and used in conjunction with models with complementary characteristics that use optimization or econometric analysis, such as CGE models, energy sector optimization models, and biophysical models.

There are various options to represent different segments of the population in SD models. For instance, GDP in low-income rural areas that are highly dependent on natural capital can be considered separately, facilitated by the explicit integration of natural capital in the model (Bassi, 2015). This can be especially important in countries where the rural and urban populations may have very distinct livelihoods, such that aggregate GDP impacts could mask substantial underlying national differences.

For policy analysis, a set of scenarios is simulated that includes a BAU and one or multiple climate policy scenarios. Climate scenarios could include renewable energy targets, land conversion, or increased energy or resource efficiency in key sectors. A comparison of the results then provides insights on the relative outcomes along various dimensions between the policy scenarios, including the investment required to meet the targets.

SD simulations such as the C-ROADS and En-ROADS platforms[43] have also been used by policymakers, climate negotiators, and business leaders to game out scenarios for decarbonization, analyze policy impacts, and as a learning tool to help decision-makers understand climate, energy, and policy dynamics (Kapmeier et al., 2021; Rooney-Varga et al., 2018, 2021).

3.2.7.5. Agent-Based Models (ABMs)[44]

Agent-Based Models (ABMs): summary

Typical tool features: simulation-driven; disequilibrium features; heterogeneous agents; detailed sectoral disaggregation possible; behavioral and institutional detail.

Example policy questions typically seen as most helpful for ABMs to address:

- What are the impacts of other large-scale green fiscal policies (e.g., taxes and subsidies)? How will consumer and producer behavior change in response?
- In which sectors could a country develop a competitive advantage in the context of the green transition?
- What are the distributional impacts of the transition?
- What are the labor market implications of structural change as a result of the transition?

Commonly cited limitations:

- ABMs require substantial data and computational power, which can constrain their application.
- Calibrating ABMs as time series models is challenging.
- ABMs are relatively new in policy applications.

Commonly used software: Julia (open source), Python (open source)

ABMs are simulation models that represent individual economic agents, such as workers, households, firms, banks, and governments, and the explicit decision-making processes of those agents, to simulate how their interactions generate aggregate economic metrics (Axtell and Farmer, 2025). For instance, ABMs can simulate the selling and buying decisions of heterogenous individual producers and consumers to represent the process through which a market arrives at a price that balances supply and demand. This approach (operating via simulation rather than solving for equilibrium) enables a more flexible and realistic representation of socioeconomic systems, for example including behaviorally realistic agent decision-making or institutional details that may shape market outcomes. Furthermore, by not forcing the model to equilibrium, ABMs enable modelers to reproduce dynamics and out-of-equilibrium behavior such as financial crashes and technology transitions.

In ABMs key parameters are usually empirically estimated or drawn from distributions. The framework allows a detailed, endogenous representation of technology, including path dependence via "learning curves and complex adoption and diffusion dynamics" (Farmer et al., 2015: 348). It also makes it possible to consider the practical limits to optimal decision-making, such as lacking information on costs and supplies following a natural disaster (Henriet et al., 2012), as well as economic agents' actual behavior, such as preference for the status quo or use of rules-of-thumb instead of formal optimization.

ABMs of macroeconomies have been in development for over a decade (Delli Gatti et al., 2011). While early generation models offered significant benefits in modeling disequilibrium phenomena such as technological change and financial crises as well as distributional impacts, they were often limited to reproducing stylized facts and policy experiments that yielded comparative insights rather than quantitative forecasts. This is due to the challenges of initializing and parameterizing such large, complex models to accurately reproduce economic time series. However, an agent-based time series model of an individual economy (Poledna et al., 2023) and a global model with individual detail for the 38 OECD countries (Wiese et al., 2024) have recently been developed.

[43] See www.climateinteractive.org for further details.
[44] This section benefitted greatly from the input of Eric Beinhocker.

ABMs have been used in a policy context, including by central banks. For example, the European Central Bank and the Bank of England have applied ABMs to problems of macroprudential stress testing (Farmer et al., 2020; Montagna et al., 2020). The Bank of Canada has also experimented with an ABM for policy analysis (Hommes et al., 2025). In the UK, an ABM was used to forecast the economic shocks of the COVID-19 pandemic and provided input for UK policy; subsequent analysis showed that these forecasts were substantially more accurate than those made by conventional models at the time (Pichler et al., 2022). There are relatively few examples of application by MoFs currently, but this may be an interesting area for MoFs to consider in future research.

Disaggregated damages (at sectoral and local levels) can also be directly integrated into the ABM framework, decreasing reliance on highly aggregate damage functions that may obscure important local patterns. While this can be done for DSGE and CGE models as well, it is much more difficult as the additional constraints from damages may prevent general equilibrium models from being solvable, hence the ways damages can be integrated in such models are constrained. ABMs have more flexibility regarding the representation of damages, as they do not rely on solving for equilibrium (Farmer et al., 2015). For instance, Colon et al. (2020) explicitly represent the interactions among firms in Tanzania to explore how flood-related road closures affect supply chains in different sectors. This approach allows identification of roads and bridges that are most critical to maintaining food security (i.e., the ability of the agrobusiness sector to produce food and deliver it to consumers, especially in urban areas), manufacturing (including access to imported intermediate goods), or international trade. A criticality analysis of this kind can guide investment decisions in strengthening the most critical infrastructure and reduce the budgetary costs of improving transportation sector resilience.

Key challenges related to ABMs include that substantial computational power is often required to run them due to their complexity, and that ample data is needed to estimate parameters, which requires more effort than for models with equilibrium assumptions. Machine learning, neural networks, and other techniques can help address calibration and data limitation issues (Wiese et al., 2024). Given the complexity of ABMs, model specification and interpretation can be challenging. In this context, ABMs are emerging for use in climate–economy analysis but are not yet commonplace.

3.3. Physical climate and disaster risk models and approaches

This section draws directly on the Thematic Report on Physical Risk and Adaptation[45] from this work program.

Climate and disaster risk models and approaches can be used to assess the physical impacts of climate change. They are important on their own and as inputs into macroeconomic assessments of the impact of climate change under various mitigation and adaptation scenarios, as covered in the approaches outlined in Section 3.2 above. There are two aspects to such analysis: analyzing changes in physical climate risk due to climate change (e.g., changes to local precipitation patterns); then linking these to economic outcomes (e.g., productivity impacts in the local agricultural sector).

Such models often rest on biophysical models that take Global Circulation Models (GCMs) as their foundational inputs, which in turn draw on the natural sciences (physics, chemistry, and biology) to assess the responses of natural systems to climatic changes. Physical assessments can be used to identify specific transmission channels from physical climate change and different types of climate risks to economic impacts in specific sectors. Such assessments can differentiate between acute and chronic climate risks, for which economic impacts and suitable policy responses may differ, and they are spatially explicit. Results can be integrated into macroeconomic models to study the economic impacts of physical climate risks in a general equilibrium context via the bottom-up, enumerative approach.[46] Economic impact assessments developed via this approach tend to underestimate impacts, however,

[45] How Ministries of Finance can assess and manage physical climate risks and adaptation: available analytical tools and emerging good practice (henceforth referred to as the 'HP4 Physical Risk and Adaptation Report')
[46] See 'Strategic climate risk modeling for economic resilience: a guide for Ministries of Finance', contribution from the World Bank to the HP4 Compendium of Practice.

as it is unlikely (if not impossible) that all transmission channels can be explicitly captured.[47] Depending on how the economic impacts of physical risk are conceptualized, the resulting models may be sector-specific.

The described bottom-up approach differs from more aggregate analysis of climate change impacts on the economy, which considers the impacts of factors such as temperature anomalies on macroeconomic indicators such as GDP. While these top-down approaches can help to capture large-scale macroeconomic trends, they can struggle to account for new climate phenomena or predict cascading, complex effects, which can be better identified with an understanding of the underlying natural processes via dedicated approaches. Moreover, top-down assessments tend to average-out extreme events and outliers, even though these may be important to be aware of and prepare for.

3.3.1. Damage functions

Damage functions: summary

Typical tool features: data- or theory-driven; economic appraisal of climate change impacts and physical climate risks; while disaggregation of impacts varies, impacts are often highly aggregated and provided as a percentage of GDP.

Example policy questions typically seen as most helpful for damage functions to address:

- What are the current and expected future impacts of physical climate change on productivity and output across sectors?
- What are the current and expected future impacts of physical climate change on high-level macroeconomic outcomes?

Commonly cited limitations:

- Damage functions struggle to capture the full range of climate change impacts and risks such as tipping points, and are often criticised for underestimating damages.
- Where historical data is relied upon to inform the damage function, warming-damage relationships assessed based on past climate conditions are used to estimate impacts in future, warmer climates, and may therefore be inaccurate.

Commonly used software: R (open source), Python (open source)

Damage functions relate physical climate change to its economic impacts. Usually, damage functions express economic losses (e.g., as a percentage of GDP) from climate change as a function of changes in global mean surface temperature (or alternative climate variables) relative to the pre-industrial era. The most prominent use case for damage functions is to assess the economic impacts of different mitigation scenarios within cost–benefit IAMs (see Section 3.2.6), although CGE models, among others, also make use of them (see Section 3.2.1).[48]

Damage functions can be global, regional, or local, and typically assess long-term impacts, to 2050 or 2100. Broadly speaking, there are two types of damage functions: (i) process-based and (ii) empirical damage functions.[49] Processed-based damage functions are more common and use theory to inform the formulation of damages in a sector or the economy as a whole. They may assess damages to market goods (i.e., damages to production in a sector that produces traded goods, such as agriculture) and non-market goods (e.g., biodiversity) separately, though the latter are sometimes omitted. Empirical damage functions relate data on realized damages to temperature (usually temperature anomalies) and extreme events. Attempting to provide a comprehensive empirical damage function necessarily requires spatial and temporal extrapolation. As empirical assessments are based on historical data and use specific samples, some feedback mechanisms between climate change and the economy may not be captured. This generally means that empirically estimated damage functions are underestimated although their damages are already tendentially higher than those from process-based approaches. Sometimes, expert judgment is also used to inform damage functions.

[47] See 'Methodological recommendations for Ministries of Finance on climate change risk assessment and the enhancement of damage functions' (op. cit.).
[48] The academic literature on damage functions is large and cannot be reviewed in detail here. For a more detailed discussion and further references, see Newell et al. (2021), NGFS (2024), and Chapter 2 in Bilal and Stock (2025).
[49] See 'Methodological recommendations for Ministries of Finance on climate change risk assessment and the enhancement of damage functions' (op. cit.) and also the HP4 Physical Risk and Adaptation Report.

The empirical approach uses econometric methods to estimate the relationship between GDP and, most commonly, temperature. An important debate in this literature is whether global warming affects the level of GDP or the growth rate of GDP (see e.g., Newell et al., 2021). There is no objective way to determine which specification is the correct one. It is clear, however, that the damages from climate change are estimated to be far greater if the growth rate is affected, as damages then accumulate over time rather than being transitory only. Recent work by Bilal and Känzig (2024) indicates that it matters whether damage functions are estimated with local or global temperature shocks. The authors estimate greater macroeconomic damages from climate change using global temperature and argue that this is a better proxy for climate change than local temperature, as global temperature shocks predict a strong rise in damaging extreme events while local temperature variation does not. The conventional approach to date has been to estimate damages using short-term, local temperature variation (ibid.).

As outlined, damage functions often relate climate impacts to aggregate economic outcomes, such as GDP. This can obscure relevant information such as the variability or extremes of temperature or precipitation under different climate change scenarios, which may have severe local or temporary impacts but are not necessarily reflected in more aggregate figures. To begin to address these limitations, the World Bank has begun using 'vectors of shocks' that are based on spatially disaggregated biophysical modeling in recent Country Climate and Development Reports. These "describe the incremental impact caused by climate change in a given time period and capture local as well as short-term effects" (Abalo et al., 2025: 5) for a range of impact channels in key areas: human capital, agriculture and natural resources, and infrastructure and services.

The lack of representation of the full range of climate change impacts and risks is a key criticism of current damage functions. Damage functions specified through either the process-based or the empirical approach omit various channels through which climate change affects the economy that are not yet reflected in the literature or the data. For instance, the increasing frequency of extreme weather events, large-scale Earth system changes (i.e., 'discontinuities' or 'tipping points'), loss of biodiversity and ecosystem services, and cascading risks are often not captured or are not done so well.[50] Even where these risks are understood to exist, they may not yet be quantified and are thus difficult to include in damage functions (Stern, 2013). These omissions then lead to an underestimation of risk or damages.

To supplement analyses via damage functions, MoFs can refer to the IPCC's Sixth Assessment Report, which provides alternative physical and social risk metrics (IPCC, 2023a, 2023b).[51] Additionally, Ministries can draw on methods from the actuarial profession that seek to combine actuarial risk management principles concerned with assessing low-probability, high-impact events and the precautionary principle, with deeper understanding provided by climate science to highlight areas of risk and uncertainty (Trust et al., 2024).[52]

[50] Ibid. See also 'Methodological recommendations for Ministries of Finance on climate change risk assessment and the enhancement of damage functions' (op. cit.), including for references to applications that address some of these limitations.
[51] Ibid.
[52] See also 'The urgent need for Ministries of Finance to factor systemic climate risk into their economic analysis and modeling approaches and principles for doing so: a view from the insurance and pensions industry, contribution from the Institute and Faculty of Actuaries to the HP4 Compendium of Practice.

3.3.2. Loss and damage assessments and asset-level analyses

Loss and damage assessments: summary

Typical tool features: data- and scenario-driven; appraisal of financial risk from physical climate risks.

Example policy questions typically seen as most helpful for loss and damage assessments and asset-level analyses to address:

- What are the budget impacts of climate change in the long term and what are the implications for debt sustainability?
- What are the budget impacts of disaster risk finance in the context of the changing frequency and magnitude of extreme events?

Commonly cited limitations:

- Quantifying non-market losses can be challenging.
- Systemic impacts and feedback effects from the real economy may be overlooked.

Commonly used software: GAMS (license required), Python (open source)

Loss and damage assessments evaluate the impacts and costs associated with the adverse effects of climate change, even in the presence of mitigation and adaptation efforts. These assessments quantify economic and non-economic losses to inform policy decisions, secure funding for recovery, and guide effective adaptation strategies.[53]

Acute physical risks can also be explored through stylized stress tests that simulate the effects of extreme weather events on macroeconomic indicators such as debt-to-GDP ratios. The EU's Adaptation Strategy incorporates such an approach, using stylized stress tests to assess the fiscal implications of climate scenarios (1.5°C and 2°C of warming), as detailed in Gagliardi et al. (2022).[54]

Loss and damage assessments face challenges such as data limitations and the difficulty of quantifying non-market losses and capturing temporal and spatial variations.[55] Where historical data is used to assess economic impacts, the impacts can be underestimated because threshold effects and novel impacts in the context of unprecedented potential future circumstances, such as higher sea levels or new temperature extremes, are not reflected in the data (Abalo et al., 2025).[56]

Asset-level analyses focus on the impacts of climate change on assets such as buildings, infrastructure, and land, and can be location-specific. These analyses are used by national governments, international organizations, and private institutions to inform fiscal sustainability assessments, mobilize disaster risk financing (DRF), and design climate adaptation strategies. Asset-level analyses may overlook broader systemic and indirect economic impacts by focusing on specific assets. Here, loss and damage assessments can be complementary. Aggregating asset-level findings to derive macroeconomic insights may lead to misrepresentations if they are not carefully calibrated.[57]

Loss and damage assessments and asset-level analyses are analytical tools that can inform proactive risk management strategies for MoFs and other decision-makers. By highlighting the financial implications of physical climate risks, these tools help identify where adaptation investments can most efficiently reduce exposure and vulnerability. They can also inform the design of insurance mechanisms and contingent financing arrangements that support fiscal sustainability in the face of climate shocks. This rationale is outlined in Mechler et al. (2014), with a more detailed operational framework provided by Radu (2024).[58]

[53] See the HP4 Physical Risk and Adaptation Report and Chapter 2 in Bilal and Stock (2025) for more detail.
[54] See also 'Integrating physical climate risks into public debt sustainability in the EU Member States', contribution from the European Commission to the HP4 Compendium of Practice, and COM/2021/82 final for the Adaptation Strategy.
[55] See the HP4 Physical Risk and Adaptation Report.
[56] See also 'The urgent need for Ministries of Finance to factor systemic climate risk into their economic analysis and modeling approaches and principles for doing so…' (op. cit.).
[57] See the HP4 Physical Risk and Adaptation Report.
[58] See also the following contributions to the HP4 Compendium of Practice: 'A structured approach to disaster risk financing in the EU Member States' (from the European Commission); 'How the analytical tools and methods used in the (re)insurance industry can support Ministries of Finance in their understanding of physical climate risks and their efforts to support climate adaptation' (from Marsh McLennan); and 'The urgent need for Ministries of Finance to factor systemic climate risk into their economic analysis and modeling approaches and principles for doing so…' (op. cit.).

3.3.3. Catastrophe models

Catastrophe models: summary

Typical tool features: data- and simulation-driven; economic appraisal of physical risks; detailed disaggregation in select sectors or hazards.

Example policy questions typically seen as most helpful for catastrophe models to address:

- How great is the shortfall in resilience and protection against climate impacts currently, how great is the future shortfall likely to be, and how are the risks from extreme climate and weather events changing with climate change?
- What are the budget impacts of disaster risk finance in the context of the changing frequency and magnitude of extreme events?
- What are the benefits of adaptation, given the physical risks, across sectors and regions?
- How might financial stability be impacted by the transition, including a disorderly transition?

Commonly cited limitations:

- These models rely on exposure and vulnerability data that is often not available or is prohibitively expensive.
- Hazards are highly localized phenomena for which it is hard to make a generalized model.
- Catastrophe models at local scales are often proprietary and therefore expensive. Some global-scale models are available on an open-source basis, but these may be less suited for country-level analysis.

Commonly used software: Python (open source), R (open source), GIS tools such as ArcGIS (requires license) or QGIS (open source), specialized modeling platforms

Catastrophe models estimate potential losses from extreme events, including climate- and weather-related events, using a bottom-up approach that draws on scientific and engineering knowledge to explicitly capture the hazard, exposure, and vulnerability levels. While this means models are designed based on expert knowledge, they are calibrated and validated based on historical events. Additionally, climate projection data can be incorporated when developing the hazard module of catastrophe models, and data on risk reduction measures can be incorporated to consider alternative adaptation scenarios.[59]

Because catastrophe models simulate the physical outcomes of natural hazards using geographical information systems (GIS), they are useful for the creation of hazard maps, which provide more detailed estimates of different aspects of a hazard, such as inundation depths and flow velocity (Jonkman et al., 2008). Depending on available data, hazard maps can be built at the city, regional, or global levels, and, in conjunction with data on exposure and vulnerability of exposed assets, can be used to estimate potential damages (de Moel et al., 2015). This also means catastrophe models rely on assumptions about the value of land, buildings, and other infrastructure, alongside records of natural hazard characteristics (Schröter et al., 2018). While incredibly important, this may also be limiting because such data is often not available, and where it does exist, it can be prohibitively expensive, proprietary information. As a result, procuring the data required for effective catastrophe modeling can be challenging.

Catastrophe models also draw on damage functions to estimate economic losses associated with specific natural hazards. However, relative to aggregate damage functions usually employed in cost–benefit IAMs (discussed in Section 3.2.6 above), these damage functions are hazard-specific and generally more detailed. Regarding economic impacts, for instance, they tend to reflect impacts on specific assets rather than on aggregate macroeconomic indicators. Catastrophe models also draw on probabilistic damage functions, which account for uncertainty in the relationship between the hazard intensity and the level of damage.[60]

[59] See 'Stronger analytics for better financial resilience against climate shocks and disasters', contribution from the World Bank Finance, Competitiveness & Innovation Global Practice (FCI GP) to the HP4 Compendium of Practice.
[60] See the HP4 Physical Risk and Adaptation Report.

The availability of catastrophe models is uneven across regions, and developing models or databases can be resource-intensive. Where existing models are unavailable or unsuitable, a sequential approach of leveraging available global and local datasets for initial risk estimates prior to developing a full catastrophe model may be appropriate.[61] Catastrophe risk pools, for instance, hold regional repositories of hazard and exposure data that can help underpin analytics to inform catastrophe risk insurance and broader risk management investments in the relevant region.

It is likely out of scope for MoFs to develop catastrophe models, and the underlying hazard models are the product of extensive scientific research. However, it is valuable for MoFs to utilize the results of catastrophe models, including as an input into macroeconomic models.

The distribution of damage or financial loss estimates provided by catastrophe models can be used as inputs to estimating climate-related contingent liabilities, financial protection gap analysis, and climate risk finance instrument structuring and pricing, among other areas.

Results from catastrophe models can be used as inputs to macroeconomic models by simulating the impact of a single event as represented by the catastrophe model. This is commonly done with events with a 100-year or 1,000-year return period (i.e., an annual probability of occurrence of 1% or 0.1%). It can also be done in a 'Monte Carlo' setting, in which the macroeconomic model is run many times, with a stochastic process (based on the catastrophe model) determining for each timestep whether a disaster can happen and what the losses are. As previously mentioned, introducing disaster impacts usually requires adjustments of the macroeconomic model being used. Simply reducing the capital stock (or increasing depreciation) does not properly represent disaster impacts (see examples in Hallegatte and Vogt-Schilb, 2019).

To capture disaster impacts, the macroeconomic model should be able to represent: (1) the complementarity across physical assets and non-marginal asset losses; (2) the special role of infrastructure (and its complementarity with the capital stock); and (3) the practical, technical, and financial constraints to the reconstruction and replacement of lost assets.[62] Hallegatte et al. (2024) provide an example of connecting a catastrophe model for floods and earthquakes to a macrostructural model.

3.3.4. Extreme Event Attribution (EEA)[63]

Extreme Event Attribution (EEA): summary

Typical tool features: data- and scenario-driven; economic appraisal of physical climate risks; disaggregation of impacts varies, but often includes non-market impacts such as loss of life.

Example policy question typically seen as most helpful for EEA to address:

- What are the budget impacts of disaster risk finance in the context of changing frequency and magnitude of extreme events?

Commonly cited limitations:

- Results critically depend on the robustness of the climate models employed.
- Extreme events are inherently variable, rendering attribution of risk difficult.

Commonly used software: R (open source), Python (open source), MATLAB (requires license)

[61] See 'Stronger analytics for better financial resilience against climate shocks and disasters' (op. cit.).
[62] Representing disaster losses as a reduction in the stock of capital is equivalent to assuming that only the marginal capital (i.e., the least productive) is affected or that capital can be freely and instantaneously reallocated toward its most productive use. This is, of course, not the case, especially when infrastructure is affected; for instance, a key bridge may be damaged by a flood. Because disaster impacts can affect submarginal capital, they can lead to larger output losses than capital losses (Hallegatte and Vogt-Schilb, 2019).
[63] This section draws on Newman and Noy (2023).

Extreme Event Attribution (EEA) seeks to estimate the change in the occurrence of extreme events that have actually occurred that is attributable to anthropogenic climate change. To that end, climate models are run in two scenarios: a current climate and a counterfactual climate without anthropogenic greenhouse gas emissions. The difference in occurrences of extreme events provides the differential attributable to climate change, and it can be a difference in the expected intensity or the probability of the extreme event occurring. Using probabilistic methods, the Fraction of Attributable Risk (FAR) metric can be estimated, which quantifies "what portion of the risk of an extreme weather event occurring is the result of climate change" (Newman and Noy, 2023: 1).

Taking this one step further, by combining the risk of an event occurring that is attributable to climate change with data on economic damages from the event yields an estimate of the cost of climate change from the changing risk of natural disasters in that instance. Applying this method to many EEA studies and extrapolating for events not explicitly captured can, in theory, provide an estimate of the global economic impact of climate change from extreme weather events.

Using EEA and data on economic damages to measure the costs of climate change is an attribution-based, i.e., bottom-up rather than top-down, method that specifically accounts for the impact of extremes. These are less well captured in top-down damage functions that relate global or regional mean annual surface temperature (more specifically, its deviation from the pre-industrial era temperature average) to economic damages.

EEA relies on complex models and the quality of input data. The inherent complexity and variability of extreme events along with the imperfect nature of models can complicate accurate attribution of extreme events and quantification of economic losses due to anthropogenic climate change.[64] Additionally, the data coverage of natural events and their socioeconomic consequences is not comprehensive or sufficiently accurate (Newman and Noy, 2023). Nonetheless, continuous improvements in both the method and the data can make this method more precise over time.

3.4. Decision-making frameworks and other analytical tools

The qualitative and quantitative decision-making frameworks and other analytical tools outlined in this section can be used for analysis upstream or downstream of quantitative models or can be used in parallel to inform and complement the analysis. In some cases, they may also be used instead of large modeling tools, including where the use of sophisticated modeling approaches is beyond the initial analytical capability of an MoF. Their purpose is to provide methodologies or systems for making a range of decisions, including on climate policy and determining suitable modeling approaches, in particular in the context of uncertainty and risk.

Such approaches can help develop an understanding of a sector or a country's entire economic system to help identify leverage points (e.g., via systems mapping), determine strategic sectors or technologies to support (e.g., via complexity analysis), estimate the costs and benefits of major policies or large-scale investment programs at a single or several points in time (e.g., via cost–benefit, risk–opportunity, or multi-criteria decision analysis), and analyze outcomes under different potential futures (e.g., via real options theory or robust decision-making). Some of these approaches are qualitative but can inform and be combined with quantitative analysis or modeling. Others are highly quantitative and rely on many simulations and extensive data. Additionally, some approaches have similar underlying principles and informed the design of some of the models discussed in the preceding sections. For instance, cost–benefit analysis covered here is the underlying principle of cost–benefit IAMs discussed above.

Explicitly non-quantitative methods can be useful to counter the narrowing of perception and analysis that can occur with quantitative analysis due to a focus on matters that are more readily quantifiable (Zenghelis et al., 2024). Issues that are complex, dynamic, and difficult to think about intuitively or integrate into quantitative models can be clarified via non-quantitative analysis, even if only at a conceptual level. This can be useful for

[64] See also the HP4 Physical Risk and Adaptation Report.

policy design or as an input to future development of quantitative methods. Key facets of the transition, such as deep uncertainty, extreme risk, endogenous preferences, and rapid technological change, are difficult to capture quantitatively in comprehensive modeling frameworks. Nonetheless, these issues cannot be ignored, and additional methods of analysis can be helpful in this regard—including for developing better underlying descriptive models of factors such as relevant market failures and the behavior of investors, firms, and individuals (Stern et al., 2022).

3.4.1. Cost–Benefit Analysis (CBA)

Cost–Benefit Analysis (CBA): summary

Tool features: various timeframes; economic appraisal of climate change impacts and climate policy.

Typically seen as helpful for addressing many policy questions, but particularly:

- Which policies should be used to support technology development and deployment? (E.g., the economic costs and benefits—direct, indirect, induced—of a major green technology support program.)

Commonly cited limitations:

- CBA is a method for marginal analysis that, on its own, can struggle to account for the general equilibrium effects of an intervention.
- Dynamic feedback effects are not often captured.

Cost–Benefit Analysis involves tallying up the costs and benefits associated with a project over time and discounting the net benefits into present value (PV) using a discount rate.[65] If this is positive or the ratio between the PV of benefits and the PV of costs exceeds one, the project would, within the remit of CBA, be considered worthwhile. More elaborate applications of CBA further distinguish between different potential courses of action. This principle underpins, for instance, IAMs that compare the welfare implications of alternative emissions trajectories or calculate the optimal emissions trajectory outright by trading-off costs and benefits.

To analyze climate change impacts and climate policies using CBA, all the costs and benefits need to be measured in monetary units.[66] Where the ‘good’ in question is a non-market good (e.g., cleaner air, environmental quality of various kinds, biodiversity, or ecosystem services), monetization cannot rely on directly observed market prices. This is a challenge because different individuals value non-market goods differently and there is no clear way to arrive at a social value. An additional complication arises due to the cross-border nature of environmental pollution, including emissions. Various methods are employed to overcome this, such as revealed and stated preference techniques, but it remains a challenging task.

CBA is a useful method for systematically comparing the expected costs of action against the expected benefits of avoided damages and future savings. By quantifying both tangible and intangible outcomes to the extent possible, CBA provides a structured approach to balancing short-term expenditures with long-term benefits. While monetization of different impacts can be difficult and incomplete, this approach does provide a tractable method to trade-off dimensions against one another. This can help decision-makers prioritize investments that maximize environmental and economic returns.

CBA has been criticized as a tool to help answer climate policy questions for struggling to integrate and account for transformative change and using a static rather than dynamic approach. It is usually seen as a method for marginal analysis, where the intervention in question is assumed to not affect the economic structure or prices (Sharpe et al., 2020). When large-scale climate policy is being considered, this assumption may not hold. If information is available on how the economic structure, prices, and so forth are expected to change due to a

[65] The discount rate applied is often the social discount rate. This is a key parameter of CBA and needs to be considered carefully. It is discussed further in Sections 2.5 and 3.2.6 above.

[66] To evaluate emissions within CBA, the social cost of carbon (SCC) is often applied, which measures the external cost of emissions and is usually expressed in currency per tonne of CO_2. The SCC is usually calculated via cost–benefit IAMs, and governments may determine the SCC that is to be used in the appraisal of public projects. See Section 3.2.6 and references therein for a more detailed discussion.

policy, this can, in principle, be reflected in the costs and benefits in the corresponding periods. Additionally, CBA has been criticized for masking distributional impacts by aggregating costs and benefits in monetary terms, even though the marginal utility of income can vary significantly across heterogenous agents. Distributional weights may be applied to the costs and benefits to consider differential impacts within CBA. In this context, some emphasize that the commonly cited limitations of CBA lie with how it is being applied rather than the method itself.

CBA is usually considered to not readily handle risk and uncertainty. It is based on expected costs and benefits, which sets aside the full distribution of possible futures. Especially in the context of decision-making under deep uncertainty, this may not be appropriate, hence it is also considered to be less suitable than certain other methods for analyzing low-probability catastrophic events.[67]

More generally, applying CBA usually means the objective is to maximize the expected outcome (or benefit). For alternative decision criteria, such as not risking losing more than 10% of wealth or staying within a specific carbon budget, alternative tools are required. The Robust Decision-Making approach, for instance, can be more appropriate to help design strategies that prevent unacceptable outcomes (see Section 3.4.4 for more detail).

3.4.2. Cost-Effectiveness Analysis (CEA)

Cost-Effectiveness Analysis (CEA): summary

Typical tool features: various timeframes; cost minimization; economic appraisal of climate change impacts and climate policy.

Typically seen as helpful for addressing many policy questions, but particularly:

- Which policies should be used to support technology development and deployment? (E.g., establishing which are the most cost-effective options for delivering a major green technology support program.)

Commonly cited limitations:

- Focusing on costs alone may mean the timing of some costs and benefits are omitted from the analysis, which may lead to suboptimal conclusions.

Rather than asking what the best course of action is to maximize net benefits, CEA is concerned with identifying the least costly way to achieve a policy goal. This approach enables the political process to determine the aim and economic analysis to contribute to reaching it via cost-effective means.

Stern et al. (2022) have argued for this approach, as it allows targets to be set to avoid catastrophic outcomes rather than to maximize expected utility, which can have methodological limitations when it comes to extreme risks. This is in accordance with the precautionary principle, and the authors argue that the Paris Agreement goal of limiting warming to well below 2°C was set in this spirit. In contrast, Aldy et al. (2021) argue that moving away from CBA and the social cost of carbon and towards CEA is not desirable because it lacks a scientific assessment of damages and is instead dependent on a political goal potentially subject to arbitrary change, and because future abatement costs are uncertain and sensitive to assumptions about future technological developments. In this context, it is important to keep in mind that damages (see Section 3.3.1) are not precisely estimated either, such that determining policy ambition based on the SCC alone also has limitations. This latter point is one reason why some argue for CEA as part of the "guardrail approach" of avoiding unacceptable risks (e.g., Stern et al., 2022).

A more technical concern with CEA is that if the analysis of pathways to achieve long-term targets disregards benefits, the pathway determined as optimal may turn out to be suboptimal in terms of welfare if damages are considered (Dietz and Venmans, 2019). Dietz and Venmans compare two approaches—maximizing welfare and minimizing costs given a temperature constraint—and find that abatement is delayed under CEA that only takes

[67] See also the HP4 Physical Risk and Adaptation Report.

costs into account (ibid.). This suggests that even within the "guardrail approach" of setting a target to avoid catastrophic outcomes, maximizing net benefits could be a viable approach in place of minimizing costs alone.

In practice, governments have set climate policy targets that may have been informed though not necessarily determined by an SCC estimate. In that context, analyzing cost-effective paths to achieving these targets remains a pressing question, and ESMs and process-based IAMs in particular have been applied to address it (see Sections 3.2.4 and 3.2.5 above). Keeping in mind the caveat that neglecting damages may lead to suboptimal timing of abatement, the analysis of cost-effective mitigation pathways is undoubtedly useful and there is much ongoing research in this area.

3.4.3. Risk–Opportunity Analysis (ROA)[68]

Risk–Opportunity Analysis: summary

Typical tool features: various timeframes; economic appraisal of climate change impacts and climate policy under uncertainty.

Typically seen as helpful for addressing many policy questions, but particularly:

- What are the impacts of other large-scale green fiscal policies (e.g., taxes and subsidies)? How will consumer and producer behavior change in response?
- Which technologies have the most potential for cost reductions and deployment at scale?
- How does climate policy affect other domestic policy priorities? How can it align with maintaining price stability, energy security, economic growth, and other policy priorities?

Commonly cited limitations:

- ROA does not provide a single economic value of a policy option, which can make communicating its results to policymakers challenging.
- ROA is relatively unrefined and untested to date. While not a limitation of the method, it does mean that capabilities and understanding of the method are limited.

ROA is an approach that explicitly focuses on addressing the challenges of implementing CBA in the context of structural change, uncertainty, and heterogeneous impacts. Ideally, CBA would take these into account, but in practice this is not necessarily the case, hence ROA is singled out as an extended form or generalization of CBA, while recognizing that a well-executed analysis using CBA can be quite similar.

The motivation for a more general form of CBA arises because point estimates used in CBA may be unsuitable where there is substantial uncertainty about the costs and benefits of an intervention. ROA can be more encompassing in that it evaluates interventions based on distributions of outcomes rather than single figures, by considering, for instance, the expected, best-, and worst-case scenarios of the possible outcomes along various dimensions.

Additionally, when undertaking CBA, marginal changes are usually assumed, which means the underlying structure of the economy and key parameters, such as prices, are assumed to be fixed in relation to the intervention being evaluated. This assumption does not hold when considering structural change and transformation.

[68] This section draws on: 'Risk–opportunity analysis: policy appraisal in contexts of structural change, uncertainty, and diverse interests', contribution from S-Curve Economics to the HP4 Compendium of Practice; 'The value of using systems mapping to help Ministries of Finance understand the impacts of transformative climate policy', contribution from the University of Oxford to the HP4 Compendium of Practice; Mercure et al. (2021); and Sharpe et al. (2025: 55, 57).

The process of ROA involves three main steps:[69]

1. An assessment of how an intervention affects change processes and expected outcomes at specific points in time. Here, systems mapping can be used to help understand system dynamics that may be impacted and whether the intervention is likely to be self-amplifying or self-limiting. To quantify the dynamics, system dynamics or agent-based models can be used.
2. A multi-dimensional policy assessment that avoids collapsing all outcomes into one metric. This preserves the diversity of actors, interests, and policy outcomes that may be impacted and avoids making a judgment on the relative value of different dimensions at this stage.
3. An assessment of uncertainty to consider how outcomes may be impacted by factors beyond the control of the policymaker. Here, scenario analysis can be helpful.

These steps enable the comparison of policies based on their dynamic effects and the possible range and sensitivity of outcomes under uncertainty. Detailed quantitative modeling can be an input to ROA, but may not always be necessary.

3.4.4. Real options theory and Robust Decision-Making (RDM)

Real options theory and Robust Decision-Making (RDM): summary

Typical tool features: simulation of strategies under alternative scenarios, identifying vulnerabilities.

Typically seen as helpful for addressing many policy questions, but particularly:

- How could a disorderly transition impact the economy?

Commonly cited limitations:

- Can be data- and computationally-intensive if sensitivity to all potential uncertainties identified is to be evaluated.

A family of analytical approaches that include real options theory and Robust Decision-Making (RDM) has been developed to acknowledge dynamic and deep uncertainty in economic appraisal. This is particularly relevant in the context of climate change adaptation and mitigation, which involve large, often irreversible investments with long-term consequences. These analytical tools support the development of flexible strategies with policies that can be adapted in response to how uncertainty evolves (e.g., concerning emission pathways, technology costs, and energy efficiency).

Real options theory extends financial options analysis to real-world investment decisions, offering a framework to manage uncertainty and flexibility in decision-making.[70] The theory enables investors and policymakers to respond to changing economic, technological, or market conditions without locking into decisions that cannot be cost-effectively unwound later on (Anderson, 2000). It concerns an option or right, but not an obligation, to undertake, defer, or cancel an investment. This option can then be quantified and given a value. The higher the risk, the more valuable the option.

In the context of strategic policy, real options theory helps policymakers value the option to delay, expand, contract, or abandon projects. This is especially useful when policy outcomes depend on irreversible investments and highly uncertain environments. For example, governments face uncertainty over which green technologies will succeed (such as renewables, hydrogen, heat pumps, advanced nuclear, or carbon capture). Real options theory can help evaluate clean energy R&D, infrastructure, and carbon pricing strategies (Pindyck, 2000) and support investment into a portfolio of options, preserving the ability to scale-up winners later on (Blyth et al., 2007).

[69] See 'Risk–opportunity analysis: policy appraisal in contexts of structural change, uncertainty, and diverse interests' (op. cit.).
[70] This and the following three paragraphs on real options theory greatly benefitted from the input of Dimitri Zenghelis.

Climate change also alters the risk profile associated with assessments of the value of investing in adaptation options. Flexible implementation of adaptation options can provide significant option value. Recent examples include flood risk assessments for the City of Boston's transit system in the U.S., and New Zealand's coastal flood defenses (Martello et al., 2024; Stroombergen and Lawrence, 2022). The UK's Climate Change Risk Assessments (CCRAs) and the EU's Green Deal both reflect growing alignment with real options theory principles.[71]

While real options approaches are receiving substantial attention in the academic literature, they remain a relatively niche or emerging approach in policy decision-making. In part, this reflects difficulties associated with the assumptions underpinning the analysis. For example, it is not straightforward to assess the baseline used as a counterfactual against which to assess options or the probability distribution of weighted outcomes across different scenarios (Kwakkel, 2020) (though such difficulties are not unique to real options theory). Further development and refinement could help options theory to become a more generally adopted, practical part of policymakers' toolkits.

Robust Decision-Making (RDM) is a related approach for decision-making under deep uncertainty, where possible futures or outcomes are not necessarily known or assigned probabilities (Hallegatte et al., 2012).[72] RDM does not aim to determine the 'best' or 'optimal' strategy. Rather, it helps identify strategies that are robust in the sense that they achieve an acceptable outcome across many possible futures. Effectively, it is an approach for stress-testing strategies.

The starting point for RDM is a strategy for the future and metrics to measure its success. The next step is to ask what uncertainties could make this strategy fail and lead to unacceptable outcomes. Such uncertainties could include uncertainties in climate projections, sectoral impacts of climate change, economic conditions, technological development, or the policy environment. RDM then enables users to explore: (1) whether the strategy can be adjusted so that it does not fail in the possible future scenarios identified, and (2) whether the scenarios in which the strategy fails are sufficiently unlikely for the risk of their occurrence to be tolerated. RDM is an iterative process. Once suitable adjustments to the strategy that would seem to reduce vulnerabilities have been identified, the amended strategy should be assessed for vulnerabilities that could make it fail as well.

Usually, RDM involves quantitative analysis to assess strategies under different possible future scenarios. In those cases, RDM is a simulation-based method for analysis, with many runs performed under different assumptions, based on the uncertainties and possible future scenarios identified. It thereby inverts sensitivity analysis, as the aim is to identify strategies that are insensitive to such perturbations (Lempert et al., 2006). More heuristic applications can be useful where strategies can be framed as a sequence of decisions during which new information is revealed over time.

The benefits of RDM include that vulnerabilities and risks can be analyzed extensively without a requirement for associated probabilistic information. It is a relatively transparent method that enables stakeholders to engage in identifying the measures for success and uncertainties that should be considered. It makes managing uncertainty the explicit subject of analysis via an adaptive process, rather than considering it ex-post. Drawbacks can include that it is data- and time-intensive when conducted quantitatively, and the quality of the analysis depends on the choice of uncertainties and scenarios considered.

Adaptive policymaking and RDM support strategic policymaking by recognizing the value of flexibility in the face of uncertainty and providing frameworks to manage uncertainty and flexibility in decision-making. This is especially valuable for making adaptive decisions in high-impact, uncertain environments characterized by climate change, technological innovation, and long-term infrastructure investment.

[71] For more information on the UK's CCRAs see 'The analysis of climate impacts, adaptation costs, and adaptation benefits in the UK', contribution from Paul Watkiss Associates to the HP4 Compendium of Practice.
[72] This and the following three paragraphs on RDM draw on Hallegatte et al. (2012).

3.4.5. Multi-Criteria Decision Analysis (MCDA)

Multi-Criteria Decision Analysis (MCDA): summary

Typical tool features: appraisal of climate change impacts and climate policy along multiple dimensions.

Typically seen as helpful for addressing many policy questions, but particularly:

- What is the best way to design carbon pricing policies?
- Which policies should be used to support technology development and deployment?
- How can climate and environmental considerations be integrated into development of a budget?
- How does climate policy affect other domestic policy priorities? How can it align with maintaining price stability, energy security, economic growth, and other policy priorities?

Commonly cited limitations:

- When making a decision, different dimensions need to be weighed up against one another, and MCDA usually provides limited guidance on how to navigate trade-offs.

MCDA includes approaches that estimate the impact of an intervention on an array of identified variables, rather than collapsing the impact into a single metric such as GDP (or GDP equivalent). This can avoid the need to value or monetize all impacts while still considering environmental and social outcomes alongside economic impacts, which is valuable for integrating diverse stakeholder perspectives, evaluating trade-offs, and balancing multiple policy goals. It is a flexible approach that can incorporate both qualitative and quantitative information and be executed through stakeholder engagement and public consultation.

MCDA usually involves identifying the range of variables or factors against which different options should be evaluated and scoring each option accordingly. Scales for each factor may vary, for reasons including that some factors may be objective and quantitative while others are more subjective or not naturally expressed in terms of numbers. Scores across the range of factors can be aggregated to make a comparison (though this is not always done). If scores are aggregated to compare them across options, weights of different factors depend on both the units of measurement and the importance attached to different factors, which can be subjective and elicited through consultation (DESNZ, 2024). Sensitivity analysis on both scores and weights is helpful too.

Challenges with MCDA include quantifying impacts, especially where these are subjective, and systematically comparing and choosing between policies given that the relative weighting between criteria is not objectively clear. In some cases, options may be incomparable because good performance on one factor does not compensate for poor performance on another (Government Analysis Function, 2024). Outranking approaches to MCDA are tailored to such cases (see Ishizaka and Nemery, 2013 for methodological details), but struggle to inform value-for-money assessments (Government Analysis Function, 2024).

A plethora of methods to conduct MCDA have emerged. It is beyond the scope to outline them here; see Ishizaka and Nemery (2013) for a more detailed exposition of a range of MCDA methods and Neofytou et al. (2019) for an application of one MCDA method for an impact assessment of climate and energy policy scenarios for the EU. Green budgeting tools could be considered a use-case of MCDA, though again are beyond the scope of this report.

3.4.6. Systems mapping[73]

Systems mapping: summary

Typical tool features: qualitative analysis to provide systematic understanding; disaggregation varies and can be detailed.

Typically seen as helpful for addressing many policy questions, but particularly:

- Which barriers to adaptation are there, and how can they be overcome?
- What are the impacts of other large-scale green fiscal policies (e.g., taxes and subsidies)? How will consumer and producer behavior change in response?
- How does climate policy affect other domestic policy priorities? How can it align with maintaining price stability, energy security, economic growth, and other policy priorities?
- Are there synergies between climate policy or addressing climate change and other policy priorities? If so, how can they best be exploited?

Commonly cited limitations:

- Policymakers in MoFs tend to make decisions based on quantitative analysis, so systems mapping may need to inform or be supplemented by additional analysis.
- Systems mapping is easy to do badly and runs the risk of being very subjective.
- The output can be convoluted and difficult to communicate.
- The strength of feedback effects is not always determined, which can make drawing conclusions from systems mapping more difficult.

Systems mapping describes methods that are used to describe or model a system, often by depicting a network via boxes and arrows to represent causal flows. It is a qualitative method that enables consideration of aspects that are difficult to quantify comprehensively or for which data is unreliable, but that are critical to the design and impact of climate action and socioeconomic processes more widely: aspects such as feedback effects, relationships, trade-offs, and synergies. It is also considered a useful method for Ministries of Finance that are not very familiar with climate modeling, providing a starting point for understanding the links between climate, economic, and fiscal outcomes.

It is important that outputs of systems mapping exercises are directly useful. Systems maps, and specifically Participatory Systems Mapping (PSM), can be used in conjunction with quantitative modeling and non-modeling approaches to help identify the aspects that are well covered, and, crucially, potential blind spots such as omitted variables or processes in existing analyses. Causal Loop Diagrams (CLDs) are particularly useful for understanding feedback effects and Theory of Change diagrams (ToCs) can help unpack the assumptions, intentions, and causal links that underly and motivate an intervention, which in turn can help discipline policy design discussions or inform ex-post policy evaluation studies.

[73] This section draws on 'The value of using systems mapping to help Ministries of Finance understand the impacts of transformative climate policy', (op. cit.).

3.4.7. Complexity analysis[74]

Complexity analysis: summary

Typical tool features: data-driven; appraisal of potential competitive advantages and growth opportunities.

Example policy questions typically seen as most helpful for complexity analysis to address:

- In which sectors could a country develop a competitive advantage in the context of the green transition?
- Are there synergies between climate policy or addressing climate change and other policy priorities? If so, how can they best be exploited?

Commonly cited limitations:

- Heavily reliant on detailed and relevant data.
- Based on historical data on capabilities, such that potential opportunities for more substantial diversification may be overlooked. It also cannot help forecast the potential size of opportunities.

Economic complexity analysis concerns methods that investigate the granular structure of economic activities and are explicit about capital assets and economically relevant knowledge being non-fungible, activity-specific, and place-bound. The methods set out to measure an economy's embedded knowledge, production capabilities, and patterns of specialization, which are related to complexity because complex economies combine different capabilities to produce diverse and knowledge-intensive products. In practice this is achieved by analyzing the spatial distribution of production, i.e., by assessing which products are co-produced and which economic activities occur in which locations. Economic complexity analysis is therefore a top-down analysis but one that is still granular, tractable, and scalable, with the potential advantage that it does not require specialized knowledge of individual industries.

Complexity is of interest because of its link to economic growth. Indices of economic complexity correlate with economic growth, suggesting that "economic growth involves diversification into more (and more complex) industries".[75] This in turn suggests that climate action can be an opportunity for economic growth via strategic efforts to diversify into green industries while playing to a country's strengths. Complexity analysis can help identify which sectors and industries these might be in each country context by helping to determine in which sectors a country is competitive, which green industry supply chains are near or related to a country's economic structure, in which sectors a country is well-suited to drive future growth based on factors such as its competitive position, and whether a country has successfully diversified in the recent past and what the sticking points were if not.

These methods have some advantages over various existing approaches. CGE modeling, for instance, implicitly assumes relatively fungible economic assets and factors of production, which may not necessarily be an accurate representation of reality. Complexity analysis captures regional specialization, relatedness, and adjacency of activities. Older methods, such as input–output analysis or revealed comparative advantage, analyze regional specialization and industry structure. However, they do not go so far as analyzing underlying regional capabilities in a way that is useful to assess future potential, meaning complexity analysis provides relatively more information on which products could be sensible to produce in a similar location or a country could succeed at producing in the future.

In addition, while complexity analysis is in principle backward-looking at the level of capabilities, as it leverages historical data, current capabilities can indicate whether a country has a competitive advantage in capabilities required in emerging and growing industries and whether such capabilities could be built up. Furthermore, time-series data can indicate the development of a country's economy and economic structure over time, which can also provide guidance in contexts where technology and economic structure are changing.

[74] This section draws on 'The Atlas of Economic Complexity: supporting strategic economic planning and green industrial policy in Ministries of Finance', contribution from the Harvard Growth Lab to the HP4 Compendium of Practice.
[75] Ibid.

3.5. Ex-post case studies and evaluations

Ex-post case studies and evaluations: summary

Typical tool features: analysis of experience and actual impacts of designing and implementing climate policy.

Typically seen as helpful for addressing many policy questions, but particularly:

- Which policy mixes are needed to reach net zero goals?
- What is the best way to design carbon pricing policies?
- What are the impacts of other large-scale green fiscal policies (e.g., taxes and subsidies)? How will consumer and producer behavior change in response?

Commonly cited limitations:

- Does not provide concrete quantitative predictions.
- Ex-post assessments can take years to be finalised, over which timescales the societal and economic structures being studied may change. This means it can be difficult to draw conclusions for new policies based on old findings (or indeed findings from another country).

Ex-post case studies and evaluations of the impacts of climate policy and sustainable economic transformation are global, regional, or country studies that seek to evaluate and learn from past experience of implementing climate policies and their actual impacts in terms of design, logistics, implementation, effectiveness, and so forth. They draw on economic history and longitudinal data to assess the actual climate and economic impacts of previous policies (or packages of policies) to determine what has been most effective in driving change, including in different contexts. Two important types of use-cases are first, detecting firsthand when a policy or approach does not work (or when it causes unintended negative side effects) and adjusting it to prevent further or greater negative impacts; and second, learning from others what works and what does not.

For example, Stechemesser et al. (2024) recently reviewed more than 1,500 climate policies deployed over the last two decades to determine which have worked best to reduce emissions. This large-scale analysis was made possible through access to the OECD's detailed database of climate policies. Another example is work by the World Bank (Hallegatte et al., 2024), which used a similar database, maintained by the NewClimate Institute, to develop a tool that helps countries strategically select and sequence policies. Acknowledging the dynamic nature of the political economy and institutional context, the tool helps identify feasible policies that can simultaneously build political support and reduce the costs of climate action over time. Such ex-post assessments can act as powerful examples in determining what is possible, deliverable, and likely to be effective, especially where due attention is given to methods able to track the cumulative impacts of policies and how they build over time.

In addition to large-scale analyses seeking to draw relatively general conclusions, case studies of a series of policies within a specific sector or specific climate policies in a particular country can provide useful insights. Sector-specific case studies can illustrate how technological change has been incentivized and supported, including which conditions were conducive to the transition. A contribution to the HP4 Compendium of Practice by Gregory Nemet at the University of Wisconsin-Madison, for instance, outlines how policies from various countries at different points in time contributed to expanding the market for solar PV and declining costs in the sector.[76] Country-specific case studies can provide insights into the initiation and design of specific climate policies and showcase lessons from implementation that other MoFs may find useful for informing their own strategies.

Taking into consideration ex-post case studies and evaluations enables learning from the experience of others and prevents MoFs from repeating mistakes that others have already made and learned from. It can also establish connections and open avenues for further knowledge exchange between peers and between science

[76] 'How government actions have accelerated clean energy innovation: lessons for economic analysis and modeling by Ministries of Finance', contribution from the University of Wisconsin-Madison to the HP4 Compendium of Practice.

and policy. More practical peer learning via active engagement and exchange between Ministries interested in developing similar capabilities and implementing similar policies can be especially valuable for learning about the cutting edge of both analytical tools and policy.

When drawing on ex-post case studies and evaluations, the time lag between policy implementation and the availability of analysis (which is often dependent on data availability) can mean that economic and social structures will have since changed in material ways. Conclusions may then no longer directly apply. For instance, as costs for green technologies such as electric vehicles (EVs) change, economic policies incentivizing their use would be expected to have a different impact now than a few years ago. This also applies more broadly to using case studies from different countries. The policy challenges and effects in one country may be vastly different than in another, based on varying social, economic, and regulatory contexts. Any such potentially material differences in context need to be considered when drawing on ex-post case studies and evaluations, but do not mean such analysis will not be useful. Features of the analysis itself, such as the use of control variables, can help address these challenges.

4. Mapping analytical tools to policy questions

As Section 3 has shown, a plethora of analytical tools are available to support Ministries of Finance to drive forward climate action and MoFs can certainly benefit from drawing on a diverse range of these tools. Of course, decision-makers in MoFs typically look to modeling capacity and analytical tools to help answer *specific* policy questions. To meet this need and maximize the potential of these tools, MoFs should place special attention on matching tools with the particular pressing policy questions they face, while taking into account the availability of resources and time. Specific analytical approaches and modeling tools tend to be better at answering some questions than others.

Table 4.1 provides an indicative mapping of overarching themes and associated policy questions, and the types of analytical tools suited to addressing them, as outlined in Section 3. Note that this mapping is indicative—a more definitive mapping would require further work.[77] It is based on matching types of tools to the characteristics of the policy questions under consideration; we have not made a judgment of the suitability of each tool in this context. There is also a tendency for modeling teams to feel the model they develop and use can address (or be adapted to address) most climate-related policy questions, making it hard to objectively discern their suitability. (For more detailed examples of how specific models and analytical tools have been employed to help answer specific policy questions, see Section 5.)

What this exercise does suggest is how important it is for MoFs to exercise care in their selection of tools, in order to land on those that are the best suited to addressing the specific questions they face rather than simply choosing the tools that appear on paper to be strong and reputable. This assessment can only be made at the Ministry and country level.

The table is dominated by climate-enhanced macroeconomic and sectoral models, and physical climate and disaster risk models, as covered in Sections 3.2 and 3.3. This is because the decision-making frameworks, other analytical tools, and ex-post case studies and evaluations covered in Sections 3.4 and 3.5 are flexible methods applicable to a wide range of questions. In that context, their lower profile in Table 4.1 does not reflect limited usefulness and should rather be seen as indicative of these tools being overarching frameworks and methods that can be applied widely.

Additionally, the table has a greater focus on climate change mitigation than on adaptation, in part reflecting the same greater focus regarding models within the HP4 Compendium. This does not reflect any diminished importance of adaptation, and in a future expansion of this work more attention could be given to this aspect of climate policy. Also, while financing, including private sector financing, is included in the table, this aspect is only thinly covered in this report. In part this is because not many of the analytical approaches included have detailed representations of the financial sector and many of them struggle to indicate what kind of financing mechanisms may be suited to different country circumstances or sectors. The role of the private sector is important, however, and deserves careful consideration; it is simply beyond the scope of this report to cover it in detail here.

[77] See Sharpe et al. (2025) for a similar table that maps policy questions to analytical tools.

Table 4.1. The importance of mapping analytical tools to policy questions to determine suitability—illustrative examples

Category	Question	Sub-questions	Analytical tools typically seen as useful
Physical risk	What physical climate risks are there and what are their economic implications?	What are the current and expected future impacts of physical climate change on productivity and output across sectors?	Computable General Equilibrium (CGE) models Dynamic Stochastic General Equilibrium (DSGE) models Structural Econometric Models (SEMs) Sectoral models Demand-led models Damage functions System Dynamics (SD) models
		What are the budget impacts of climate change in the long term and what are the implications for debt sustainability?	SEMs CGE models Loss and damage assessments and asset-level analyses
		What are the current and expected future impacts of physical climate change on high-level macroeconomic outcomes?	Cost–benefit Integrated Assessment Models (IAMs) Damage functions SD models Input–Output (IO) models
		How great is the shortfall in resilience and protection against climate impacts currently, how great is the future shortfall likely to be, and how are the risks from extreme climate and weather events changing with climate change?	Catastrophe (CAT) models
		What are the budget impacts of disaster risk finance in the context of changing frequency and magnitude of extreme events?	CAT models, also linked with macroeconomic models (e.g., macroeconometric models) Extreme Event Analysis (EEA) Loss and damage assessments and asset-level analyses
	How does the economy rely on nature and ecosystem services?	What are the economic impacts from nature- and ecosystem-related risks to the economy?	CGE models SD models
Adaptation	What is the economic case for adaptation?	What are the benefits to adaptation, given the physical risks, across sectors and regions?	CGE models SEMs Demand-led models CAT models
	What measures can drive adaptation and resilience?	What barriers to adaptation are there, and how can they be overcome?	Systems mapping
Green transition	What measures can drive the green transition and climate change mitigation?	What policy mixes are needed to reach net zero goals?	CGE models SEMs Demand-led models Ex-post case studies and evaluations
		What is the best way to design carbon pricing policies?	CGE models DSGE models Sectoral models Cost–benefit IAMs Ex-post case studies and evaluations Multi-Criteria Decision Analysis (MCDA)
		What are the impacts of other large-scale green fiscal policies (e.g., taxes and subsidies)? How will consumer and producer behavior change in response?	CGE models DSGE models SEMs Systems mapping Risk–Opportunity Analysis (ROA) Agent-Based Models (ABMs) Ex-post case studies and evaluations

Category	Question	Sub-questions	Analytical tools typically seen as useful
Green transition *(cont.)*	Which technologies should a country focus on?	Which technologies have the most potential for cost reductions and deployment at scale?	SEMs Sectoral models ROA
		Given cost projections, what are the decarbonization costs in different sectors?	Sectoral models Process-based IAMs
		In which sectors could a country develop a competitive advantage in the context of the green transition?	Complexity analysis ABMs
	What measures can drive the scale-up of technologies?	What policies should be used to support technology development and deployment?	Sectoral models CBA CEA MCDA
	What are the domestic impacts of international climate policy?	What are the domestic impacts of other countries' carbon border adjustment mechanisms, green subsidies, or investments in critical technologies?	CGE models IO models Gravity models
	What are the macroeconomic impacts of the transition and how can they be managed?	What are the high-level macroeconomic effects of the transition?	CGE models DSGE models SEMs Sectoral models (as an input to macroeconomic models) Cost–benefit IAMs
		What are possible decarbonization pathways in different sectors?	Sectoral models CGE models if supplemented with sectoral models Process-based IAMs
		Which sectors are most impacted by decarbonization?	CGE SEMs Demand-led models Process-based IAMs
		How could a disorderly transition impact the economy?	SEMs Process-based IAMs Sectoral models (as an input to macroeconometric and other models) Real options theory and Robust Decision-Making (RDM)
		How does uncertainty concerning the transition impact the economy?	CGE models SEMs
	What are the risks to the financial system from the transition and how can they be managed?	How might financial stability be impacted by the transition, including a disorderly transition?	DSGE models SEMs CGE models CAT models (including as an input to the macroeconomic models above)
		What are the monetary policy implications of the transition?	SEMs DSGE models
	What are the fiscal impacts of the transition and how can they be managed?	What are the investment requirements for the transition (e.g., of reaching NDC targets)?	CGE models SEMs Sectoral models Process-based IAMs
		How is the tax base projected to change, especially as fossil fuels are phased out?	CGE models SEMs Sectoral models
		How can climate and environmental considerations be integrated into the development of a budget?	CGE models MCDA
		What potential new sources of tax revenue are there and what is their revenue-raising potential?	Sectoral models (including as input into, e.g., CGE models)
		How can carbon pricing revenue best be recycled?	CGE models DSGE models

Category	Question	Sub-questions	Analytical tools typically seen as useful
Green transition *(cont.)*	What are the distributional and socioeconomic impacts of the transition and how can they be managed?	What are the labor market implications of structural change as a result of the transition?	CGE models SEMs Demand-led models ABMs
		What are the distributional impacts of the transition?	CGE models SEMs Demand-led models ABMs
		What policies can help manage distributional impacts and facilitate a just transition?	CGE models SEMs Sectoral models
Financing	How can MoFs help finance investment in the green transition?	What is the most appropriate split between public and private investment to support decarbonization and adaptation efforts?	CGE models
Synergies	How does climate policy interact with other policy priorities and mandates for which MoFs are responsible and how can the synergies by maximized?	How does climate policy affect other domestic policy priorities? How can it align with maintaining price stability, energy security, economic growth, and other policy priorities?	CGE models SEMs Sectoral models Demand-led models Systems mapping ROA SD models MCDA
		Are there synergies between different climate policies or between addressing climate change and other policy priorities? If so, how can they best be exploited?	CGE models Systems mapping Complexity analysis

Source: Authors, drawing on the HP4 Compendium of Practice

5. Showcase of analytical tools and approaches in action

5.1. Introduction

For each of the four analytical tool categories considered—climate-enhanced macroeconomic and sectoral models, physical climate and disaster risk models and approaches, decision-making frameworks and other analytical tools, and ex-post case studies and evaluations—this section showcases them in action, drawing on case studies from Ministries of Finance and beyond from the HP4 Compendium of Practice and HP4 Physical Risk and Adaptation Report. In the case of climate-enhanced macroeconomic and sectoral models, and physical climate and disaster risk models, examples that have been described or mentioned in the Compendium of Practice are listed in Tables 5.1 and 5.2.

The section emphasizes informative best-practice case studies to showcase potential applications of analytical tools to answer specific policy questions as well as how challenges in model deployment can be overcome. We present only a selection; more can be found in the Compendium of Practice and its Summary Report,[78] Section 2 of which provides an overview of all contributions and Section 4 summaries of the contributions relevant to analytical tools specifically—though contributions in other parts of the Compendium may be helpful to consider as well. The examples are not equally distributed around the world: many case studies focus on Europe. More attention in future will need to be paid to applications in other regions, and particularly emerging markets and developing countries.

5.2. Climate-enhanced macroeconomic and sectoral models—overview and case studies

Table 5.1 lists examples of climate-enhanced macroeconomic and sectoral models.[79] The model types map to the model types described in Section 3.2 above. Further details on the models listed can be found in Appendix A. A series of case studies showcasing the models in action follows Table 5.1.

[78] The Compendium Summary Report is available at https://greenandresilienteconomics.org/publications/economic-analysis-and-modeling-tools-to-assist-ministries-of-finance-in-driving-green-and-resilient-transitions/.
[79] This is not an exhaustive list. Another overview of models is provided by the IAM Consortium at www.iamconsortium.org/resources/models-documentation/.

Table 5.1. Climate-enhanced macroeconomic and sectoral models

Model name[80]	Principal institution/lead developer	Partner institution/ developer	Model type	Geographical scope[81]
GTEM (Global Trade and Environment Model)	Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES)		CGE	Global
Finance Canada Climate CGE model	**Canada—Department of Finance**		**CGE**	**Global**
IMACLIM-R	Centre International de Recherche sur l'Environnement et le Développement (CIRED)		CGE	Global
TERM (The Enormous Regional Model)	Centre of Policy Studies, Victoria University		CGE	Single country (multiple, including Australia and U.S.)
GreenREFORM	**Danish Research Institute for Economic Analysis and Modelling (DREAM)**		**CGE**	**Denmark**
I3E (Ireland, Environment, Energy and Economy) model	**Economic and Social Research Institute (ESRI)**		**CGE**	**Ireland**
JRC-GEM-E3	**European Commission**	**National Technical University of Athens (NTUA/E3M-Lab) (leading partner), Katholieke Universiteit of Leuven (KUL), University of Manheim and the Centre for European Economic Research (ZEW), Ecole Centrale de Paris (ERASME)**	**CGE**	**Global (EU focus)**
ICES (Inter-temporal Computable General Equilibrium System)	European Institute on Economics and the Environment (EIEE)		CGE	Europe (EU + UK)
GTAP-E	Global Trade Analysis Project (GTAP)		CGE	Global
IMF-ENV	**International Monetary Fund (IMF)**		**CGE**	**Global**
IRENCGE-DF (Italian Regional and Environmental Computable General Equilibrium of Department of Finance)	**Italy—Ministry of Economy and Finance**	**World Bank**	**CGE**	**Italy**
DEPF CGE model	**Morocco—Ministry of Economy and Finance**	**World Bank**	**CGE**	**Morocco**
Short-term climate scenarios	**Network for Greening the Financial System (NGFS)**		**CGE, SFC, credit-risk**	**Global**
ENV-Linkages model	Organisation for Economic Co-operation and Development (OECD)		CGE	Global
RegFinDyn (Regional model for Finland, Dynamic version)	Ruralia Institute, University of Helsinki		CGE	Finland, Sweden, EU
ThreeME (Multi-sector Macroeconomic Model for the Evaluation of Environmental and Energy policy)	**Sciences Po—French Economic Observatory (OFCE)**	**Multiple**	**CGE**	**Single country (multiple)**
EMEC (Environmental Medium-term Economic) model	**Sweden—National Institute of Economic Research (NIER)**	**National Institute of Economic Research (NIER)**	**CGE**	**Sweden**
Budget impact model	**Switzerland—Federal Department of Finance**	**Ecoplan**	**CGE and ESM**	**Switzerland**
SATIM-GE (South African Times Model—General Equilibrium)	University of Cape Town		CGE and ESM	South Africa

[80] Models written in **bold** are described in further detail in the Compendium of Practice. Brief descriptions of these can be found in Section 4 of the Compendium Summary Report and the full contributions can be found online. Some of these examples are also included in the form of case studies below.
[81] Where the geographical scope is 'single-country' with a set number of countries or 'multiple' in brackets, this indicates the model is a single-country modeling framework that can be applied to various countries. If a number is provided, this indicates the approximate number of countries the model has been applied to.

Model name[80]	Principal institution/lead developer	Partner institution/ developer	Model type	Geographical scope[81]
UPGEM (University of Pretoria General Equilibrium Model)	University of Pretoria	Centre of Policy Studies, Victoria University	CGE	South Africa
ENVISAGE (Environmental Impact and Sustainability Applied General Equilibrium) model	**World Bank**	**Multiple**	**CGE**	**Global**
MANAGE-WB (Mitigation, Adaptation, and New Technologies General Equilibrium at the World Bank)	**World Bank**	**Multiple**	**CGE**	**Single country (50 countries)**
EMuSe	Bundesbank		DSGE	Germany
NAWM (New Area-Wide Model)	European Central Bank (ECB)		DSGE	Euro area
E-QUEST	**European Commission**		**DSGE**	**EU**
GMMET (Global Macroeconomic Model for the Energy Transition)	**IMF**		**DSGE**	**Global**
Global Macro-Financial Model (GFM)	IMF		DSGE	Global
GEEM (General Equilibrium Environmental Model)	**Italy—Ministry of Economy and Finance**	**University of Rome**	**DSGE**	**Italy**
EREMS (Estimated Rational Expectation Model for Spain)	University of Valencia	BBVA Research	DSGE	Spain
REMS (Rational Expectations Model for the Spanish Economy)	University of Valencia	BBVA Research	DSGE	Spain
TIM (Treasury Industry Model)	Australia—Department of the Treasury		DGE	Australia
DIGNAD (Debt, Investment, Growth, and Natural Disasters) model	**IMF**		**DGE**	**Single country**
NiGEM (National Institute Global Econometric Model)	National Institute of Economic and Social Research (NIESR)		SEM	Global
G-cubed model	Warwick McKibbin and Peter Wilcoxen		SEM	Global
MFMod CC (Macro-Fiscal Model—Climate Change)	**World Bank**		**SEM**	**Single country (~70 countries)**
TIMES (The Integrated MARKAL-EFOM System)	Energy Technology Systems Analysis Program (IEA-ETSAP)		Sectoral—optimization	Global
GLOBIOM (Global Biosphere Management Model)	International Institute for Applied Systems Analysis (IIASA)		Sectoral—optimization	Global
MAgPIE (Model of Agricultural Production and its Impact on the Environment)	Potsdam Institute for Climate Impact Research (PIK)		Sectoral—optimization	Global
POTEnCIA (Policy-Oriented Tool for Energy and Climate Change Impact Assessment)	European Commission		Sectoral—hybrid	Europe
FTT (Future Technology Transformations)—Household heating	Cambridge Econometrics		Sectoral—simulation	Global
FTT (Future Technology Transformations)—Power	Cambridge Econometrics		Sectoral—simulation	Global
FTT (Future Technology Transformations)—Transport	Cambridge Econometrics		Sectoral—simulation	Global
BUEGO (Bottom-Up Geological and Economic Oil Field Model)	Christophe McGlade		Sectoral—simulation	Global
GAPTAP (Global Gas Production, Trade, and Annual Pricing Model)	Daniel Welsby		Sectoral—simulation	Global
POLES (Prospective Outlook on Long-term Energy Systems)	European Commission		Sectoral—simulation	Global (EU focus)
SiSePuede (SImulation of SEctoral Pathways and Uncertainty Exploration for DEcarbonization)	**Inter-American development Bank (IDB)—open source**		**Sectoral—simulation**	**Single country (multiple)**

Model name[80]	Principal institution/lead developer	Partner institution/ developer	Model type	Geographical scope[81]
CP+ (Carbon Pricing Plus) Model	**Universidad de Los Andes**	**Environment for Development (EfD), Centro de Estudios Manuel Ramirez (CEMR), Environmental Defense Fund (EDF)**	**Sectoral**	**Colombia**
PRIMES (Price-Induced Market Equilibrium System)	**European Commission**		**ESM**	**Europe**
METIS (Markets and Energy Technologies Integrated Software)	**European Commission**	**Artelys, Tractebel, Fraunhofer**	**ESM**	**Europe**
OSeMOSYS (Open Source energy MOdelling SYStem)	**N/A—open source**		**ESM**	**Single country (multiple)**
LEAP (Low Emissions Analysis Platform)	Stockholm Environment Institute (SEI)		ESM	Single country (multiple)
TIAM-UCL (TIMES Integrated Assessment Model)	University College London (UCL)		ESM	Global
CPAT (Carbon Policy Assessment Tool)	**World Bank and IMF**		**ESM**	**Single country (multiple)**
WITCH (World Induced Technical Change Hybrid)	European Institute on Economics and the Environment (EIEE)		Process-based IAM	Global
MIMPAS (Integrated macroeconomic model for projection and simulation analysis)	Morocco—Ministry of Economy and Finance		Process-based IAM	Morocco
GLUCOSE (Global Least-cost User-friendly CLEWs Open-Source Exploratory)	N/A—open source	KTH Royal Institute of Technology	Process-based IAM	Global
GCAM (Global Change Analysis Model)	Pacific Northwest National Laboratory (PNNL)		Process-based IAM	Global
REMIND (REgional Model of Investment and Development)	Potsdam Institute for Climate Impact Research (PIK)		Process-based IAM	Global
PAGE-ICE (Policy Analysis of Greenhouse Effect—Ice, Climate, Economics)	Dmitry Yumashev	Chris Hope	Cost–benefit IAM	Global
DICE (Dynamic Integrated model of Climate and the Economy)	**William Nordhaus**	**Lint Barrage, Paul Sztorc**	**Cost–benefit IAM**	**Global**
e3 model	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)	Multiple	IO	Single country (Kazakhstan, Georgia, Mongolia)
CPIC (Carbon Pricing Incidence Calculator)	**Mercator Research Institute on Global Commons and Climate Change (MCC)**		**IO—multi-regional**	**Single country (multiple)**
MINDSET	**World Bank**		**IO—multi-regional**	**Global**
E3ME	**Cambridge Econometrics**		**Demand-led**	**Global**
GEMMES (General Monetary and Multisectoral Macrodynamics for the Ecological Shift)	Agence Française de Développement (AFD)		Demand-led—SFC	Global, Europe, and single country (multiple)
EIRIN model	EDHEC-Risk Climate Impact Institute		Demand-led—SFC	Single country (multiple)
DEFINE (Dynamic Ecosystem-FINance-Economy) model	SOAS University of London		Demand-led –SFC	Global
FSMAT (Financial Sector Mitigation and Adaptation Tool)	**World Bank and Agence Française de Développement (AFD)**		**Demand-led—SFC**	**Single country (multiple)**
C-ROADS (Climate-Rapid Overview and Decision Support)	Climate Interactive, Ventana Systems, UML Climate Change Initiative, and MIT Sloan		SD	Global
En-ROADS (Energy-Rapid Overview and Decision-Support)	Climate Interactive, MIT Sloan, and Ventana Systems		SD	Global

Model name[80]	Principal institution/lead developer	Partner institution/ developer	Model type	Geographical scope[81]
EPS (Energy Policy Simulator)	Energy Innovation LLC		SD	Single country (multiple)
IGEM (Integrated Green Economy Modelling) framework	**Partnership for Action on Green Economy PAGE**	**United Nations agencies: UNEP, UNDP, ILO, UNIDO, UNITAR**	**SD, CGE, IO**	**Single country (multiple)**
Eurogreen	University of Pisa		SD	France
Green Economy Model (GEM)	World Resources Institute (WRI)	KnowlEdge Srl	SD	Single country (multiple)
DisruptSupplyChain	International Institute for Applied Systems Analysis (IIASA)	World Bank	ABM	Single country

Using CGE modeling in the GreenREFORM Model of the Danish Research Institute for Economic Analysis and Modelling (DREAM)[82]

DREAM developed the GreenREFORM model in response to an unresolved need for appropriate analytical tools that would facilitate the systematic integration of climate and environmental considerations into the design of economic policy in Denmark. At its core is a dynamic CGE model with forward-looking behavior, overlapping generations, and frictions to achieve credible short-run dynamics. Production is divided into 52 sectors with 81 products and services, including 26 types of energy. Energy demand is categorized into six tax purposes, for accurate representation of marginal tax rates. Sub-models provide sectoral detail, and the abatement sub-model contributes a bottom-up representation of technological abatement options across sectors. The model is designed to evaluate the combined effects of economic and environmental policy within a unified framework. It provides information on emission accounts, land-use and livestock accounts, changes to return on capital and the value of firms in each sector, changes to the market price of agricultural land, macroeconomic impacts (including changes in production, employment, wage rates, private consumption, exports, imports, and investments), and detailed fiscal impacts (including derivate changes to unemployment benefits, VAT revenues and more).

A key innovation for this model is that sub-models are solved simultaneously yet can be turned on and off at will. This full model integration is more efficient than iterating between a CGE and a sectoral system optimization model. Given a baseline, results for standard shocks can be generated in minutes and thus be used in political negotiations.

The primary challenge during development was reformulating existing power market and energy system models into a continuous problem space, for seamless integration with the macroeconomic model. A key to success has been close collaboration between a dedicated model team, university researchers, sector experts, and end users. Getting various ministries engaged during development was challenging, showcasing the importance of top-down commitment and enforcement, planning, and stakeholder management when developing and introducing a complex new tool across institutions.

The model's success also relies on Denmark's high data quality and the sophistication of other models already in use at DREAM, the MoF, and the Energy Agency. Where these elements are not guaranteed, a lower initial level of ambition may be advisable while making sure the core framework supports the level of ambition ultimately desired.

The current focus is supporting model implementation in the MoF and other government agencies, with courses run to build capacity and agencies developing plans for making the best use of relevant sub-models. DREAM is also engaged in a Technical Support Instrument (TSI) sponsored by the European Commission to develop a 'workhorse' version of GreenREFORM for institutions in four EU countries. The project also serves as a blueprint for other countries to build customized models.

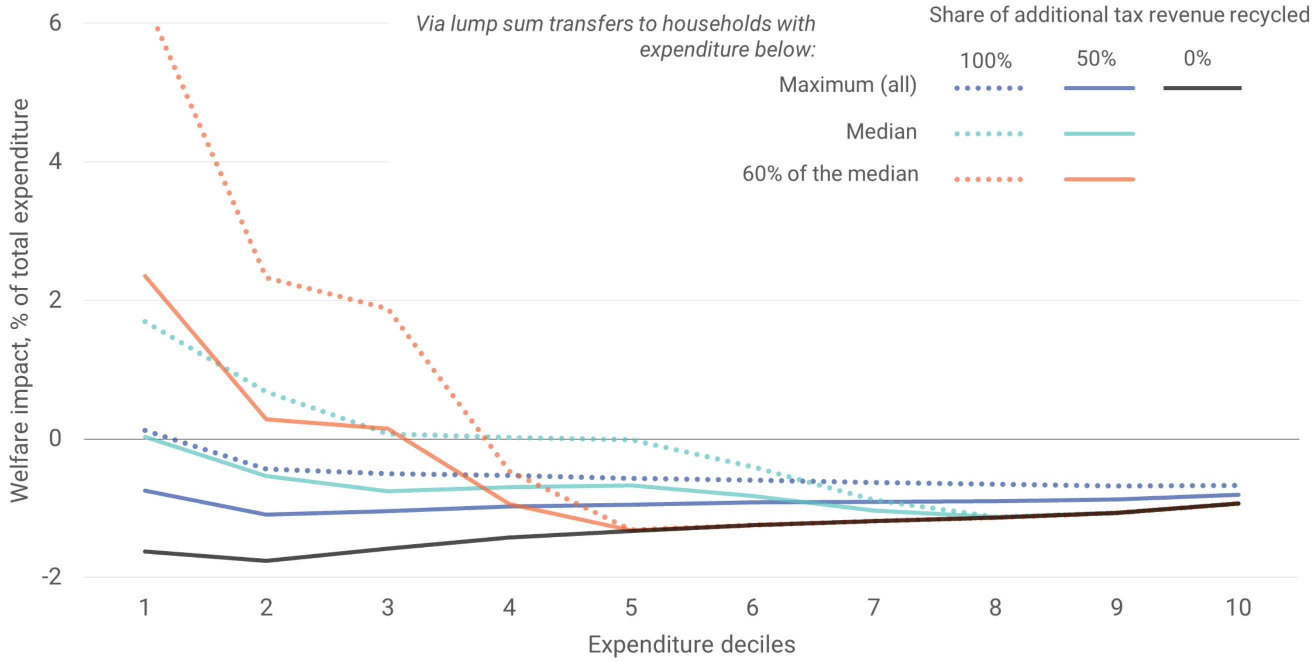
[82] This case study draws on 'The GreenREFORM Model', contribution from DREAM to the HP4 Compendium of Practice.

Augmenting CGE model results: assessing the distributional consequences of the transition in the EU[83]

The European Commission's Joint Research Centre (JRC) recently added the assessment of distributional consequences of climate policy to its analytical tools. The existing CGE model, JRC-GEM-E3, is designed to capture the macroeconomic implications of energy and climate policies and is typically coupled with an Energy System Model (ESM) such as PRIMES or POLES. It is sector-specific and yields price changes due to factors including emissions pricing. As the model uses one representative household, it does not capture distributional consequences. The European Household Budget Survey (HBS) contains data on household expenditure. Applying price changes due to climate policies as evaluated using the JRC-GEM-E3 model to the expenditure data within the HBS provides more detail on how climate policies affect different groups of the population, and can indicate how adverse effects can be mitigated, e.g., through redistribution of the revenues from carbon pricing (Weitzel et al., 2023).

This process was used to analyze the distributional consequences of implementing the EU's Fit for 55 package. Implementing the policy would increase the cost of energy (and related equipment) relative to the baseline, with regressive effects in the absence of redistribution (European Commission, 2020). The analysis also shows a progressive effect can be achieved by a lump sum transfer using a fraction of the additional revenue from the package's expanded carbon pricing, especially when this is targeted at households at risk of poverty (see Figure 5.1). In the case of the Fit for 55 package, these insights contributed to the design of the Social Climate Fund meant to support a just transition.

Figure 5.1. Distributional impact of reaching the EU's 55% net emission reduction target, including an extension of the EU Emissions Trading Scheme to buildings and road transportation



Note: Impacts are shown across household expenditure deciles with different recycling schemes for carbon revenues.
Source: European Commission (2021)

The richness of the HBS data enables analysis of distributional consequences along additional socioeconomic dimensions, such as location, dwelling, and car ownership (Vandyck et al., 2022). Moreover, this modeling framework can be used to analyze the distributional effects of employment shifting out of 'brown' (polluting) sectors.

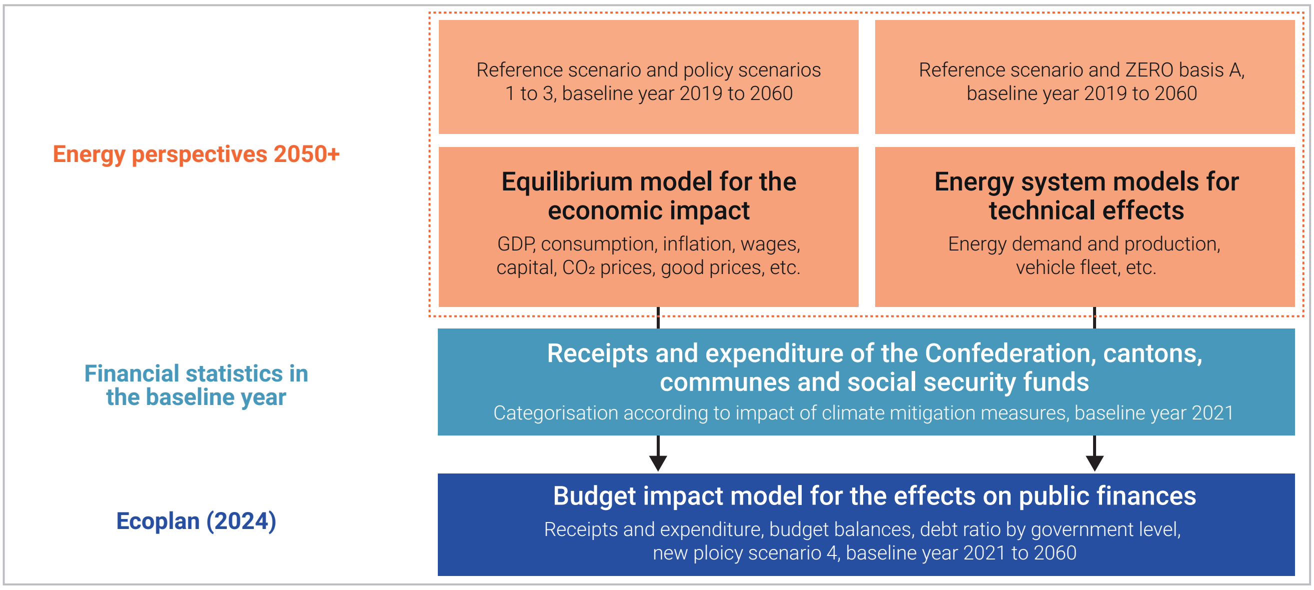
[83] This case study draws on 'Assessing the distributional consequences of the transition in the EU', contribution from the European Commission to the HP4 Compendium of Practice.

Augmenting CGE model results: modeling the fiscal impacts of Switzerland's net zero emissions target within fiscal sustainability analysis[84]

In its 2024 Fiscal Sustainability Report, the Swiss Federal Department of Finance introduced a pilot study to analyze the long-term impact of achieving the net zero emissions target on the public finances via a budget-impact model (Federal Department of Finance, 2024).

The model draws on energy system models (ESMs) and a computable general equilibrium (CGE) model developed for the Energy Perspectives 2050+ of the Swiss Federal Office of Energy (DETEC, 2022). These are combined via soft links to create the budget-impact model to exploit their respective strengths. ESMs allow in-depth analysis within sectors (e.g., electricity, transportation, industry) that require accurate and detailed data on the energy system. The CGE model assesses the macroeconomic impact of the energy transition, incorporating market clearing mechanisms to ensure macroeconomic equilibrium. Both direct and indirect fiscal effects of mitigation measures are considered during the energy transition. Figure 5.2 outlines the model's main steps.

Figure 5.2. Processing steps in the budget-impact model



Source: Federal Department of Finance (2024), based on Ecoplan (2024)

The analysis considers economic and fiscal impacts of the energy transition to reach Switzerland's target of net zero emissions by 2050. Key variables are GDP, consumption and wages, and the composition of the public finances, including public revenues (e.g., income taxes, profit taxes, VAT, CO_2 levy, mineral oil tax) and public expenditure (e.g., subsidies, social contributions, wages, interest on debt), as well as public budget balances and debt ratios for all levels of government, relative to a business-as-usual scenario. Due to a high degree of uncertainty and a lack of data, neither the costs of climate change and adaptation measures, nor endogenous technological advancements during the energy transition, could be considered. These omissions also mean that the models do not capture climate damages avoided through the energy transition. The models rely on various assumptions about the evolution of the energy system, macroeconomic development, and policy effectiveness.

Achieving net zero by 2050 is modeled through policy scenarios that simulate an increase in carbon pricing, stricter emissions standards for buildings and vehicles, and an increase in subsidies as part of the Climate and Innovation Act (CIA) and to support the acquisition of negative emissions technology (NET) capacity abroad. Direct effects of such policy measures on public finances include higher carbon tax revenues in the short and medium term, but lower revenues when carbon dioxide emissions decrease over time, and a gradual decrease in revenues from the mineral oil tax due to electrification of the transportation sector. In the model, it is assumed

[84] This case study draws on 'Modeling the fiscal impacts of the net zero target within fiscal sustainability analysis', contribution from the Swiss Federal Department of Finance to the HP4 Compendium of Practice.

that the latter is compensated for by the introduction of a replacement levy on EVs.[85] Indirect effects include decreased revenue from income tax, profit tax, and VAT due to lower growth in GDP, consumption, and wages. The projections show that from a fiscal perspective, the path to net zero emissions can be reached most efficiently with carbon pricing and emissions standards (i.e., regulation).

Lessons from this case study include that modeling should focus more on insights than on numbers, and the importance of the high degree of uncertainty in medium- and long-term analyses in this field. Understanding the channels and potential impacts of climate change and mitigation measures is an important step before quantitatively assessing their economic and fiscal implications. To this end, a chapter of the 2021 Fiscal Sustainability Report was dedicated to a qualitative evaluation of the costs of climate change in Switzerland, building on cooperation with the OECD (Baur et al., 2021; Brändle, 2021).

In the Swiss case, the analysis was outsourced to Ecoplan, a Swiss consulting firm, though closely monitored by the Federal Department of Finance. This choice was made because Ecoplan had already developed the CGE model employed and used it in combination with other models to assess the economic cost of the climate and energy strategy for the Department of Environment, Transport, Energy, and Communication (DETEC, 2022). Nonetheless, the need to build up in-house capacity is recognized.

Macroeconomic and monetary impacts of disasters: adapting the MFMod macrostructural model to assess the vulnerability of the Turkish economy[86]

A recent paper explores the economic impacts of natural disasters, focusing on the damage to public and private infrastructure capital (Hallegatte et al., 2024). The paper uses simulations conducted using the World Bank's Macrostructural Model (MFMod) to explore the importance of macroeconomic and monetary policies in determining the total impact of natural disasters. The simulations involve generating a model-determined baseline without shocks and then introducing a shock in the form of infrastructure stock destruction.

To conduct this analysis, MFMod was adapted to capture the channels through which economic impacts from natural disasters occur and the reconstruction period that follows a disaster. This adaptation includes three main changes:

1. Disaggregating the capital stock into infrastructure and non-infrastructure capital to better analyze the specific impacts of disaster-caused capital damage and representing the complementarity between infrastructure and non-infrastructure physical capital.
2. Representing the non-marginal impact on capital through a combined impact on the capital stock and its average productivity.
3. Representing a realistic reconstruction trajectory, considering the practical, technical, and financial constraints to reconstruction.

The key findings are:

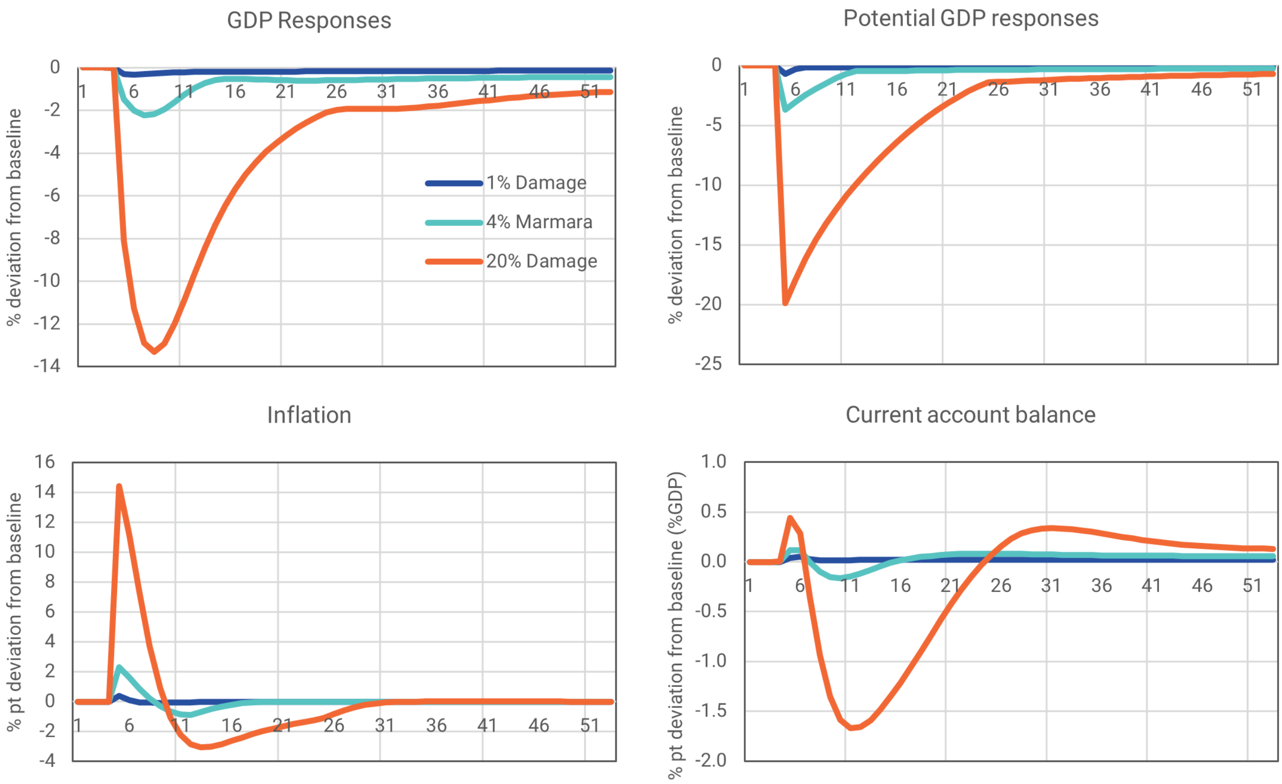
- First, output and consumption losses grow more than linearly with capital losses, and macroeconomic and monetary effects matter mostly for large-scale disasters. Monetary policy affects the reconstruction process through the cost of financing and impact on inflation. Macroeconomic and monetary mechanisms tend to reduce the welfare impact for small disasters and magnify it for large disasters. The economic conditions at the time of the disaster, such as whether the economy is in expansion or recession, play a crucial role in determining the total impact of natural disasters on welfare.

[85] See also 'Introduction of a replacement levy on electric vehicles', contribution from the Swiss Federal Department of Finance to the HP4 Compendium of Practice.

[86] This example was provided by Stepháne Hallegatte and Florent McIsaac. It blurs the divide between climate-enhanced macroeconomic models and physical climate and disaster risk models. It is included here as the underlying model, MFMod, is considered a macroeconomic model of the former kind, but the case study could alternatively have been included in the following section which focuses on case studies of physical climate and disaster risk models and approaches.

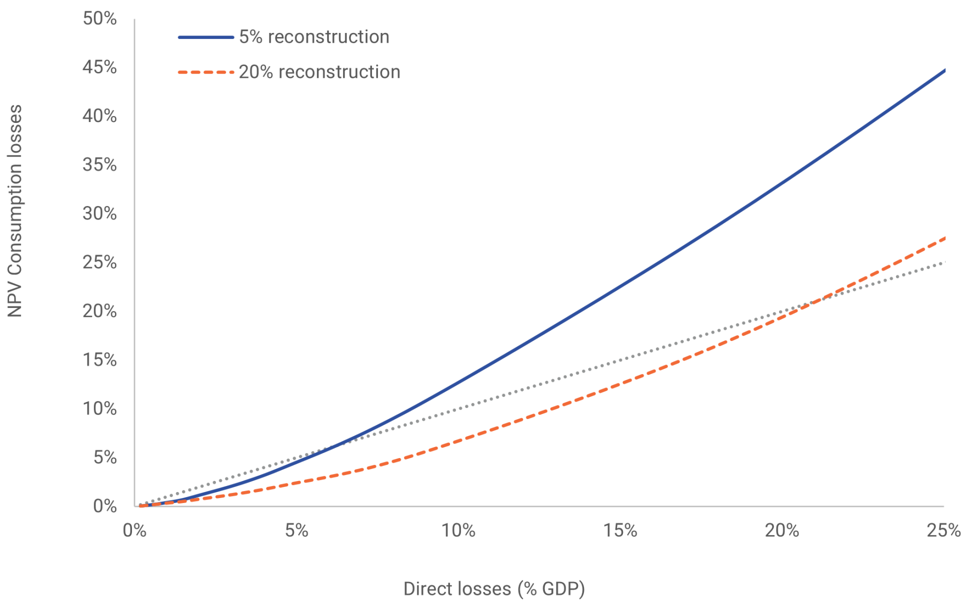
- Second, fast resource reallocation of government spending from capital expenditures toward reconstruction investment can speed up recovery and reduce welfare losses. Reconstruction investments often deliver a greater return on capital than additional capital investments by restoring temporary lost productivity from undamaged assets.

Figure 5.3. Sensitivity of economic response (GDP, potential GDP, inflation, and current account balance) to capital losses of different intensity, including an illustration of the impact of the 1999 Marmara earthquake



Source: MFMod macrostructural model, Hallegatte et al. (2024)

Figure 5.4. Net present value (NPV) of consumption losses, as a function of direct losses, for two assumptions regarding the ability of the economy to redirect investments toward reconstruction



Note: The light dotted gray line is the 45-degree line.

Source: MFMod macrostructural model, Hallegatte et al. (2024)

Using an Energy System Model (ESM) to analyze the fiscal impacts of decarbonizing the transportation sector in Costa Rica[87]

OSeMOSYS is a bottom-up Energy System Model initially developed to assess the costs and benefits of net zero strategies for the energy sector (Godínez-Zamora et al., 2020; Howells et al., 2011). The Inter-American Development Bank (IDB) has added a tax and a distributional impact module to this model.

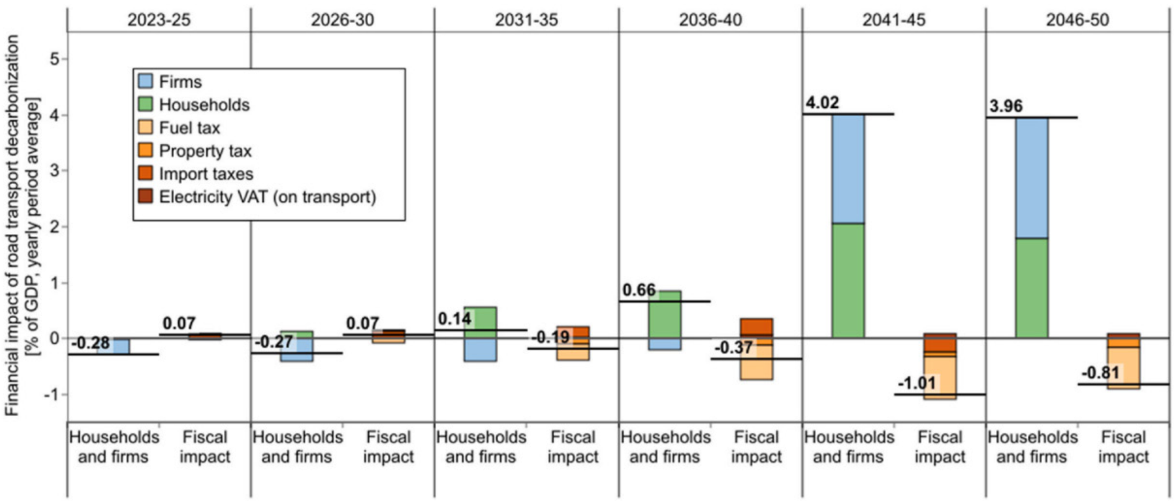
OSeMOSYS starts from projected mobility demand (in passenger km/year) and freight demand (in ton-km/year) based on assumed GDP and population scenarios and then calculates the cost to satisfy these demands using different means of transportation. The model accounts for capital costs, maintenance, and fuel expenses, and estimates the cost to deploy the needed infrastructure (e.g., bus lanes or EV charging stations).

Next, the model computes the costs and benefits of decarbonization versus business-as-usual (BAU), including the incidence of costs and benefits by household income quintile or region of residence and for different companies (e.g., bus companies). This analysis is facilitated by surveys that reveal the means of transportation typically used by different households, vehicle registration data, and energy balances, which account for the production, transformation, and consumption of energy products in the economy.

The Inter-American Development Bank (IDB) applied the model to Costa Rica (Victor-Gallardo et al., 2024), which was among the first developing countries to issue a National Decarbonization Plan and establish a net-zero-by-2050 target (Costa Rica, 2019). To achieve this, key policies include electrifying 95% of the light vehicle fleet and 85% of buses, increasing journeys by bike and on foot by 10%, and deploying liquefied petroleum gas and hydrogen vehicles in the cargo sector. However, because taxes on gasoline, diesel, vehicle ownership, and import duties comprise up to 20% of fiscal revenues (Ministry of Finance, 2021), this will have fiscal implications.

The analysis indicates that between 2023 and 2050, decarbonizing transportation will bring financial benefits of 1.49% of GDP to households and firms (see Figure 5.5). These include lower energy expenses that more than offset the higher upfront cost of buying an EV but exclude nonfinancial benefits such as a reduction in congestion or accidents (see Groves et al., 2020 for an estimation of these benefits). Absent tax adjustments, the government faces a fiscal loss of 0.41% of GDP, primarily because reduced fuel tax revenue is only partially offset by increased revenue from property taxes and import duties (EVs are currently costlier to buy than petrol vehicles), and VAT on electricity. As the plan reduces the total number of vehicles on the road, revenue from import and property taxes is lower than in the BAU scenario by 2050.

Figure 5.5. The financial impact of the decarbonization of road transportation for households, firms, and the government in Costa Rica



Source: Victor-Gallardo et al. (2024)

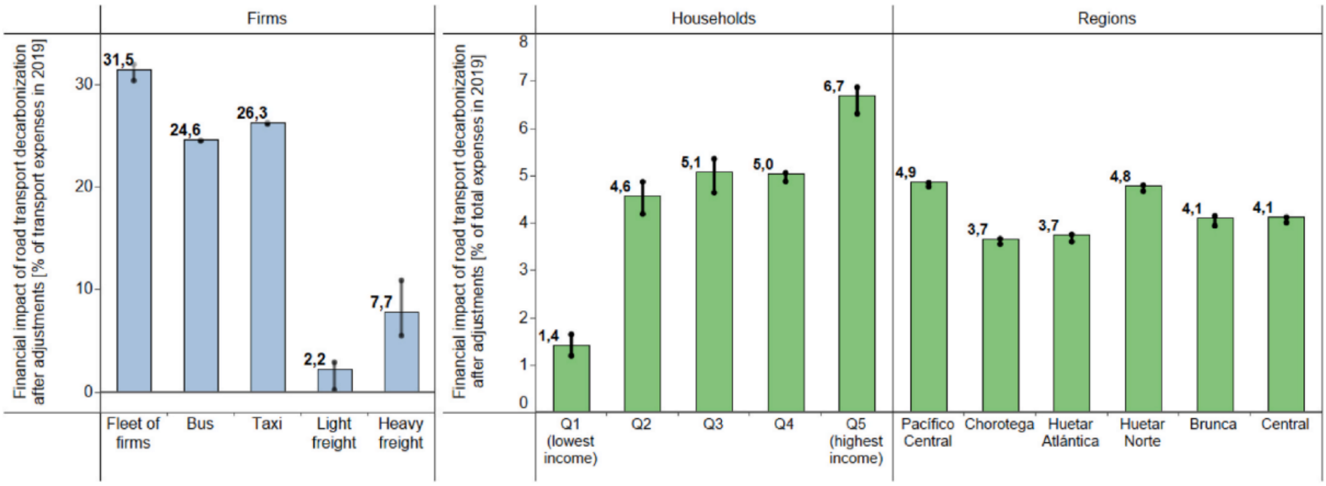
[87] This case study draws on 'Managing the fiscal impacts of electric vehicles, public transportation, and cycling', contribution from the Inter-American Development Bank (IDB), French Development Agency (AFD), and University of Costa Rica to the HP4 Compendium of Practice.

The model evaluates 10 individual options for the government to restore revenue: increasing property or import taxes on gasoline or EVs, increasing excise taxes on diesel, gasoline, LPG, electricity, or hydrogen; and creating a new road user tax (taxing vehicles based on miles traveled). The consumer response to taxes is not modeled. While any of the individual taxes could offset the fiscal impact of road decarbonization if sufficiently high, this may be politically unfeasible. For instance, to offset the fiscal impact via a diesel tax, the tax rate on diesel would need to increase 48-fold by 2050, and becomes ineffective when almost no diesel vehicles remain on the road. This would affect the bottom line of truck drivers and cost the poorest households 1.8% of their income (Victor-Gallardo et al., 2024).

More positively, a combination of more modest tax adjustments can offset the government's fiscal impact while providing net benefits to firms, households, and regions. One option is to increase property taxes and fuel taxes by less than 15%, electricity taxes by less than 25%, and set the road-use tax at less than US$7 per thousand kilometers in 2050. This would leave government revenues unchanged while all groups of households and firms would be better off.

Many other combinations of tax adjustments could achieve this outcome. Figure 5.6 shows the incidence of 1,000 different tax reforms, all of which offset the fiscal impact. In all, households and firms gain income, compared with the BAU scenario without decarbonization. Moreover, all income groups and all regions are better-off, avoiding the creation of winners and losers at this level. There is no single best strategy.

Figure 5.6. The financial impact on firms, households, and regions of decarbonizing transportation along with fiscal adjustments using tax combinations in Costa Rica



Source: Victor-Gallardo et al. (2024)

All in all, OSeMOSYS, which is fully documented and available for free, helps Ministries of Finance pick a strategy that suits them. It can easily be applied to other countries: for instance, it was recently used to investigate the fiscal impact of decarbonizing transportation in Peru (World Bank Group, 2022).

The documentation is available at https://osemosys-cr-v2.readthedocs.io/en/latest/ and the model code at https://github.com/EPERLab/osemosys-cr-v2.

Using Future Technology Transformation (FTT) models to analyze technology policy in three sectors[88]

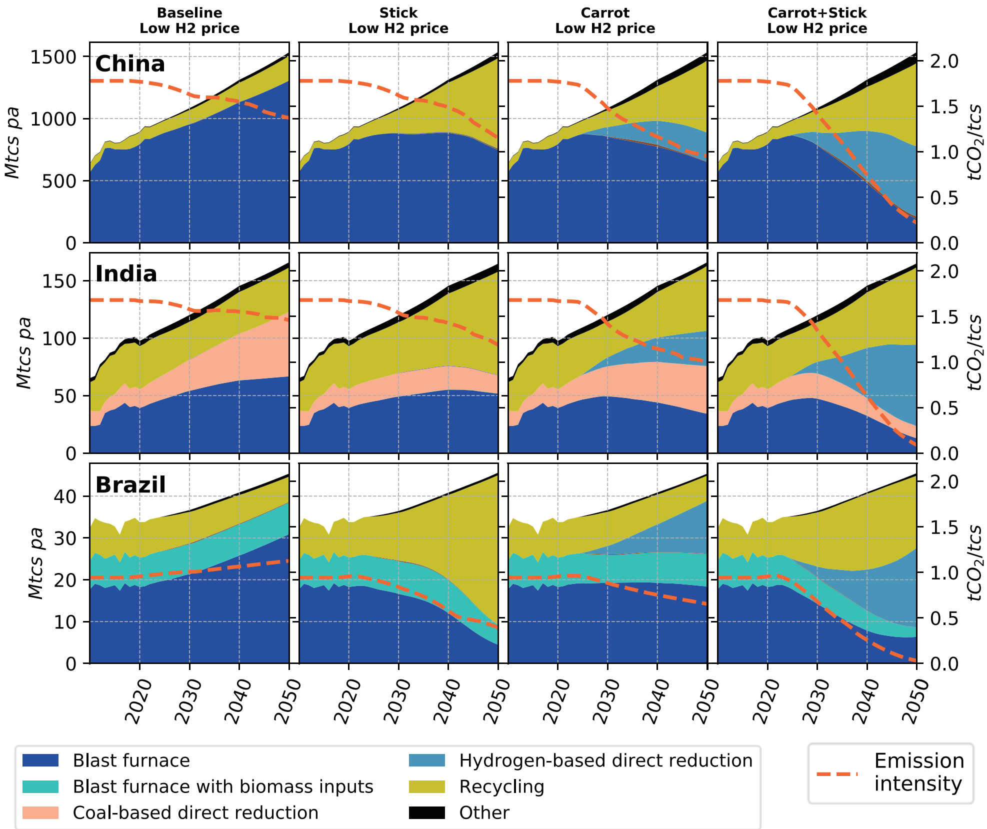
This case study looks at the use of FTT models for the steel, road transportation, and power sectors.

The steel sector is in the 'emergence' stage of the low-carbon transition, with technologies for near-zero-emission primary-steel production being tested in pilot plants but as yet barely beginning to enter the market on a commercial scale.

Vercoulen et al. (2021) applied the FTT model to China, India, and Brazil to compare three policy packages and a baseline 'no policy' scenario (see Figure 5.7):

- 'Stick' policy package: i) a carbon tax, starting at €50 per tonne CO_2, gradually growing to €298 per tonne CO_2 in 2045, and leveling off afterwards; ii) phase-out regulations on carbon-intensive technologies that prevent the construction of new plants, starting in 2021; and iii) an energy tax of 25% on coal and gas, starting in 2021.
- 'Carrot' policy package: i) upfront subsidies on capital, starting in 2021, at 25% on carbon capture and storage (CCS) applications and 50% on hydrogen-based steelmaking and scrap recycling; ii) subsidies on low-carbon energy carriers, starting in 2021, at 25% on electricity, charcoal and biogas, and 75% on hydrogen; and iii) government procurement, starting in 2025, translating into a 0.005% per annum addition to hydrogen-based steelmaking capacity.
- 'Carrot and stick': a combination of the two policy packages described above.

Figure 5.7. Evolution of production in the steel sector under four policy scenarios in China, India, and Brazil



Note: Numbers are in mega tonnes of crude steel per annum (Mtcs pa) on the left-hand axis. Average emission intensities of the whole steel sector in each country are indicated by the dashed line and relate to the right-hand axis (in tCO_2/tcs). For further explanation see Figure 2, p9, of Vercoulen et al. (2021).

Source: Vercoulen et al. (2021)

[88] This case study draws on 'Policy packages for cost-effective transitions: learning from the past, simulating the future with the Future Technology Transformations models, and case studies from the Economics of Energy Innovation and System Transition project' (op. cit.), along with several publications from the Economics of Energy Innovation and System Transition (EEIST) led by the University of Exeter, as indicated.

The simulation of the baseline scenario suggests that in the absence of policy, steel production is likely to remain dominated by coal-burning blast furnaces. The 'stick' policy package makes coal-burning blast furnaces more expensive, such that the industry moves toward the cheapest alternative: recycling of scrap steel and a shift to electric arc furnaces. However, a constrained supply of scrap steel precludes full decarbonization. The 'carrot' policy package promotes a switch toward hydrogen-based steelmaking. This prevents the growth of high-emitting production pathways but does not achieve a substantial reduction. Combining the carrot and stick policy packages is significantly more effective, as the policy packages are mutually reinforcing. In China and India, their combined effect on the growth of hydrogen-based steelmaking is nearly double the sum of their individual contributions and eliminates most traditional high-emitting production.

The future price of hydrogen is uncertain. Assuming high or low hydrogen prices changes the relative shares of different technologies in each of the scenarios but does not change the finding that the combination of 'carrot' and 'stick' policy packages is more effective than either package alone.

The road transportation transition is in the 'diffusion' stage, with electric vehicles (EVs) spreading rapidly and accounting for 18% of all cars sold globally in 2023 (IEA, 2024). Lam et al. (2023) used the FTT model to compare four policies to support decarbonization in each of the world's four largest car markets (Europe, the U.S., China, and India) at varying levels of stringency: purchase subsidies for EVs, taxes on internal combustion engines, efficiency regulations, and zero emission vehicle mandates.

Regulatory policies are likely to be the most effective in driving the transition, while subsidies and taxes, even at very high levels, appear likely to be relatively ineffective when used alone. Zero emission vehicle mandates appear more effective than efficiency regulations, as they force a faster shift to new technology and thereby activate deployment–cost reduction feedbacks. Mandates and efficiency regulations generally outperform subsidies in terms of cost-effectiveness in EV deployment, while taxes are the least cost-effective by far. Relative cost-effectiveness can vary by country and stage of transition. In the U.S., subsidies appear more cost-effective than regulations and mandates early in the transition when the cost premium of EVs is high, but this reverses as EV costs decrease (see Figure 5.8). In China, a greater proportion of EVs are already cost-competitive with gasoline cars and subsidies are less cost-effective than regulation from the outset. Some policy packages achieve more and some less than the sum of their parts. Combining zero emission vehicle mandates with taxes and efficiency regulations on combustion engine vehicles results in the greatest gains by increasing the availability of the new technology while reducing the attractiveness of the old (Lam and Mercure, 2021).

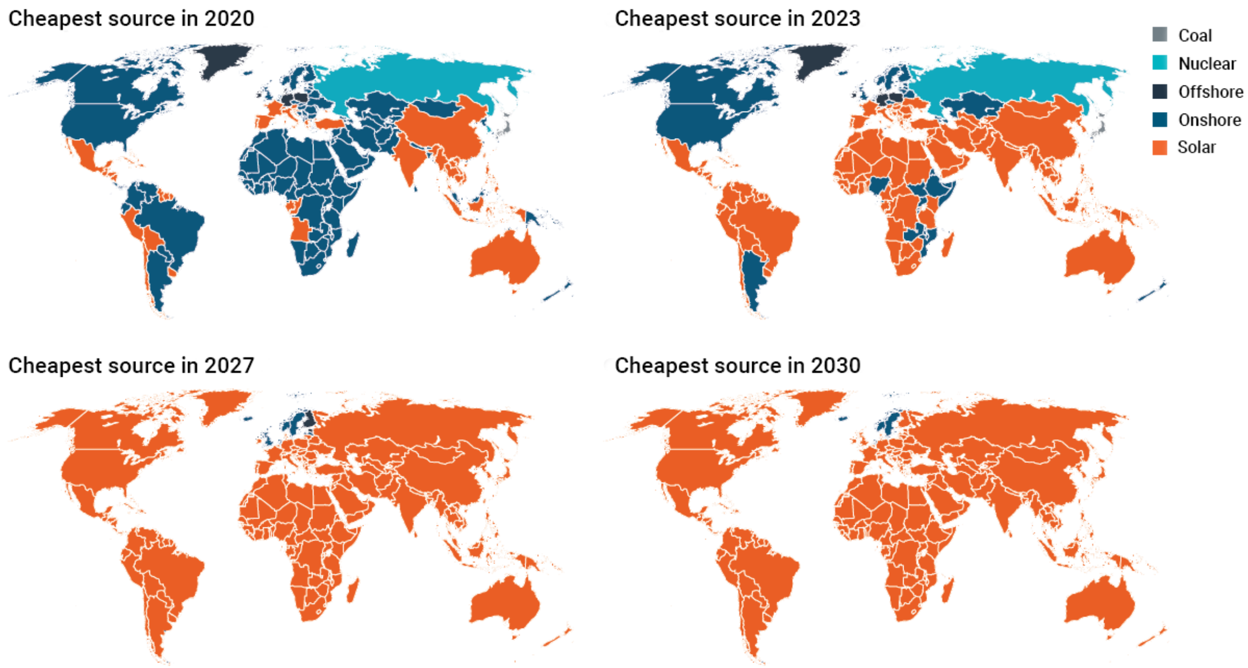
Figure 5.8. Cost of EV deployment under alternative decarbonization policies for road transportation, United States

Source: Lam et al. (2023)

The power sector transition is approaching the 'reconfiguration' stage in leading markets, with clean power accounting for around 80% of electricity generation capacity additions globally in 2023.

The FTT model projects that without any new policies, solar power (with the cost of energy storage included) is set to become the cheapest form of power generation almost everywhere in the world within the next few years (see Figure 5.9). The biggest shift occurs between 2020 and 2027, which sees a range of technologies give way to solar PV as the cheapest form of energy. This arises because of the positive deployment–cost reduction feedback in the model and because solar has a steeper learning curve than wind (there is no significant learning for coal, gas, nuclear, or hydro). These projections differ significantly from those of other models: while FTT projects that solar could account for over half of global electricity generation by 2050, the International Energy Agency's (IEA) baseline scenario, produced at a similar time, projects a 20% share for solar by 2050 (IEA, 2021b).

Figure 5.9. Energy sources with the lowest levelized costs of electricity (including necessary storage) in 70 world regions, in 2020, 2023, 2027 and 2030



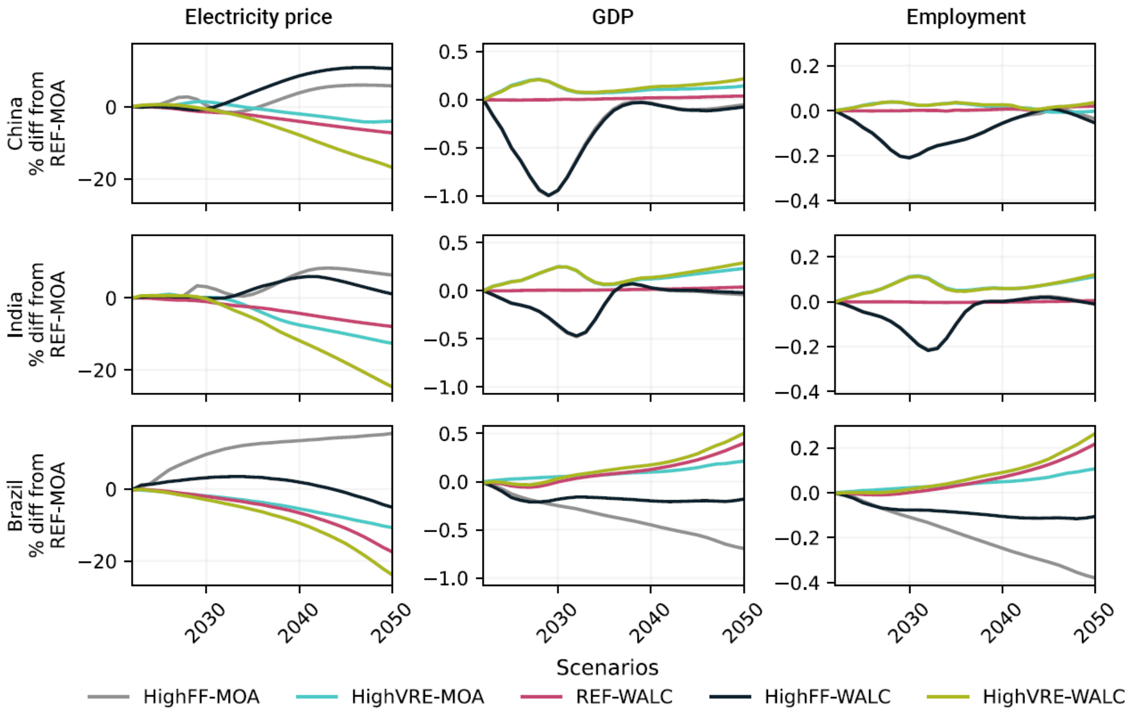
Source: Nijsse et al. (2022)

FTT model simulations suggest that renewables subsidies or carbon prices will make little difference to the transition to clean power over the coming years (renewable power is already cheaper than coal or gas power in most of the world), while regulatory policies that force out coal could make a significant difference (Nijsse et al., 2024). Additionally, policies that are not explicitly modeled, such as the rate of expansion of electricity grids, the speed of permitting for renewables, and the cost of capital in developing countries, could make a significant difference.

The model also shows how choices regarding future market design could interact with technology choices to produce higher or lower electricity prices. The modeled results consistently indicate lower electricity prices in high renewable energy scenarios than in high fossil fuel scenarios, reflecting the lower cost of renewables compared with fossil fuels (see Figure 5.10). At the same time, market design that incorporates a weighted average levelized cost (WALC) achieves significantly lower electricity prices than the merit order approach (MOA), where the price is often set by more expensive fossil fuels. The model results show some differences across countries: in China and Brazil the reference technology scenario with WALC market design outperforms the high variable renewable energy (VRE) scenario with MOA market design, while the opposite is found in India. This is because India has the highest share of solar power in its system, and toward the end of the simulation the marginal cost of renewables sets the price in the MOA market for a substantial amount of time.

Outcomes for GDP and employment can be elucidated when FTT is coupled with the macroeconomic model E3ME. In each country, the scenarios with low electricity prices have more positive outcomes for GDP and employment. Lower electricity prices reduce household energy bills and industrial production costs, which enables increased consumer spending. An increase in construction also contributes positively to GDP and employment in high VRE scenarios. Net changes in GDP and employment mask larger changes across sectors.

Figure 5.10. Comparison of electricity prices, total employment, and GDP of each scenario in percentage difference to the reference scenario (merit order approach [MOA]) in China, India, and Brazil



Source: Vercoulen et al. (2023)

5.3. Physical climate and disaster risk models and approaches—overview and case studies

Table 5.2 lists examples of physical climate and disaster risk models and approaches. The list is not comprehensive; many more approaches are available.[89] Additionally, further guidance is available on how to conduct risk assessments that are not necessarily fully fledged catastrophe models but still provide information on the risks of natural disasters.[90] A selection of case studies showcasing the use of these models and approaches follow the table.

Table 5.2. Physical climate and disaster risk models and databases

Model name[91]	Institution/lead developer	Model type
CLIMADA	**ETH Zürich**	**Catastrophe model**
Morocco Natural Hazards Probabilistic Risk Assessment (MnhPRA)	Morocco	Catastrophe model
OasisLMF (Oasis Loss Modelling Framework)	N/A—open-source	Catastrophe model

[89] The ISIMIP (Inter-Sectoral Impact Model Intercomparison Project) "aims to improve global and regional risk management by advancing knowledge of the risks of climate change through integrating climate impacts across sectors and scales in a multi-impact model framework" (ISIMIP, 2018: 1). A plethora of models feed into this exercise and are documented at https://www.isimip.org/impactmodels/. Output data from the project is available at https://data.isimip.org/. See also Appendix B of this report for further data resources relating to physical risk.
[90] See, for instance, World Bank and ADB (2017).
[91] Models written in **bold** are described in further detail in the Compendium of Practice. Brief descriptions of these can be found in Section 4 of the Compendium Summary Report and the full contributions can be found online. Some of these examples are also included in the form of case studies below.

Model name[91]	Institution/lead developer	Model type
CAT model for typhoons in the Philippines	Philippines—Department of Finance with World Bank and Verisk (formerly AIRWorldwide)	Catastrophe model
CIAM (Coastal Impact and Adaptation Model)	Delavane B. Diaz	Loss and damage assessment/asset-level analysis
DIVA (Dynamic Interactive Vulnerability Assessment)	DIVA Consortium (Global Climate Forum, University of Southampton, and Kiel University, with Cambridge University Coastal Research Unit, University of Lincoln, and University of Sussex)	Loss and damage assessment/asset-level analysis
LISCOAST (Large Scale Integrated Sea-level and Coastal Assessment Tool)	European Commission Joint Research Centre (JRC)	Loss and damage assessment/asset-level analysis
Resilience Design and Monitoring Tool (RMDT)	International Fund for Agricultural Development (IFAD)	Loss and damage assessment/asset-level analysis
CATSIM (Catastrophe simulation)	International Institute for Applied Systems Analysis (IIASA)	Loss and damage assessment/asset-level analysis
Q-CRAFT (Quantitative Climate Change Risk Assessment Fiscal Tool)	**International Monetary Fund (IMF)**	**Loss and damage assessment/asset-level analysis**
WEAP (Water Evaluation and Planning System)	Stockholm Environment Institute	Loss and damage assessment/asset-level analysis
Coastal Property Model	U.S. Environmental Protection Agency (EPA)	Loss and damage assessment/asset-level analysis
DRFIP Financial Risk Assessment Tool	World Bank—Finance, Competitiveness & Innovation Global Practice (FCI GP)	Loss and damage assessment/asset-level analysis
COACCH (CO-designing the Assessment of Climate CHange costs) project	CMCC Foundation (Euro-Mediterranean Center on Climate Change), Paul Watkiss Associates, IIASA, Universität Graz, VU Foundation, Ecologic Institute, Charles University, Netherlands Environmental Assessment Agency (PBL), Basque Centre for Climate Change (B3C), Climate Analytics, Deltares, Global Climate Forum (GCF), Potsdam Institute for Climate Impact Research (PIK)	Damage functions
CLIMRISK-RIVER	VU Amsterdam	Damage functions (floods)

Estimating the costs of adapting to sea level rise globally[92]

Adaptation to sea level rise is a useful example of a public adaptation investment need that requires practical assessment. The benefits of seawalls and other coastal adaptation measures are generally confined to protecting the coastline from storms and rising sea levels. The IMF Fiscal Affairs Department developed a baseline scenario with sea level rise, projected coastal development, and no adaptation as a reference case using a model. The cost and benefits of alternative adaptation options can be calculated using this reference case. If the government uses Cost–Benefit Analysis as a choice rule, the optimal adaptation strategy is the one with the largest net present value. Other normative criteria can be used to determine the optimal level of protection. All these calculations can be simulated using models that have been used widely over the past three decades (Diaz, 2016; Hallegatte et al., 2013; Nicholls et al., 2019; Nicholls and Tol, 2006; Hinkel et al., 2018).

IMF staff have used the Coastal Impact and Adaptation Model (CIAM) to estimate the cost of sea level rise under alternative adaptation strategies. CIAM is a global model used to estimate the economic cost and benefits of adaptation to sea level rise (Diaz, 2016). The model divides the global coastline into more than 12,000 segments of different length, grouped by country. Each segment is further divided into areas of different elevation. For each segment, the model has data on capital, population, and wetland coverage at different elevations. Projections of local sea level rise from Kopp et al. (2014) under different representative concentration pathways over time are used as inputs to estimate which areas will be inundated and the amount of capital and population at risk,

[92] This case study draws on Box 1 in 'The critical role of Ministries of Finance for investment in adaptation and the analytical principles and tools available', contribution from the International Monetary Fund (IMF) Fiscal Affairs Department to the HP4 Compendium of Practice.

considering that storms cause periodic inundations on top of sea level rise. Increased risk from river flooding is not considered.

The model calculates the cost of sea level rise—i.e., the protection costs plus residual losses—under alternative adaptation options:

- The ***no-adaptation*** scenario assumes that the population does not move (i.e., it keeps building and maintaining capital) until the area is inundated by the sea and then it relocates to a higher elevation, abandoning the capital. The cost of sea level rise is calculated as the sum of the residual value of abandoned capital, demolition costs, and the value of land that is inundated. The model uses the rental value of agricultural land near the coast, following Yohe et al. (1990), and population density and development opportunity costs are assumed to be capitalized in agricultural land values. The negative welfare impacts of reactive migration are monetized.
- The ***protection*** scenario assumes that society invests in cost-effective seawalls and other barriers along the entire coastline to avoid inundation from sea level rise. Storms can still periodically inundate protected areas and cause capital and human losses if protection is not sufficiently high, but capital and land are not lost, and the population does not move. The cost of sea level rise is equal to the cost of protection plus the expected value of the cost of storms.
- The ***planned retreat*** scenario involves gradual retreat from areas that will be subject to inundation, with a move to higher ground. Coastal areas continue to be used without building new capital, letting the existing capital depreciate in value. Land and some residual value of capital will be lost, but coastal protection costs are avoided. The cost of sea level rise is equal to the sum of the residual cost of capital, the value of inundated land, and the disutility cost of relocation. In the base scenario the retreat perimeter is calculated to deal only with permanent inundation of land, but it can be pushed to also avoid storm surges (from 1 in 10 to 1 in 10,000 year events).

For each coastal segment, the model calculates the net present value of the costs of sea level rise for each adaptation strategy. Loss of life is monetized using the 'Value of Statistical Life'; loss of wetlands due either to sea level rise or protection by barriers that impede the normal circulation of tidal waters is monetized using estimates of willingness to pay for biodiversity preservation. The cost of building and maintaining seawalls and other parameters come from the literature. Storm surge costs are incremental with respect to a baseline scenario in which storms occur without sea level rise.

The ***least-cost adaptation strategy*** for each coastal segment and the lowest possible cost of sea level rise for the country can be found by comparing sea level rise costs across all scenarios. Coastal protection is usually the least-cost strategy in areas with large existing capital and high population density. Where there is little capital and low population density, planned retreat is usually the least-cost strategy. The optimal height for coastal protection infrastructure and the optimal retreat perimeter depend on the projected incremental costs of protection, the opportunity cost of abandoning land not normally flooded, the size of capital and population at risk, and different sea level rise scenarios, among other factors.

The model has been used to complement the IMF's Article IV country reviews and in Technical Assistance missions by IMF staff related to resilience and sustainability, to highlight risks and suggest a path toward making informed and consistent policy choices. CIAM has been used in countries including Palau, Vanuatu, Morocco, Jamaica, Dominican Republic, Papua New Guinea, Togo, Curacao, and Antigua and Barbuda. The results produced by the model should be treated as preliminary and incomplete; any final decision requires more granular data and much greater resources. Nonetheless, the model provides a practical way to think through a complex problem, based on an objective assessment of benefits and costs. It is also a useful way to illustrate the logic of CBA applied to climate change adaptation, highlighting trade-offs between alternative adaptation options, and provides a blueprint for the use of similar assessment tools in other sectors.

IMF staff provide access to model simulations using a simple Excel spreadsheet and the model is open-access and can be used and modified by economists in MoFs. The model is written in GAMS, an optimization software that requires a paid subscription, though a version called pCIAM written in Python, which is open-access, is also available. The GAMS version is available at https://github.com/delavane/CIAM and the python version, pCIAM, at https://github.com/ClimateImpactLab/pyCIAM.

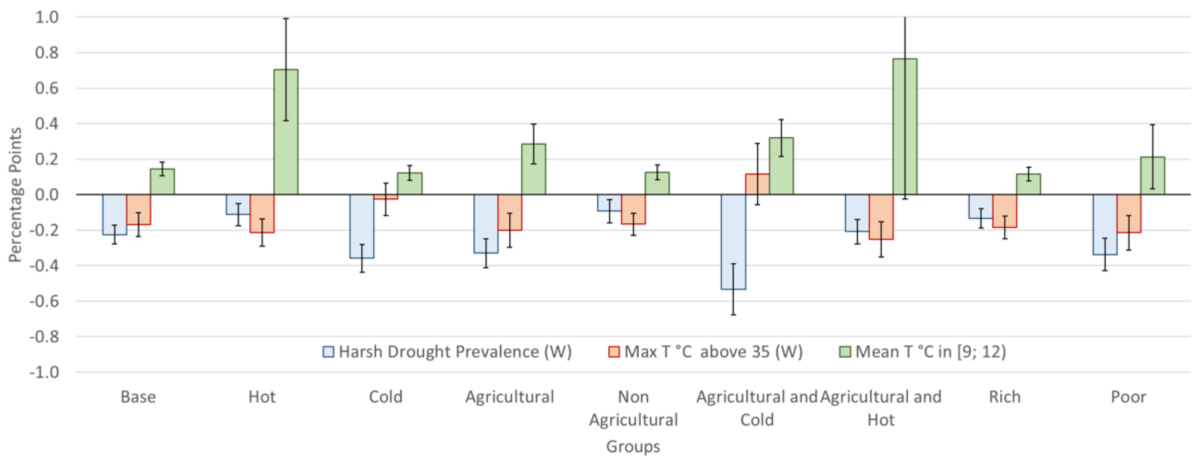
Estimating the macro-fiscal impacts of weather shocks using billions of weather observations[93]

Estimating the impact of weather shocks on macro-fiscal variables is a useful starting point for tackling the effects of long-term climate change. While weather shocks are very different from climate change—weather is the year-to-year, day-to-day realization of climate—estimating their effect on GDP per capita and other macro-fiscal variables provides insights into key vulnerabilities of the economy that could be exacerbated by long-term climate trends.

A recent study by Akyapi et al. (2025) moves the literature beyond an assessment of average annual weather patterns by leveraging hundreds of billions of daily weather measurements using machine learning methods. From high-resolution daily observations of temperature and precipitation they build hundreds of weather variables that can potentially explain economic outcomes. To select the most important variables to explain economic impacts they use the Least Absolute Shrinkage and Selection Operator (LASSO). They expand the analysis beyond weather's effect on GDP to examine fiscal aggregates such as expenditure and revenue.

An increase in the occurrence of high temperatures and severe droughts, and scarcer incidence of mild temperatures, serve to reduce GDP. These variables can account for substantially more of the variation in GDP than average annual temperature. A variation of one standard deviation in the selected variables leads to impacts of around 0.2 percentage points of GDP. The results for the full panel specification and for selected sub-groups of countries are shown in Figure 5.11. The response of fiscal variables to weather shocks tends to mitigate the effects of a weather shock through countercyclical adjustments, with larger fiscal deficits when the shock has negative consequences for GDP.

Figure 5.11. Impact of weather shocks on GDP per capita



Notes: The figure illustrates the estimated impact of each weather variable using the baseline specification of Akyapi et al. (2025) and for different sub-groups. The vertical lines show the 95% confidence intervals using standard errors clustered by country. Climate variables are standardized. Harsh Drought Prevalence means the share of grid-months during which the Palmer Drought Severity Index (PDSI) is < -4. Max T °C above 35 means the share of grid-days with maximum daily temperature greater than 35°C. Mean T °C in [9; 12) means the share of grid-days with mean temperature in the interval [9,12). (W) indicates population-weighted variables. The figure shows results only for groups that include the country.

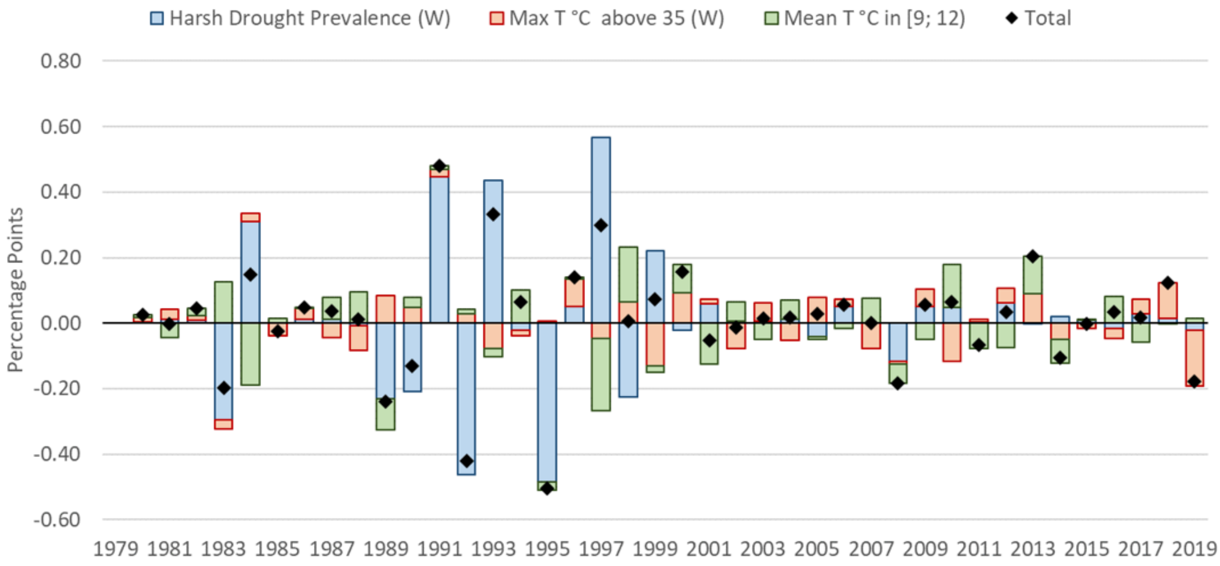
Hot (N=3,315): 1979-2019 average temperature > 22.8°C. Cold (N=3,338): 1979-2019 average temperature ≤ 22.8 °C. Agricultural (N=3,130): share of "Agriculture, forestry, and fishing, value added (% of GDP)" in 2002 is above median across countries. Non-Agricultural (N=3,062): countries that are not Agricultural. Agricultural Cold (N=1,334): agricultural and cold. Agricultural Hot (N=1,785): agricultural and hot. Rich (N=3,823): "High Income" and "Upper Middle Income" in WDI. Poor: "Low Income" and "Lower Middle Income" in WDI (N=2,727).

Source: Emanuele Massetti using data from Akyapi et al. (2025)

[93] This case study draws on Box 2 in 'The critical role of Ministries of Finance for investment in adaptation and the analytical principles and tools available' (op. cit.).

The empirical setup is not ideal for quantifying the effect of climate change on long-run growth rates but it provides insights into the effects of past weather shocks. For example, Figure 5.12 shows the aggregate effect of observed values of the three selected weather variables on historical GDP per capita. Weather shocks are defined as the change in weather variables from one period to the next (first differences) and tend to offset each other, leaving average economic growth largely unchanged, but they explain interannual fluctuations that can be sizeable. The analysis can also reveal changes in the vulnerability to weather shocks over time.

Figure 5.12. Impact of selected climate variables on GDP per capita (percentage points)



Notes: Impact on GDP per capita in a randomly selected country of variables selected in by Akyapi et al. (2025). Harsh Drought Prevalence means the share of grid-months during which the Palmer Drought Severity Index (PDSI) is < -4. Max T °C above 35 means the share of grid-days with maximum daily temperature greater than 35°C. Mean T °C in [9; 12) means share of grid-days with mean temperature in the interval [9,12). (W) indicates population-weighted variables. Black diamonds indicate the net impact of all variables.

Source: Emanuele Massetti, using data from Akyapi et al. (2025).

Analyzing current and future physical climate risks and impacts on the macroeconomy and public finances in Finland[94]

Some potential ecosystem-related economic risks for Finland have been analyzed using forest and agricultural models combined into a macroeconomic model (the regional, dynamic general equilibrium model: RegFinDyn). Current and future economic risk levels for selected sectors were assessed using the sector models and their results were fed into the macroeconomic model to obtain partial national and regional economic estimates. Based on the results, the cascading risks in Finland are expected to be larger than the damage from extreme weather events (Perrels et al., 2022). In forest ecosystems alone, the impacts of changing climate and disturbances may be substantial, and new modeling approaches have been developed to cover both carbon sequestration and biodiversity-related impacts for forests (Forsius et al., 2021; Honkaniemi et al., 2024).

The Finnish Prime Minister's Office has begun to conduct annual societal sustainability assessments to scope out research results and knowledge gaps in ecosystem-related risks to the Finnish economy and society in the short to medium term, alongside the various other sustainability challenges the country faces. In addition, with leadership by the Prime Minister's Office, Finland's new €50 million EU-funded LIFE Biodiversity project focuses on biodiversity policy coherence among various ministries, including the Ministry of Finance.

[94] This case study draws on 'Improving the inclusion of nature and ecosystem service impacts in assessments of the economic impacts of climate risk by Ministries of Finance and economic decision-makers: the experience of Finland' (op. cit.).

Identifying and addressing the largest climate resilience gaps in the UK[95]

In the United Kingdom, a hybrid approach was used to conduct England's Third Climate Change Risk Assessment (CCRA3). Carried out between 2017 and 2021, it adopted a bottom-up approach for individual risks and sectoral analysis to assess the economic costs of climate change, complemented with top-down economic modeling analysis (CGE) (HM Government, 2022).

The assessment found that many (but not all) early adaptation investments can deliver high value for money. The benefit–cost ratios typically range from 2:1 to 10:1—i.e., every £1 invested in adaptation could result in £2–10 in net economic benefits. This could be achieved, first, by building in climate resilience and including the costs within planned programs and investments where adaptation is a secondary objective, including in large-scale infrastructure; second, through targeted adaptation programs and investments where adaptation is the primary objective, such as increasing spending on coastal defenses to address sea level rise; and third, sitting between these, through investments where adaptation is one of several objectives, such as investing in peatland restoration which delivers multiple benefits, including enhanced climate resilience both on-site and off-site. These costs—and their benefits—can then be fed into macroeconomic and fiscal models.

This approach builds on recent studies that use CGE models that look at the effects of climate change and adaptation on GDP, welfare, and the public finances (Watkiss and Preinfalk, 2022). Such studies indicate that adaptation reduces the macroeconomic disruption of climate change.

Using Extreme Event Attribution to estimate the global economic impact of extreme weather events

Newman and Noy (2023) leveraged EEA studies and data on associated economic damages to arrive at an estimate of the global economic impact of extreme weather events that are attributable to climate change. Their results indicate climate change accounts for US$143 billion per year in costs from extreme events, 63% of which stems from the loss of human life.

The authors collated Fraction of Attributable Risk (FAR) estimates from studies with frequentist approaches to EEA and combined these with the socioeconomic costs caused by the underlying events. As the studies are not comprehensive, Newman and Noy applied the estimated impact of specific types of extreme events to the International Disaster Database (EM-DAT), to arrive at an estimate of the global cost from extreme weather events via extrapolation.

Particularly when performed at the regional level, such an extrapolation might need to be based on a very small number of data points, which is a clear limitation. Another limitation is that only the direct economic impacts of extreme weather events, such as destruction of capital, are considered. Further, indirect effects, such as decreased economic activity due to supply chain disruptions, are omitted but in reality the indirect costs can be substantial, especially for large-scale disasters, and hence the cost is underestimated using this method.

The authors also compared their bottom-up approach to assessing the costs of climate change with the top-down approach adopted in damage functions that often feature in IAMs. Such damage functions often define damages in proportion to GDP to be a polynomial function of the deviation of annual mean surface temperature from that of pre-industrial times. By relying on mean surface temperature, such damage functions do not explicitly capture changes in temperature extremes, i.e., changes to the distribution of realized temperatures (or that of extreme weather events more generally). The authors calculated that a 25% increase in economic damages to adjust for extreme events within the DICE model in 2013 accounts for an increase less than the cost of extreme weather events they calculate via EEA. Thus, they concluded that, depending on the damage function, IAMs underestimate the economic impact of extreme events, and that EEA can usefully contribute to this literature to improve estimates.

95 This case study draws on the HP4 Physical Risk and Adaptation Report. See also 'The analysis of climate impacts, adaptation costs, and adaptation benefits in the UK' (op. cit.) and Methodological recommendations for Ministries of Finance on climate change risk assessment and the enhancement of damage functions' (op. cit.).

5.4. Decision-making frameworks and other analytical tools—case studies

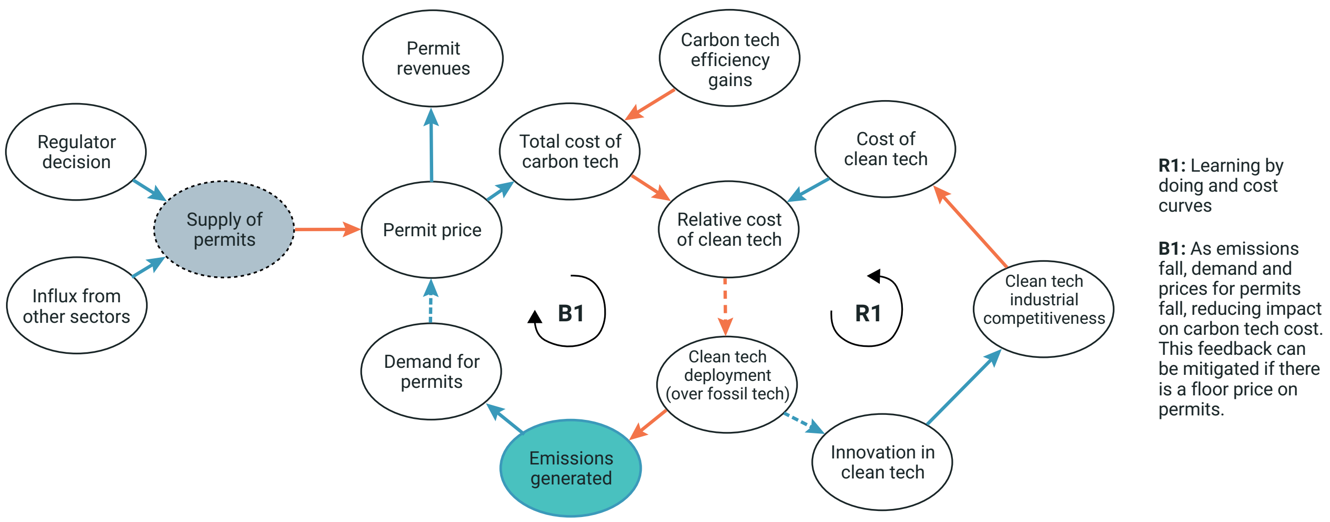
Using causal loop diagrams to analyze Chinese power sector reform[96]

Causal loop diagrams (CLDs) are a type of systems mapping focused on describing the key causal influences in a system. They are organized around feedback loops, which can dominate the behavior of a system. Researchers from the EEIST project based at Oxford University, University College London, World Resources Institute, Tsinghua University, Beijing Normal University, and the Energy Research Institute in China are currently using CLD to analyze reform of the Chinese power sector and to understand how many new policies, in different sectors, are interacting.

Figure 5.13 is an example CLD from this study. It describes how the supply of permits in an emissions trading scheme can introduce a balancing feedback loop (B1), undermining the reinforcing feedback loop (R1) of learning-by-doing in clean energy technology. It shows that induced innovation generates cost reductions in clean technologies but, without a tightening of the cap, also generates cost reductions in fossil technologies as fewer permits are demanded. This blunts the incentives to innovate which would otherwise further propagate the clean innovation dynamics of learning-by-doing, economies of scale and so on that make greenhouse gas mitigation cheaper.

Overall, Figure 5.13 shows that the emissions trading scheme supports the reinforcing feedback of learning-by-doing (R1), but also introduces a balancing feedback. As emissions drop, there is less demand for permits, which tends to reduce the effect of the carbon price on the costs of carbon technology (B1).

Figure 5.13. Causal loop diagram to show the impacts of the supply of permits in an emissions trading scheme



Notes: The blue arrows represent positive causal influences (i.e., factors moving in the same direction), and the red arrows represent negative influences (i.e., factors moving in opposite directions to one another). The dotted arrows represent less certain influences. The supply of permits is highlighted as a key policy lever, and emissions are highlighted as the key outcome.

Source: Barbrook-Johnson et al. (2023: 74)

[96] This case study draws on 'The value of using systems mapping to help Ministries of Finance understand the impacts of transformative climate policy' (op. cit.), and Barbrook-Johnson et al. (2023).

Using economic complexity analysis to identify green growth opportunities in South Africa[97]

Economic complexity analysis has been used in South Africa to identify opportunities for competitiveness in emerging supply-chains critical to the global low-carbon transition. The analysis compared the closeness of value chains for a range of clean technologies, as well as products throughout each of those value chains, with South Africa's areas of current and potential comparative advantage.[98] It was complemented with stakeholder consultations and qualitative research.

The analysis revealed strong low-carbon growth opportunities for South Africa. Opportunities to become competitive in products such as batteries, electric vehicles, and green hydrogen were considered to be grounded not only in plentiful natural resources of solar, wind, and minerals, but also in existing industrial capabilities in metals, electronics, machinery, and chemicals. For batteries, South Africa has existing comparative advantage in products across the supply chain, whereas for green hydrogen the country is competitive in some parts of the value chain but would need to invest significantly to become competitive in others—making green hydrogen a more challenging strategic bet (Hausmann et al., 2023). South Africa's Industrial Development Corporation, the national development finance institution owned by the government and key to implementing the country's industrial policy, used the analysis to inform its policy positions on the transition to EVs, and its engagement with the automotive sector.

The Treasury is now using this analytical approach to review and evaluate sector-specific industrial plans and policies, and to inform the next iteration of green growth strategy development. The Treasury is considering complementing this with strategic 'Foresight' studies to generate insights into emerging and likely trends.[99] Recognized challenges include: the method's focus on economic growth but not job creation or inequality reduction; the need for other tools to address constraints such as the high costs of capital; and the need for more coordinated policies across government departments to build competitive value chains.

Using Risk–Opportunity Analysis to promote offshore wind subsidies in the UK[100]

In the UK, subsidies for the first round of deployment of offshore wind were not strongly supported by cost–benefit analysis. It was criticized as being "among the most expensive ways of marginally reducing carbon emissions known to man" (*The Economist*, 2014). In 2015, offshore wind generated electricity at around four times the market price (Tovey, 2017; Jennings, 2020). Burning biomass was a cheaper way to reduce emissions (Department of Energy & Climate Change, 2013) but risk–opportunity analysis supported the case for investing in offshore wind rather than biomass. The data for onshore wind, a similar technology, suggested a good potential for cost reduction through learning-by-doing and economies of scale (see Way et al., 2022). Market analysis suggested offshore wind had better opportunities for job creation than biomass, while lifecycle assessments showed biomass had significant environmental risks.

Within a decade, the UK's targeted subsidies had driven down the cost of offshore wind power to below the market price of electricity. The sector now supports 32,000 jobs (The Crown Estate, 2024), and its long-term contracts for electricity generation are increasingly subsidy-negative (Jennings et al., 2020).

[97] This case study draws on 'Low-carbon innovation and industrial strategy: analytical tools and frameworks for Ministries of Finance', contribution from S-Curve Economics, University of Manchester, and University of Exter to the HP4 Compendium of Practice. The work described was undertaken with support from the Harvard Growth Lab.
[98] This differs from other approaches to economic complexity, which identify comparative advantage in individual green products, but not value chains (e.g., see Mealy and Teytelboym, 2022).
[99] See NACI Foresight reports: https://www.naci.org.za/index.php/foresight-reports/
[100] This case study draws on 'Risk–opportunity analysis: policy appraisal in contexts of structural change, uncertainty, and diverse interests' (op. cit.).

5.5. Ex-post case studies and evaluations

How government policies around the world accelerated innovation in solar PV[101]

Over the past decade, the transition to a decarbonized global economy has become much more feasible and affordable due to dramatic cost reductions in multiple technologies. In particular, the cost of solar PV has fallen by a factor of 10,000 over the past seven decades, and this should be seen as a consequence of strategic public investment by multiple governments.

Governments of five countries, the United States, Germany, China, Japan, and Australia, contributed to this outcome through different interventions at various points. The cost reductions over time were also facilitated by the free flow of ideas, people, machines, finance, and products. Barriers to these exchanges would have delayed innovation and thus cost reductions.

A summary of the actions taken are as follows (see Nemet, 2019 for further details):

- In 1957, the U.S. Navy purchased solar cells for the Vanguard II satellites.
- In the 1970s, the U.S. federal government contributed billions of dollars to R&D of solar power, and a public procurement program to help develop necessary human capital. This effort spawned the first commercial lines of solar PV cells.
- In 1994, the Japanese government launched a major rooftop solar subsidy program with a declining rebate schedule. This showcased substantial consumer demand for solar PV.
- In 2000, Germany established a feed-in tariff. This expanded the market for solar PV by a factor of 4. As a result, technology to automate and scale up production was developed.
- In the 2000s, a reform of the Chinese tax system supported mostly Australian-trained Chinese entrepreneurs in building supply chains and factories at the gigawatt scale. During the financial crisis, these capacities were sustained by low-cost loans from the Chinese MoF.
- In 2011, China adopted a feed-in tariff and, in addition to production, installation began at scale.

The technological characteristics of solar PV also helped enable the cost reductions. PV is modular, meaning it could be employed in various niche markets and be improved iteratively. As a result, successive markets could be tapped in line with the increasing scale of PV cells.

Access to up to date information on technology costs, explicit characterization of the adoption of small-scale end-use technologies, linkages across sectors of the economy, and a more realistic treatment of the potential for demand-side solutions (Creutzig et al., 2023) would support the integration of such cost-reduction processes into analytical tools and models.

Accelerating the development and adoption of new technologies[102]

Studies of past technology transitions have discovered patterns in their progress and identified the types of policies most likely to accelerate a transition in each of its early, middle, and late stages (Geels and Schot, 2007). The Multi-Level Perspective on transitions organizes this understanding into a conceptual framework, the policy implications of which can be summarized as follows:

- In the 'emergence' stage of the transition uncertainty is high and a variety of new technologies are developed and tested in small market niches until a dominant design emerges. Governments can accelerate this by supporting research, development and demonstration projects, and by using public procurement or targeted subsidies to establish niche markets for first deployment.

[101] This case study is based on 'How government actions have accelerated clean energy innovation: lessons for economic analysis and modeling by Ministries of Finance' (op. cit.).
[102] This case study is based on 'Policy packages for cost-effective transitions: learning from the past, simulating the future with the Future Technology Transformations models, and case studies from the Economics of Energy Innovation and System Transition project' (op. cit.).

- In the 'diffusion' stage the new technology spreads and begins competing with the incumbent technology system. Governments can accelerate diffusion with policies that provide the new technology with an advantage, including regulations, subsidies, taxes, and investments in infrastructure.
- In the 'reconfiguration' stage, as the new technology becomes dominant, economic systems and structures are adapted and reorganized around it. Governments can accelerate this by supporting the development of complementary technologies (which make the new core technology more useful), reforming markets, extending new infrastructure networks, and training workers.

In the early stages of the transition, policies that directly support the deployment of new technologies—such as targeted subsidies, public procurement, or concessional lending—tend to be particularly effective because they benefit from positive feedback loops in technology development and diffusion. These self-amplifying processes include learning-by-doing (the more something is produced, the higher the productivity), economies of scale (the more it is produced, the cheaper it gets), and the emergence of complementary technologies (the more it is used, the more complementary products to enhance performance are developed). Taxes on the incumbent technology do not necessarily benefit from these forms of positive feedback early in the transition, because they may simply incentivize the incumbent system to operate more efficiently. Further into the transition, it may be possible for taxes, subsidies or regulations to help the new technology cross a tipping point beyond which it becomes more attractive than the old technology to consumers, producers, and investors, and the transition continues with self-accelerating momentum as a result (Lenton et al., 2022).

Some of the most outstanding successes in low-carbon transitions experienced so far in terms of cutting costs and creating jobs can be seen as part of this pattern. For example, in Brazil, subsidies together with concessional finance drove the fastest expansion of onshore wind power of the large emerging economies, creating over 150,000 jobs (Drummond et al., 2021). In India, public procurement was central to cutting the cost of energy-efficient lighting by 85% in four years, and bringing electric lighting to many homes for the first time (Waghray and Mathur, 2021). These successes illustrate the effectiveness of targeted policies that create demand for clean technologies in the early stages of the transition, enabling their deployment, and driving innovation and cost reduction through positive feedback loops. A systematic review of academic studies on induced innovation in energy technologies and systems found strong evidence for this effect, as well as for carbon pricing playing a positive role, and suggested that rather than relying on any single policy instrument, governments should implement packages of policies crafted to overcome the multiple barriers to the transition in any given sector (Grubb et al., 2021).

In some of the fastest examples of low-carbon transitions, the effect of tipping points is visible. In the UK, for example, a tax that made coal power more expensive than gas power, alongside other policies driving rapid growth in renewable power, helped achieve power sector decarbonization roughly eight times faster than the global average over the decade 2010 to 2019 (see IEA, 2021a; Staffell et al., 2020). In Norway, a subsidy-and-tax combination that made EVs cheaper to buy than equivalent petrol cars was central to a policy package that drove the world's fastest transition in road transportation (Sharpe and Lenton, 2021).

6. Conclusion

This report has underscored the importance of equipping Ministries of Finance with the economic analysis and modeling tools they need to help address the multifaceted challenges posed by the need to accelerate green and resilient transitions.

MoFs face complex policy questions regarding the direct and indirect economic impacts of climate change and the policy implications of adaptation and the transition. To address these questions, MoFs need to assess the upfront investment needs, the scale of long-term economic benefits, the fiscal risks and opportunities of physical climate change and the transition, adaptation opportunities, and the best measures to support the transition in currently carbon-intensive sectors, among many other issues.

In providing a structured review of more than 20 analytical and modeling tools available to MoFs and their partners to help address the climate policy questions they face, and the wide range of use cases, this report has aimed to provide an overview of tools that are in use and emerging, and to indicate where the gaps remain. The aim has been to aid readers, including newcomers in MoFs, in making sense of an often difficult-to-navigate modeling landscape steeped in acronyms and technical detail, and practitioners to choose the right tools for the questions at hand.

The report shows that MoFs are increasingly adapting economic tools to inform responses to climate policy challenges—and that there is a substantial and expanding toolbox available. Many MoFs will find they can start from familiar foundations by enhancing workhorse economic models and decision-making frameworks such as cost–benefit and cost-effectiveness analysis. Some will be able to go further, introducing new tools or combining tools to develop tailored suites to help answer difficult climate policy questions. MoFs with limited capacity to analyze green and resilient transitions can take a pragmatic approach: building on the tools, data, and expertise they already have. In each case, it is important that MoFs understand the tools in detail so they can adopt those that meet their needs and circumstances, and, where desired, make informed decisions to expand existing or adopt new approaches. MoFs can start by identifying the most critical climate policy questions they face, explore the tools they have and that are otherwise available, and build analytical capabilities from there.

Many analytical tools, data sets, and user guides from institutions such as the IMF, World Bank, OECD, and UNEP, as well as academia and the research community, are publicly available or made available to MoFs by international organizations or via research partnerships.[103] That these tools, data, and guides are continually improved is greatly necessary, and the research community is constantly developing existing tools and methodologies to better reflect innovation, technological change, and extreme risk. Researchers also emphasize the importance of methods that help devise strategies that are robust in the face of uncertainty and the value of insights from qualitative methods such as systems mapping to help inform strategic policymaking. Continued expressions of demand for research from MoFs and engagement between policymakers and academia are needed to accelerate this process.

Summary of learning points

- **No single analytical tool can help MoFs address all the climate policy questions they face.** Instead, a combination of tools, continuous learning, and peer collaboration can help them effectively manage the transition to a green and resilient economy. There can be benefits to hybrid approaches and linking models for more comprehensive analysis.

[103] See Appendix A for links to models and model documentation and Appendix B for links to further resources, mainly data.

- **Conventional economic models and analytical tools used by MoFs can be adapted to incorporate climate factors.** Retrofitting models or adapting methodologies already in use can be a fruitful starting point for building analytical capabilities for many MoFs. New purpose-built tools for analyzing climate impacts and climate policy can be a useful complement or alternative approach, depending on national circumstances and needs.
- **It is important for MoFs to carefully select tools that best address the priority policy questions they face, considering the resources and time available.** Limitations of the analytical methods and data sources used, and the vulnerabilities they might create, including those made apparent through past performance, are important to keep in mind.
- **The field is fast-moving, with new insights, methods, data, and support becoming available to MoFs.** Through engagement with peers and partners in other government departments, scientists, investors, and academia MoFs can draw on expertise to support the integration of climate considerations into their analysis and decision-making processes.

Areas for improvement

The review of existing tools and their use in practice in this report highlights a range of areas in which tools for MoFs could be improved or enhanced. Many MoFs need a suite of tools that are better at:

- Assessing physical climate risks and adaptation options and integrating them into macroeconomic analysis.
- Capturing the scale and uncertainty of climate impacts and the transition.
- Analyzing the impacts of combinations of policy options to support the development of complementary climate policy packages.
- Assessing technology costs and their potential trajectories over time, especially for emerging green technologies—the potential evolution of technology costs and deployment possibilities are critical and drive results in many analytical tools.
- Assessing the opportunities to enhance competitiveness as part of the transition.
- Assessing the co-benefits and non-market impacts of the transition, including for integration into higher-level analytical tools.
- Integrating more detailed financial systems into analytical tools, including to help manage transition risks in the financial system and understand impacts on the macroeconomy.
- Assessing the various distributional consequences of the transition and specific climate policies, including to develop strategies to mitigate these impacts.

By leveraging the strengths of various analytical tools and fostering an environment of continuous engagement, MoFs can better navigate the complexities of climate-related economic policy and drive meaningful climate action.

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Appendix A: Further details of climate-enhanced macroeconomic and sectoral models

Model name	Principal institution/ lead developer	Partner institution/ developer	Model type	Geographical scope	Description	Documentation and further resources
GTEM (Global Trade and Environment Model)	Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES)		CGE	Global	A recursive dynamic general equilibrium model. Trade and investment link the regions, and a range of taxes and subsidies capture government policies. The model assumes multiple production technologies for three energy-intensive sectors: the electricity, transport, and iron and steel sectors.	Pant H (2007) *Overview of the Global Trade and Environment Model (GTEM)*. Australian Bureau of Agricultural and Resource Economics and Sciences: Department of Agriculture. Available at: https://daff.ent.sirsidynix.net.au/client/en_AU/ABARES/search/results?qu=GTEM&te=ASSET.
Finance Canada Climate CGE model	Canada—Department of Finance		CGE	Global	A CGE model with a nested production structure that allows substitution between energy types, energy efficiency improvements through substitution with capital inputs, and abatement to reduce process-based emissions.	N/A
IMACLIM-R	Centre international de recherche sur l'environnement et le développement (CIRED)		CGE	Global	A hybrid recursive general equilibrium model of the world economy that is split into 12 regions and 12 sectors (Sassi et al., 2007). The base year of the model is 2001 and it is solved in a yearly time step. It is built on the GTAP-6 database that provides, for the year 2001, a balanced Social Accounting Matrix (SAM) of the world economy, detailed in 87 regions and 57 sectors. A country version of the model also exists.	Sassi O, Crassous R, Hourcade JC, et al. (2010) IMACLIM-R: a modelling framework to simulate sustainable development pathways. *International Journal of Global Environmental Issues* 10(1/2): 5–24. Sánchez A (2021) IMACLIM R-Monde. Web page. Available at: https://www.centre-cired.fr/en/imaclim-r-monde/.
TERM (The Enormous Regional Model)	Centre of Policy Studies, Victoria University		CGE	Single country (multiple, including Australia and U.S.)	A bottom-up CGE model that treats each region as a separate economy. It is a useful tool for examining the regional impacts of shocks (especially supply-side shocks) that may be region-specific. It also has a particularly detailed treatment of transport costs and is naturally suited to simulating the effects of improving particular road or rail links.	Centre of Policy Studies Knowledgebase (n.d.) The TERM Model. Web page. Available at: https://www.copsmodels.com/term.htm.
GreenREFORM	Danish Research Institute for Economic Analysis and Modelling (DREAM)		CGE	Denmark	A dynamic CGE model that represents a small open economy (Denmark) and evaluates combined effects of economic and environmental policy within a unified framework. It has sectoral detail and incorporates forward looking behavior, overlapping generations, and frictions to achieve credible short-run dynamics.	Danish Research Institute for Economic Analysis and Modelling [DREAM] (n.d.) GreenREFORM publications. Web page. Available at: https://dreamgroup.dk/economic-models/greenreform/publications.
I3E (Ireland, Environment, Energy and Economy) model	Economic and Social Research Institute (ESRI)		CGE	Ireland	An intertemporal CGE model with multiple firms, one representative household group, multiple commodities, government, enterprises, and rest of the world accounts. It describes the Irish economy with sectoral detail and includes a detailed description of energy inputs and concomitant greenhouse gas emissions. It has been developed to investigate the economic and environmental impacts of climate policies in Ireland.	de Bruin KC and Yakut AM (2021) *Technical Documentation of the I3E Model, V4.0*. ESRI Survey and Statistical Report Series Number 109. The Economic and Social Research Institute [ESRI]. Available at: https://esri.ie/publications/technical-documentation-of-the-i3e-model-v40.

Model name	Principal institution/ lead developer	Partner institution/ developer	Model type	Geographical scope	Description	Documentation and further resources
JRC-GEM-E3	European Commission	National Technical University of Athens (NTUA/E3M-Lab) (leading partner), Katholieke Universiteit of Leuven (KUL), University of Manheim and the Centre for European Economic Research (ZEW), Ecole Centrale de Paris (ERASME)	CGE	Global (EU focus)	A multi-regional, multi-sectoral, recursive dynamic CGE model that provides details on the macro-economy and its interaction with the environment and the energy system. It can assess the macroeconomic effects of energy and climate policies and is often run toge ther with an ESM such as PRIMES, POTEnCIA, or POLES.	Capros P, Van Regemorter D, Paroussos L, et al. (2013) *GEM-E3 model documentation*. JRC Technical Reports Report EUR 26034 EN. European Commission Joint Research Centre: Institute for Prospective Technological Studies.
ICES (Inter-temporal Computable General Equilibrium System)	European Institute on Economics and the Environment (EIEE)		CGE	Europe (EU + UK)	A recursive dynamic multiregional CGE model to assess impacts of climate change on the economic system, evaluate costs of mitigation and adaptation policies, describe the key role of public sector for mitigation and adaptation policies, and draw future sustainability scenarios.	ICES (Inter-temporal Computable Equilibrium System). Web page. Available at: https://www.icesmodel.org/.
GTAP-E	Global Trade Analysis Project (GTAP)		CGE	Global	Incorporates energy substitution in the standard specification of the GTAP model, a global CGE model. Additionally, it incorporates carbon emissions from the combustion of fossil fuels and a mechanism to trade these emissions internationally. This extension of the GTAP model addresses the previously incomplete linkages between energy, economy, environment, and trade.	Burniaux J-M and Truong TP (2002) *GTAP-E: An Energy-Environmental Version of the GTAP Model.* GTAP Technical Paper No. 16. Global Trade Analysis Project, Purdue University. Available at: https://www.gtap.agecon.purdue.edu/uploads/resources/download/1203.pdf.
IMF-ENV	International Monetary Fund		CGE	Global	A recursive dynamic CGE model in which emissions of greenhouses gases and other air pollutants are linked to economic activities either with fixed coefficients, such as those for emissions from fuel combustion, or with emission intensities that decrease (nonlinearly) with carbon prices. It can assess both direct and indirect domestic structural changes and cross-border spillover effects of policies.	Château J, Rojas-Romagosa H, Thube S, et al. (2025) *IMF-ENV: Integrating Climate, Energy, and Trade Policies in a General Equilibrium Framework*. IMF Working Papers 25/77. International Monetary Fund. Available at: https://doi.org/10.5089/9798229005029.001.
IRENCGE-DF (Italian Regional and Environmental Computable General Equilibrium of Department of Finance)	Italy—Ministry of Finance	World Bank	CGE	Italy	A recursive dynamic CGE model for analyzing the impact of climate-related tax policies on macroeconomic indicators and their distributional effects. It is based on the World Bank's MANAGE model and uses a primarily neo-classical growth specification. The model has a detailed energy specification that allows capital/labor/energy substitution in production, intra-fuel energy substitution across all demand agents, and a multi-output multi-input production structure.	IRENCGE-DF Model Documentation (n.d.). Available at: https://www.finanze.gov.it/export/sites/finanze/.galleries/Documenti/Varie/Report-tecnico-D3_IRENCGEDF_Documentation_v6.pdf.

Model name	Principal institution/ lead developer	Partner institution/ developer	Model type	Geographical scope	Description	Documentation and further resources
DEPF CGE model	Morocco—Ministry of Economy and Finance	World Bank	CGE	Morocco	A CGE model for simulating the effects of different carbon tax scenarios. It is a static neoclassical model, with Walrasian general equilibrium and perfect competition, which considers the optimizing microeconomic behavior of economic agents. In this model, markets are balanced by flexible prices. The Economic agents are a representative household, companies, the government and the rest of the world.	N/A
Short-term climate scenarios	Network for Greening the Financial System (NGFS)		CGE, SFC, credit-risk	Global	The suite of five scenarios draws on a CGE model (GEM-E3), an SFC model (EIRIN), and climate credit risk model (CLIMACRED).	Network for Greening the Financial System (2025) *NGFS Short-Term Climate Scenarios Technical Documentation V1.0*. Available at: https://www.ngfs.net/en/publications-and-statistics/publications/ngfs-short-term-climate-scenarios-central-banks-and-supervisors.
ENV-Linkages model	Organisation for Economic Co-operation and Development (OECD)		CGE	Global	A global (recursive-) dynamic CGE model that links economic activity to environmental pressure, specifically to emissions of greenhouse gases. The links between economic activities and emissions are projected for several decades into the future and thus shed light on the impacts of environmental policies for the medium- and long-term future.	Château J, Dellink R and Lanzi E (2014) *An Overview of the OECD ENV-Linkages Model: Version 3*. 65, OECD Environment Working Papers. Available at: https://dx.doi.org/10.1787/5jz2qck2b2vd-en.
RegFinDyn (Regional model for Finland, Dynamic version)	Ruralia Institute, University of Helsinki		CGE	Finland, Sweden, EU	A dynamic CGE simulation model for studying the effects of changes in regional economic conditions.	Törmä H, Kujala S and Kinnunen J (2015) The employment and population impacts of the boom and bust of Talvivaara mine in the context of severe environmental accidents – A CGE evaluation. Resources Policy 46: 127–138.
ThreeME (Multi-sector Macroeconomic Model for the Evaluation of Environmental and Energy policy)	Sciences Po—French Economic Observatory (OFCE)	Multiple	CGE	Single country (global)	An open-source CGE model that differs from standard CGE models as it applies neo-Keynesian assumptions and is hybrid in the sense that it combines the top-down approach of CGE models with the bottom-up approach of energy models.	Reynès F, Callonnec G, Saussay A, et al. (2021) *ThreeME Version 3 Multi-sector Macroeconomic Model for the Evaluation of Environmental and Energy policy: A full description*. Available at: https://www.threeme.org/_files/ugd/e33ac5_0fb7e9f40b3e413f87bbc132822dc816.pdf. GitHub: https://github.com/ThreeME-org/ThreeME_V3-open

Model name	Principal institution/ lead developer	Partner institution/ developer	Model type	Geographical scope	Description	Documentation and further resources
EMEC (Environmental Medium-term Economic) model	Sweden—National Institute of Economic Research (NIER)		CGE	Sweden	A CGE model of the Swedish economy that enables analysis of the long-run impacts of several energy and environmental policies on the economy and emissions of several pollutants and how these policies can be designed in effective, cost-efficient and equitable ways.	Otto VM and von Below D (2023) *The Environmental Medium-Term Economic (EMEC) Model: Version 4.* Working Paper No. 158. National Institute of Economic Research. Available at: https://www.konj.se/media/fk5fankr/working-paper-156-the-environmental-medium-term-economic-emec-model.pdf.
Budget impact model	Switzerland—Federal Department of Finance	Ecoplan	CGE and ESM	Switzerland	A budget impact model that analyzes the long-term impact of achieving the Swiss net-zero target on public finances, based on ESMs and a CGE model.	Federal Department of Finance (2024) *2024 fiscal sustainability report for Switzerland: Ageing and net zero target.* April. Available at: https://backend.efd.admin.ch/fileservice/sdweb-docs-prod-efdadminch-files/files/2024/04/30/88a5c4fc-f3aa-4c85-91e1-1a10b037a570.pdf.
SATIM-GE (South African Times Model—General Equilibrium)	University of Cape Town		CGE and ESM	South Africa	A full energy sector model for South Africa that combines electricity and liquid fuels sectors on the supply side with industrial, transportation, and residential users on the demand side. A dynamic linking of this ESM with a macroeconomic general equilibrium model (the SAGE model) enables economic analysis of energy-system decisions and ensures that inputs to SATIM are based on economic forecasts rather than arbitrarily specified.	Arndt C, Davies R, Gabriel S, et al. (2016) A sequential approach to integrated energy modeling in South Africa. Applied Energy 161: 591–599. Merven B, Arndt C and Winkler H (2017) *The development of a linked modelling framework for analysing the socioeconomic impacts of energy and climate policies in South Africa.* WIDER Working Paper 2017/40. United Nations University World Institute for Development Economics Research. Available at: https://www.wider.unu.edu/node/65413.
UPGEM (University of Pretoria General Equilibrium Model)	University of Pretoria	Centre of Policy Studies, Victoria University	CGE	South Africa	A detailed CGE model of South Africa that can be run in either static or dynamic mode, and with sub-regional detail. The model has been developed over many years in collaboration with the Center of Policy Studies (CoPS) to provide additional detail on environmental aspects, among others.	Model theory is based on Centre of Policy Studies-style models. See *Centre of Policy Studies Knowledgebase* (n.d.) Economic Models at CoPS. Web page. Available at: https://www.copsmodels.com/models.htm.
ENVISAGE (Environmental Impact and Sustainability Applied General Equilibrium) model	World Bank	Multiple	CGE	Global	A global recursive dynamic equilibrium CGE model designed to assess the interactions between economies and the global environment. It is a relatively standard recursive dynamic multi-sector multi-region CGE model, complemented with an emissions and climate module that directly links economic activities to changes in global mean temperature.	Van Der Mensbrugghe D (2024) *The Environmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) Model, Version 10.4.* GTAP Technical Paper TP/24/xx. Center for Global Trade Analysis, Purdue University. Available at: https://mygeohub.org/groups/gtap/envisage-docs.

Model name	Principal institution/ lead developer	Partner institution/ developer	Model type	Geographical scope	Description	Documentation and further resources
MANAGE-WB (Mitigation, Adaptation, and New Technologies General Equilibrium at the World Bank)	World Bank	Multiple	CGE	Single country (covering 50 countries)	MANAGE-WB is a single-country recursive dynamic CGE model that can capture country- and sector-specific physical and transition risks associated with climate change. Integration with the Global Trade Analysis Project (GTAP) provides coverage for around 140 countries across 80 sectors and with specifics on power generation, greenhouse gas emissions, and land use. It stochastically assesses climate change damages for 15 damage vectors and is mindful of resource constraints.	Beyene LM, Britz W, Christensen M, et al. (2024) *MANAGE-WB The Mitigation, Adaptation and New Technologies Applied General Equilibrium Model of the World Bank: Model Documentation and User Guide*. Available at: https://thedocs.worldbank.org/en/doc/77351105a334213c64122e44c2efe523-0500072021/related/MANAGE-WB-Documentation.pdf.
EMuSe	Bundesbank		DSGE	Germany	An Environmental Multi-Sector dynamic general equilibrium model that is particularly suited to analyzing climate policy-driven adjustment processes, also in an international context. It features several production sectors that are interconnected via input-output linkages. Emissions occur as a by-product of production. The (economic) damage caused by environmental pollution can also be accounted for. The dynamic nature of the model enables an explicit representation of the transition from an initial to a new steady state. The benchmark model features a closed economy, and an open-economy extension with up to four regions is available.	Hinterlang N, Martin A, Röhe O, et al. (2023) *The Environmental Multi-Sector DSGE model EMuSe: A technical documentation*. Technical Paper. Deutsche Bundesbank Eurosystem. Available at: https://www.bundesbank.de/en/publications/reports/technical-papers/the-environmental-multi-sector-dsge-model-emuse-a-technical-documentation-914846.
NAWM (New Area-Wide Model)	European Central Bank (ECB)		DSGE	Euro area	A a version of the ECB's New Area-Wide Model (NAWM) augmented with a framework of disaggregated energy production and use, where intermediate-good firms and households demand an energy composite for production and consumption purposes. The energy composite is produced by an energy provider which aggregates "dirty" and "clean" energy inputs. These inputs are in turn produced from imported fossil resources, the use of which causes carbon emissions, and from domestic renewable resources.	Coenen G, Lozej M and Priftis R (2024) Macroeconomic effects of carbon transition policies: An assessment based on the ECB's New Area-Wide Model with a disaggregated energy sector. *European Economic Review* 167: 104798.
E-QUEST	European Commission		DSGE	European Union	A energy-extended DSGE model that is tailored to assess climate policy scenarios, based on the QUEST III model. It is micro-founded and fully forward-looking. The transmission mechanism of climate mitigation efforts is captured via three structural elements. First, via sectoral disaggregation, as "dirty," greenhouse gas emitting and "clean," non-polluting energy sources and usage are distinguished. Second, it accounts for cutting greenhouse gas emissions through carbon taxes or government-imposed emission restrictions. Third, it accounts for the exhaustible nature of fossil fuels, the primary sources of greenhouse gas emissions.	Varga J, Roeger W and in 't Veld J (2022) E-QUEST: A multisector dynamic general equilibrium model with energy and a model-based assessment to reach the EU climate targets. *Economic Modelling* 114: 105911.

Model name	Principal institution/ lead developer	Partner institution/ developer	Model type	Geographical scope	Description	Documentation and further resources
GMMET (Global Macroeconomic Model for the Energy Transition)	International Monetary Fund		DSGE	Global	A multi-sector, multi-region dynamic macroeconomic model aimed at mapping mitigation policies to emissions reduction and to macroeconomic and sectoral variables covering the real, external, fiscal, and monetary sectors of the economy.	Carton B, Evans C, Muir D, et al. (2023) *Getting to Know GMMET: The Global Macroeconomic Model for the Energy Transition*. IMF Working Papers 23/269. Washington, DC: International Monetary Fund. Available at: https://elibrary.imf.org/openurl?genre=journal&issn=1018-5941&volume=2023&issue=269&cid=542845-com-dsp-crossref.
Global Macro-Financial Model (GFM)	International Monetary Fund		DSGE	Global	A DSGE model of the world economy, disaggregated into forty national economies and developed to support multilaterally consistent macrofinancial policy, risk, and spillover analysis. It features a range of nominal and real rigidities, extensive macrofinancial linkages, and diverse spillover transmission channels.	Vitek F (2018) *The Global Macrofinancial Model*. IMF Working Paper 18/81. International Monetary Fund. Available at: https://www.imf.org/en/Publications/WP/Issues/2018/04/09/The-Global-Macrofinancial-Model-45790.
GEEM (General Equilibrium Environmental Model)	Italy—Ministry of Economy and Finance	University of Rome	DSGE	Italy	A large-scale dynamic general equilibrium model that can integrate a cap on pollutant emissions, an electricity sector, and fuel consumption to analyze climate-energy policies for the Italian economy. It embodies elements of the New Neoclassical Synthesis, for instance, by combining nominal rigidities in wages and prices with systematic intertemporal optimization and the rational expectations hypothesis. Greenhouse gas emissions and abatement activity depend on the type of environmental regime adopted, for instance, a cap on emissions or a carbon tax.	Annicchiarico B, Battles S, Di Dio F, et al. (2017) GHG mitigation schemes and energy policies: A model-based assessment for the Italian economy. *Economic Modelling* 61: 495–509.
EREMS (Estimated Rational Expectation Model for Spain)	University of Valencia	BBVA Research	DSGE	Spain	A DSGE model for a small open economy in a currency union, estimated with Bayesian methods, which incorporates a banking and a housing supply sector, consumers and entrepreneurs who accumulate debt, a rich structure of fiscal variables and monopolistic competition in products and labor markets.	Boscá JE, Doménech R, Ferri J, et al. (2020) Financial and fiscal shocks in the great recession and recovery of the Spanish economy. *European Economic Review* 127: 103469.
REMS (Rational Expectations Model for the Spanish Economy)	University of Valencia	BBVA Research	DSGE	Spain	A small open economy dynamic general equilibrium model in the vein of the New-Neoclassical-Keynesian synthesis models, with a strongly micro-founded system of equations. In the long run REMS behaves in accordance with the neoclassical growth model. In the short run, it incorporates nominal, real and financial frictions.	Boscá JE, Díaz A, Doménech R, et al. (2010) A rational expectations model for simulation and policy evaluation of the Spanish economy. *SERIEs* 1: 135–169.

Model name	Principal institution/ lead developer	Partner institution/ developer	Model type	Geographical scope	Description	Documentation and further resources
TIM (Treasury Industry Model)	Australia—Department of the Treasury		DGE	Australia	A multisector general equilibrium model of the Australian economy that incorporates forward looking agents that can respond rationally to policy and technological changes, a balanced growth path defined endogenously, and a model consistent welfare measure. It is used for industry policy analysis.	Carlton F, Gustafsson L, Hinson M, et al. (2023) *Modelling Industry Specific Policy with TIM: Treasury's multi-sector dynamic general equilibrium model of the Australian economy.* Treasury Working Papers 2023–03. The Australian Government the Treasury. Available at: https://treasury.gov.au/sites/default/files/2023-09/p2023-437296-tim.pdf. Model outline: Jaensh J (2022) The Treasury Industry Model. Available at: https://esacentral.org.au/365/images/JackJaensch.pdf.
DIGNAD (Debt, Investment, Growth, and Natural Disasters) model	International Monetary Fund		DGE	Single country	A dynamic two-sector small open economy model designed to simulate the impact of natural disasters and associated policy trade-offs. DIGNAD assumes the existence of two types of public capital: standard physical capital, which is vulnerable to natural disasters, and adaptation capital, which is more resilient. The government can access a variety of financing sources, including external concessional loans and international grants. The model captures key mechanisms and policy issues relevant for debt sustainability analysis, particularly the linkages between public adaptation investment, economic growth, and debt.	Aligishiev Z, Ruane C and Sultanov A (n.d.) *User Manual for the DIGNAD Toolkit*. Technical Notes and Manuals 2023/03. Washington, DC: International Monetary Fund. DIGNAD pages on IMF website: https://climatedata.imf.org/pages/dignad.
NiGEM (National Institute Global Econometric Model)	National Institute of Economic and Social Research (NIESR)		SEM	Global	A macroeconometric model used by policymakers and private sector organizations across the globe for economic forecasting, scenario building, and stress testing. Based on a broadly New Keynesian structure with many of the characteristics of DSGE models, individual country models are grounded in textbook macroeconomic foundations with features such as sticky prices, rational or model-consistent expectations, endogenous monetary policy based on a Taylor rule or other standard specifications, and long-run fiscal solvency. Key behavioural equations are econometrically estimated using historical data.	National Institute of Economic and Social Research (2023) National Institute Global Econometric Model (NiGEM). Available at: https://www.niesr.ac.uk/wp-content/uploads/2023/11/NiGEM-Manual-2023.pdf.
G-cubed model	Warwick McKibbin and Peter Wilcoxen		SEM	Global	A multi-country, multisector, intertemporal general equilibrium model that has been used to study a variety of policies in the areas of environmental regulation, tax reform, monetary and fiscal policy, and international trade. It is designed to bridge the gaps between three areas of research: econometric general equilibrium modeling, international trade theory, and modern macroeconomics. This type of model is closely related to DSGE models.	McKibbin WJ and Wilcoxen PJ (2013) A Global Approach to Energy and the Environment: The G-Cubed Model. In: *Handbook of Computable General Equilibrium Modeling*. Elsevier, pp. 995–1068. Available at: https://linkinghub.elsevier.com/retrieve/pii/B9780444595683000158.

Model name	Principal institution/ lead developer	Partner institution/ developer	Model type	Geographical scope	Description	Documentation and further resources
MFMod CC (Macro-Fiscal Model—Climate Change)	World Bank		SEM	Single country (~70 countries)	A family of country-level macro-structural models akin to models traditionally used by central banks and MoFs. Short-run dynamics are data-driven, with country-specific estimated parameters reflecting the actual behavior of the economy. The equilibrium or steady state conditions are derived to be consistent with economic theory. It includes greenhouse gas emissions, five types of economic damages, transition effects, co-benefits from mitigation, and an adaptation module.	Burns A, Campagne B, Jooste C, et al. (2019) *The World Bank Macro-Fiscal Model Technical Description*. Policy Research Working Paper 8965. Washington, DC: World Bank, Macroeconomics, Trade and Investment Global Practice. Available at: https://hdl.handle.net/10986/32217.
TIMES (The Integrated MARKAL-EFOM System)	Energy Technology Systems Analysis Program (IEA-ETSAP)		Sectoral—optimization	Global	A technology-rich, bottom-up model generator, which uses linear-programming to produce a least-cost energy system, optimized according to constraints, over medium to long-term time horizons. It combines a technical engineering approach and an economic approach to modeling energy and makes simultaneous decisions on equipment investment and operation, primary energy supply, and energy trade for each region. The model is suited to the analysis of energy-environmental policies, which can be represented in detail given the explicit representation of technologies and fuels in all sectors.	IEA-ETSAP (n.d.) *Full documentation of ETSAP-TIMES model*. Available at: https://github.com/etsap-TIMES/TIMES_Documentation. IEA-ETSAP (n.d.) *The Integrated MARKAL-EFOM System (TIMES)—a bottom-up optimization model for energy-environment systems.* GitHub. Available at: https://github.com/etsap-TIMES/TIMES_model.
GLOBIOM (Global Biosphere Management Model)	International Institute for Applied Systems Analysis (IIASA)		Sectoral—optimization	Global	A partial equilibrium model that represents the main land use sectors, including agriculture and forestry. The supply side of the model is built from the bottom (spatially explicit land cover, land use, management systems and economic cost information) to the top (regional commodity markets). This detailed structure allows a rich set of environmental and socio-economic parameters to be taken into account. Based on the structure of the global model, different regional model versions have been developed.	International Institute for Applied Systems Analysis (n.d.) *GLOBIOM documentation*. Available at: https://globiom.org/documentation.html. IBF-IIASA (2023) Global Biosphere Management Model (GLOBIOM) Documentation 2023—Version 1.0. Integrated Biospheres Futures, International Institute for Applied Systems Analysis (IBF-IIASA). Available at: https://pure.iiasa.ac.at/id/eprint/18996/.
MAgPIE (Model of Agricultural Production and its Impact on the Environment)	Potsdam Institute for Climate Impact Research (PIK)		Sectoral—optimization	Global	A global land use allocation model connected to the grid-based dynamic vegetation model LPJmL, with a spatial resolution of 0.5°x0.5°. It takes regional economic conditions such as demand for agricultural commodities, technological development, and production costs as well as spatially explicit data on potential crop yields, land and water constraints (from LPJmL) into account. Based on these, the model derives specific land use patterns, yields, and total costs of agricultural production for each grid cell. The objective function of the land use model is to minimize total cost of production for a given amount of regional food and bioenergy demand.	Dietrich JP, Bodirsky BL, Weindl I, et al. (2022) *MAgPIE—An Open Source land-use modeling framework—Version 4.6.0.* Available at: https://doi.org/10.5281/zenodo.1418752 GitHub: https://github.com/magpiemodel/magpie.

Model name	Principal institution/ lead developer	Partner institution/ developer	Model type	Geographical scope	Description	Documentation and further resources
POTEnCIA (Policy-Oriented Tool for Energy and Climate Change Impact Assessment)	European Commission		Sectoral—hybrid	Europe	An economic modeling tool designed to compare alternative pathways of the EU energy system and related CO_2 emissions until 2050, thereby quantifying the impacts of energy and climate policy options in a consistent and comprehensive manner. The model follows a hybrid partial equilibrium approach in that it combines behavioral decisions with (imperfect) optimization.	European Commission (n.d.) *POTEnCIA: the Policy oriented tool for energy and climate change impact assessment.* Web page. Available at: https://joint-research-centre.ec.europa.eu/scientific-tools-and-databases-0/potencia-policy-oriented-tool-energy-and-climate-change-impact-assessment_en. Mantzos L, Matei NA, Rózsai M, et al. (2017) POTEnCIA: A new EU-wide energy sector model. In: *2017 14th International Conference on the European Energy Market (EEM)*, 2017, pp. 1–5. Available at: https://ieeexplore.ieee.org/document/7982028.
FTT (Future Technology Transformations)—Household heating	Cambridge Econometrics		Sectoral—simulation	Global	A non-equilibrium, bottom-up model based on a simulation of technology diffusion in which individual heating technologies (e.g. gas boilers, heat pumps) compete for market shares of the total heat demand. The model does not minimize or maximize an objective function, such as system cost or intertemporal utility. Instead, it simulates the decision-making of households: under given behavioral assumptions and levels of heat demand, which heating technologies would they choose, and how fast can new technologies grow within the market?	Knobloch F, Pollitt H, Chewpreecha U, et al. (2019) Simulating the deep decarbonisation of residential heating for limiting global warming to 1.5 °C. *Energy Efficiency* 12: 521–550.
FTT (Future Technology Transformations)—Power	Cambridge Econometrics		Sectoral—simulation	Global	A representation of global power systems based on market competition, induced technological change, and natural resource use and depletion. It is part of a family of sectoral bottom-up models of technology designed for integration into the global E3ME.	Mercure J-F (2012) FTT:Power: A global model of the power sector with induced technological change and natural resource depletion. *Energy Policy* 48: 799–811. Mercure J-F, Pollitt H, Chewpreecha U, et al. (2014) The dynamics of technology diffusion and the impacts of climate policy instruments in the decarbonisation of the global electricity sector. *Energy Policy* 73: 686–700.
FTT (Future Technology Transformations)—Transport	Cambridge Econometrics		Sectoral—simulation	Global	An evolutionary technology diffusion simulation model for road transport technology with sufficiently realistic features of consumers and of existing technological trajectories for simulating the impact of detailed climate policies in private passenger road transport. It functions an as an IAM sub-component and has been integrated into the E3ME model.	Mercure J-F, Lam A, Billington S, et al. (2018) Integrated assessment modelling as a positive science: private passenger road transport policies to meet a climate target well below 2 ^{0}C. *Climatic Change* 151: 109–129.

Model name	Principal institution/ lead developer	Partner institution/ developer	Model type	Geographical scope	Description	Documentation and further resources
BUEGO (Bottom-Up Geological and Economic Oil Field Model)	Christophe McGlade		Sectoral—simulation	Global	A bottom-up, medium-term model of the behavior of oil production companies choosing to develop projects based on required demand and each project's net present value. It contains historical data from 1992–2009 and models the period 2010–2035. It iteratively increases the oil price in each year to ensure there is sufficient new capacity coming on-line from projects with positive net present value to satisfy the demand levels provided by TIAM-UCL. An endogenously generated yearly average oil price is taken to be the minimum oil price necessary to bring on the marginal project to meet global demand in a given year.	McGlade C and Ekins P (2014) Unburnable oil: An examination of oil resource utilisation in a decarbonised energy system. *Energy Policy* 64: 102–112. McGlade CE (2013) *Uncertainties in the outlook for oil and gas*. UCL Energy Institute University College London. Available at: https://discovery.ucl.ac.uk/id/eprint/1418473/.
GAPTAP (Global Gas Production, Trade, and Annual Pricing Model)	Daniel Joseph Welsby		Sectoral—simulation	Global	A field-level simulation model which balances natural gas supply and demand for each year of the modeling horizon (2015–2035). The demand for natural gas is taken from the TIAM-UCL ESM. There are three key modules which sequentially bring regional supply and demand into equilibrium using market clearing algorithms: a long-term contract module, a domestic production module, and a final trade module where spot suppliers compete against residual volumes of contracted gas and each other.	Welsby DJ (2022) *Modelling uncertainty in global natural gas resources and markets*. UCL Institute for Sustainable Resources University College London. Available at: https://discovery.ucl.ac.uk/id/eprint/10141694/.
POLES (Prospective Outlook on Long-term Energy Systems)	European Commission		Sectoral—simulation	Global (EU focus)	An in-house tool of the European Commission for global and long-term analysis of greenhouse gas mitigation policies and evolution of energy markets. It simulates technology dynamics and follows the discrete choice modeling paradigm in the decision-making process. It includes a comprehensive description of the energy system and related greenhouse gas emissions for a large set of significant economies and residual regions, covering the world and including international bunkers. Through linkage with specialized tools, it also provides a full coverage of emissions, including from land use and agriculture, as well as of air pollutant emissions.	Keramidas K, Kitous A, Després J, et al. (2017) *POLES-JRC model documentation*. JRC Technical Reports, EUR 28728 EN. European Commission Joint Research Centre. Available at: https://data.europa.eu/doi/10.2760/225347.
SiSePuede (SImulation of SEctoral Pathways and Uncertainty Exploration for DEcarbonization)	Inter-American Development Bank (IDB)—open source		Sectoral—simulation	Single country (global)	A bottom-up partial equilibrium model with sector detail. Rather than using an abatement cost curve, the model links emissions to technical choices. Benefits associated with emissions reductions are systematically quantified. Using the model involves, first, translating emission reduction goals into concrete sector pathways, for which the development benefits also need to be quantified. Then, the costs and benefits of the transition are analyzed by translating the development benefits into economic terms, such as GDP, labor, or trade balances via rules of thumb and simple coefficients. The model can help explore uncertainty by running different development pathways under a wide range of future conditions.	Kalra N, Molina-Pérez E, Syme J, et al. (2023) *The Benefits and Costs of Reaching Net Zero Emissions in Latin America and the Caribbean*. Inter-American Development Bank. Available at: https://publications.iadb.org/en/benefits-and-costs-reaching-net-zero-emissions-latin-america-and-caribbean. sisepuede (2025) *Jupyter Notebook, Python*. GitHub. Available at: https://github.com/jcsyme/sisepuede.

Model name	Principal institution/ lead developer	Partner institution/ developer	Model type	Geographical scope	Description	Documentation and further resources
CP+ (Carbon Pricing Plus) Model	Universidad de Los Andes	Environment for Development (EfD), Centro de Estudios Manuel Ramirez (CEMR), Environmental Defence Fund (EDF)	Sectoral	Colombia	A user-friendly, excel-based model the brings regulated (“carbon pricing”) and unregulated (“plus”) emissions under one umbrella. Using estimated Marginal Abatement Cost (MAC) curves for the regulated sectors (energy and industry) and the unregulated sector (forestry) in Colombia, the model considers scenarios where reduced deforestation may be funded by three different sources: the national budget, a national ETS coupled with a high-intensity carbon forest offset mechanism, and international sources of funding. The analysis is carried out for 7 years, 2024–2030.	N/A
PRIMES (Price-Induced Market Equilibrium System)	European Commission		ESM	Europe	Provides detailed projections of energy demand, supply, prices and investment, covering the entire energy system including emissions for individual European countries and for Europe-wide trade of energy commodities. It combines behavioral modeling following a microeconomic foundation with engineering and system aspects, covering all sectors and markets at a high level of detail. Prices balance demand and supply simultaneously in several markets for energy and emissions. It can integrate multiple policy targets via shadow prices associated with policy constraints.	E3-Modelling (2018) *PRIMES Model Version 2018: Detailed model description*. Available at: https://e3modelling.com/wp-content/uploads/2018/10/The-PRIMES-MODEL-2018.pdf. European Commission Joint Research Center (JRC) (2024) *Model PRIMES: Price-Induced Market Equilibrium System*. Web page. Available at: https://web.jrc.ec.europa.eu/policy-model-inventory/explore/models/model-primes/.
METIS (Markets and Energy Technologies Integrated Software)	European Commission	Artelys, Tractebel, Fraunhofer	ESM	Europe	An energy system modeling software to assess the short-term operation of energy systems across the EU and neighboring countries that helps inform evidence-based energy policy making in the EU. It covers the European electricity, gas, heat, and hydrogen sectors, andenables hour-by-hour simulations of Europe’s energy systems for up to one year, taking into account uncertainties such as weather variations. The model can be used, for example, to analyze the flexibility requirements of renewable energy solutions.	European Commission (n.d.) *METIS*. Web page. Available at: https://energy.ec.europa.eu/data-and-analysis/energy-modelling/metis_en.

Model name	Principal institution/ lead developer	Partner institution/ developer	Model type	Geographical scope	Description	Documentation and further resources
OSeMOSYS (Open Source energy MOdelling SYStem)	N/A—open source		ESM	Single country (global)	A bottom-up energy modeling system initially developed for long-run integrated assessment and energy planning. It can operate at various spatial scales and focus on detailed power representations or multi-resource (material, financial, all energy) systems.	Howells M, Rogner H, Strachan N, et al. (2011) OSeMOSYS: The Open Source Energy Modeling System. *Energy Policy* 39: 5850–5870. OSeMOSYS (n.d.) Web page. Available at: http://www.osemosys.org/. OSeMOSYS (2025) GitHub. Available at: https://github.com/OSeMOSYS/OSeMOSYS. EPER Lab (2021) OSeMOSYS-CR-v2. Web page. Available at: https://osemosys-cr-v2.readthedocs.io/en/latest/index.html. EPER Lab (2021) osemosys-cr-v2. Python. GitHub. Available at: https://github.com/EPERLab/osemosys-cr-v2.
LEAP (Low Emissions Analysis Platform)	Stockholm Environment Institute		ESM	Single country (global)	An integrated, scenario-based modeling tool that can be used to track energy consumption, production, and resource extraction in all sectors of an economy. It is not a model of a particular energy system, but rather a tool that can be used to create models of different energy systems, where each requires its own unique data structures. It supports a wide range of different modeling methodologies: on the demand side these range from bottom-up, end-use accounting techniques to top-down macroeconomic modeling.	Stockholm Environment Institute (n.d.) *LEAP: Introduction*. Web page. Available at: https://leap.sei.org/default.asp?action=introduction.
TIAM-UCL (TIMES Integrated Assessment Model)	University College London		ESM	Global	An energy-economy model of the global energy system built in the TIMES framework, which uses an optimization approach to explore cost-optimal systems. The representation of the global energy system includes primary energy sources from production through to their conversion, their transport and distribution, and their eventual use to meet energy demands across a range of economic sectors. Using a scenario-based approach, the evolution of the system to meet future energy service demands can be simulated, driven by the least-cost objective.	Pye S, Butnar I, Cronin J, et al. (2020) *The TIAM-UCL Model (Version 4.1.1) Documentation*. Available at: https://www.ucl.ac.uk/energy-models/sites/energy_models/files/tiam-ucl-manual.pdf.
CPAT (Carbon Policy Assessment Tool)	World Bank and International Monetary Fund		ESM	Single country (global)	A spreadsheet-based model comprised of four modules: a mitigation module, which is a reduced-form macro-energy model, and a distribution, air pollution, and road transport module. It enables the rapid quantification of the impacts of climate mitigation policies, on factors such as energy demand, prices, emissions, revenues, welfare, GDP, households, industries, local air pollution, and health, among others.	CPAT Team (2024) *CPAT Documentation*. Available at: https://cpmodel.github.io/cpat_public/CPAT-Documentation.pdf. cpat_public (2025) R. *GitHub: Climate Policy Assessment Community of Models*. Available at: https://github.com/cpmodel/cpat_public.

Model name	Principal institution/ lead developer	Partner institution/ developer	Model type	Geographical scope	Description	Documentation and further resources
WITCH (World Induced Technical Change Hybrid)	European Institute on Economics and the Environment (EIEE)		Process-based IAM	Global	An IAM designed to generate optimal long-term (2005-2100) mitigation and adaptation strategies as a response to climate damage or an external constraint on emissions, concentrations, or temperature. The economy is modeled through an inter-temporal optimal growth model which captures long-term economic growth dynamics. A compact representation of the energy sector is fully integrated (hard linked) with the rest of the economy so that energy investments and resources are chosen optimally, together with the other macroeconomic variables. Land use mitigation options are available through a soft link with a land use and forestry model (GLOBIOM). A climate model (MAGICC) is used to compute the future climate. Climate change impacts economic output through a damage function, depending also on the rate of investments in adaptation..	The WITCH team (2017) *WITCH documentation. RFF-CMCC-EIEE European Institute on Economics and the Environment.* Available at: https://doc.witchmodel.org/witch_documentation.pdf. Drouet L, Emmerling J, Aleluia Reis L, et al. (2021) *The WITCH integrated assessment model. GAMS. GitHub*. Available at: https://github.com/witch-team/witchmodel.
MIMPAS (Integrated macroeconomic model for projection and simulation analysis)	Morocco—Ministry of Economy and Finance		Process-based IAM	Morocco	This model is paired with a regionalized agricultural model to simulate the agricultural production accounts and the wider macroeconomic effects of climate hazards.	N/A
GLUCOSE (Global Least-cost User-friendly CLEWs Open-Source Exploratory)	N/A—open source	KTH Royal Institute of Technology	Process-based IAM	Global	A highly aggregated global IAM that enables the exploration of policy measures on the future development of the integrated resource system. Thanks to its relatively simple structure, it requires few computational resources, enabling the generation of many scenarios or quick preliminary investigations. It is targeted towards education and training purposes by a range of interested parties, such as students, stakeholders, and decision-makers, to explore possible future pathways towards the sustainable management of global resources.	Beltramo A, Ramos EP, Taliotis C, et al. (2021) The Global Least-cost user-friendly CLEWs Open-Source Exploratory model. *Environmental Modelling & Software* 143: 105091. KTH division of Energy Systems (2021) *Global Least-cost User-friendly CLEWs Open Source Exploratory model*. GitHub. Available at: https://github.com/KTH-dESA/GLUCOSE.
GCAM (Global Change Analysis Model)	Pacific Northwest National Laboratory (PNNL)		Process-based IAM	Global	A dynamic-recursive model with technology-rich representations of the economy, energy sector, land use, and water linked to a climate model that can be used to explore climate change mitigation policies including carbon taxes, carbon trading, regulations, and accelerated deployment of energy technology.	Joint Global Change Research Institute (2025) *GCAM Documentation.* Web page. Available at: https://zenodo.org/doi/10.5281/zenodo.15581183. Joint Global Change Research Institute (2025) *GCAM -The Global Change Analysis Model*. GitHub. Available at: https://github.com/JGCRI/gcam-core.

Model name	Principal institution/ lead developer	Partner institution/ developer	Model type	Geographical scope	Description	Documentation and further resources
REMIND (REgional Model of Investment and Development)	Potsdam Institute for Climate Impact Research (PIK)		Process-based IAM	Global	An energy-economy general equilibrium model that links a macroeconomic growth model with a bottom-up engineering-based ESM. It differentiates various energy carriers and technologies and represents the dynamics of economic growth and international trade. Its goal is to find the optimal mix of investments in the economy and the energy sectors of each model region given a set of population, technology, policy, and climate constraints. It also accounts for regional trade characteristics on goods, energy fuels, and emissions allowances.	Potsdam Institute for Climate Impact Research (n.d.) *REMIND*. Web page. Available at: https://www.pik-potsdam.de/en/institute/departments/transformation-pathways/models/remind. Luderer G, Bauer N, Baumstark L, et al. (2023) *REMIND—REgional Model of INvestments and Development—Version 3.2.0*. Web page. Available at: https://rse.pik-potsdam.de/doc/remind/3.2.0/. Luderer G, Bauer N, Baumstark L, et al. (2025) *REMIND—REgional Model of INvestments and Development. GAMS*. GitHub. Available at: https://github.com/remindmodel/remind.
PAGE-ICE (Policy Analysis of Greenhouse Effect—Ice, Climate, Economics)	Dmitry Yumashev	Chris Hope	Cost–benefit IAM	Global	A cost–benefit IAM that includes dynamic emulators of complex physical models to explore non-linear transitions in the Arctic feedback loops and their subsequent impacts on the global climate and economy under the Paris Agreement scenarios. The climatic impacts focus on changes in the global mean surface temperature (GMST) and the economic impacts focus on the net present value (NPV) of the total cost associated with future climate change.	Yumashev D, Hope C, Schaefer K, et al. (2019) Climate policy implications of nonlinear decline of Arctic land permafrost and other cryosphere elements. *Nature Communications* 10: 1900. Yumashev D (2019) *PAGE-ICE IAM, v6.22: Technical Description*. The Pentland Centre for Sustainability in Business, Lancaster University. Available at: https://github.com/openmodels/PAGE-ICE/blob/master/PAGE-ICE%20v6.22%20Technical%20Description%20-%20v%2024%20Apr%202019.pdf?raw=true. GitHub Open Modelling Group (2025) *The PAGE-ICE Integrated Assessment Model, including both Excel and Mimi versions.Julia.* GitHub. Available at: https://github.com/openmodels/PAGE-ICE.

Model name	Principal institution/ lead developer	Partner institution/ developer	Model type	Geographical scope	Description	Documentation and further resources
DICE (Dynamic Integrated model of Climate and the Economy)	William Nordhaus	Lint Barrage, Paul Sztorc	Cost–benefit IAM	Global	An internally consistent framework based on a standard Ramsey growth model for analyzing the interplays between the macroeconomy, greenhouse gas emissions, climate policies, and climate change. Key elements include portable modules and quantifications for climate change damage functions, dynamic estimates of aggregate emissions reduction costs, a simplified carbon cycle-climate system representation, dynamic social cost of carbon estimates, and a flexible discounting module.	Nordhaus W (2024) *DICE 2023: Introduction and User's Manual*. Available at: https://yale.app.box.com/s/whlqcr7gtzdm4nxnrfhvap2hlzebuvvm/file/1539632845931. Nordhaus W (2024) *DICE Folders*. Web page. Available at: https://yale.app.box.com/s/whlqcr7gtzdm4nxnrfhvap2hlzebuvvm/folder/196571686525.
e3 model	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)	Multiple	IO	Single country (Kazakhstan, Georgia, Mongolia)	A macroeconometric IO model covering the economic structure and its main connections to the environment, i.e., the use of energy resources and greenhouse gas emissions. It enables assessing the impact of transition pathways on the whole economy and individual sectors.	Großmann A and Hohmann F (2025) *E3.KZ Model Handbook: Update 2025.* Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. Available at: https://www.adaptationcommunity.net/wp-content/uploads/2025/06/2025-e3kz-model-handbook.pdf. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH (2003) *Handbook for the e3 Prototype Model in Mongolia*. Available at: https://www.giz.de/en/downloads/giz2023-en-handbook-e3-prototype-model.pdf.
CPIC (Carbon Pricing Incidence Calculator)	Mercator Research Institute on Global Commons and Climate Change (MCC)		IO—multi-regional	Single country (global)	An interactive web tool which allows to explore the vertical and horizontal distributional consequences of carbon pricing and various compensation measures for currently 88 countries. The tool calculates the additional costs to households after a carbon price is introduced, i.e. the carbon pricing incidence. It is designed to provide insights for policy dialogue on design and implementation of carbon pricing schemes.	Steckel J, Missbach L and Schiefer T (2023) *The global Carbon Pricing Incidence Calculator (CPIC)*. Available at: http://www.cpic-global.net/.
MINDSET	World Bank		IO—multi-regional	Global	A macroeconometric input-output model that assesses impacts of climate change, adaptation measures, and mitigation strategies with high sectoral and regional granularity. The main transmission mechanism translates climate policies into price and demand changes and simulates the response of the economy to different climate policy scenarios.	Lehr U and Pollitt H (2024) *Heading Towards 1.5oC – Impacts on Labor Demand in Selected Countries.* Jobs Working Paper Issue No. 79. Washington, DC: World Bank. Available at: http://documents.worldbank.org/curated/en/099149303072417145.

Model name	Principal institution/ lead developer	Partner institution/ developer	Model type	Geographical scope	Description	Documentation and further resources
E3ME	Cambridge Econometrics		Demand-led	Global	A macroeconomic model that integrates a range of social and environmental processes. Its structure is based on systems of national accounts with linkages to energy demand and environmental emissions. It does not assume optimizing behavior and full utilization of resources, depicts the labor market in detail, with voluntary and involuntary unemployment, and depicts the financial sector with endogenous money. Integrated FTT models provide a representation of technology diffusion.	Dwesar I, Kőműves Z, McGovern M, et al. (2022) *E3ME Model Manual*. Cambridge Econometrics. Available at: https://www.camecon.com/hubfs/E3MEManual2022-1.pdf.
GEMMES (General Monetary and Multisectoral Macrodynamics for the Ecological Shift)	Agence Française de Développement (AFD)		Demand-led—SFC	Global, Europe, and single country (multiple)	An SFC model that combines the impact of global warming and the increased scarcity of natural (energy and mineral) resources with the dynamics of capital, private and public debts, and under-employment. It also takes into consideration the way in which the reduction of inequalities facilitates the resilience of a national or regional economy.	N/A
EIRIN model	EDHEC-Risk Climate Impact Institute		Demand-led—SFC	Single country (multiple)	An SFC model with heterogeneous, interacting agents of the real economy and finance. Each agent is represented by their balance sheet entries and is endowed with behavioral rules (e.g., regarding investment and consumption decisions) and adaptive expectations.	Monasterolo I and Raberto M (2018) The EIRIN Flow-of-funds Behavioural Model of Green Fiscal Policies and Green Sovereign Bonds. *Ecological Economics* 144: 228–243.
DEFINE (Dynamic Ecosystem-FINance-Economy) model	SOAS University of London		Demand-led—SFC	Global	A global ecological SFC model that analyzes the interactions between the ecosystem, the financial system, and the macroeconomy. It explicitly incorporates the laws of thermodynamics, the impact of carbon emissions on climate change, the implications of climate damages, the waste generation process, the endogeneity of money, and the impact of finance on economic activity. It produces various scenarios for the future of the ecosystem and the global economy. It is also used to evaluate the long run effects of various types of environmental policies and strategies, paying particular attention to the role of finance.	Dafermos Y and Nikolaidi M (2022) *The Dynamic Ecosystem-FINance-Economy (DEFINE) model: Manual, Version 1.1*. Available at: https://define-model.org/wp-content/uploads/2022/10/define-1.1-manual-aug-22.pdf.
FSMAT (Financial Sector Mitigation and Adaptation Tool)	World Bank and Agence Française de Développement (AFD)		Demand-led—SFC	Single country (multiple)	An empirical stock-flow-consistent (SFC) disequilibrium model developed to explore the macro-financial and environmental implications of different financing strategies and broader green financial sector interventions of the low-carbon and resilient transition at the country level. It builds on the GEMMES model and extends it by (i) incorporating a database that constructs social accounting matrices and sectoral balance sheets for over 100 countries, and (ii) enhancing the representation of low-carbon transition investments and the multiple financing strategies, instruments, and policies that can support the funding of these investments.	N/A

Model name	Principal institution/ lead developer	Partner institution/ developer	Model type	Geographical scope	Description	Documentation and further resources
C-ROADS (Climate-Rapid Overview and Decision Support)	Climate Interactive, Ventana Systems, UML Climate Change Initiative, and MIT Sloan		SD	Global	A climate simulation tool for understanding how global climate goals can be achieved through national and regional commitments. It is a globally aggregated model of climate systems linked to regional sectors of emissions and land use. The level of aggregation and several simplifying assumptions allow the model to return results in seconds and be accessible to policymakers and general audiences. It complements more disaggregated models addressing similar questions, such as IAMs or general circulation climate models, which are used for calibrating results.	Siegel LS, Campbell C, Fiddaman T, et al. (2025) *C-ROADS Technical Reference.* Available at: https://docs.climateinteractive.org/projects/c-roads-reference-guide/en/latest/ref-guide.pdf.
En-ROADS (Energy-Rapid Overview and Decision-Support)	Climate Interactive, Ventana Systems, UML Climate Change Initiative, and MIT Sloan		SD	Global	A fast climate solutions scenario tool for understanding how global climate goals can be achieved through changes in energy, land use, consumption, agriculture, and other policies. The simulator focuses on how changes in global GDP, energy efficiency, technological innovation, and carbon price influence carbon emissions, global temperature, and other factors. It is designed to provide a synthesis of the best available science on climate solutions to enable people to explore the long-term climate impacts of global policy and investment decisions in policy workshops and roleplaying games.	Siegel LS, Campbell C, Chikofsky J, et al. (2025) *En-ROADS Technical Reference.* Available at: https://docs.climateinteractive.org/projects/en-roads-reference-guide/en/latest/ref-guide.pdf. Chikofsky J, Johnston E, Jones A, et al. (2025) *En-ROADS User Guide.* Available at: https://docs.climateinteractive.org/projects/en-roads/en/latest/en-roads-user-guide.pdf.
EPS (Energy Policy Simulator)	Energy Innovation LLC	Multiple	SD	Single country (multiple)	An open-source SD model that assesses the effects of numerous energy and environmental policies on a variety of metrics, such as pollutant emissions, usage of various fuels, and lives saved from reduced particulate emissions. It is designed to operate at a national scale, but versions for states or provinces and cities have also been created. It includes five key sectors: transportation, electricity supply, buildings, industry (including agriculture), and land use/ forestry, each with various variables and policies It does not construct a BAU scenario, and instead uses an external BAU scenario as input. This scenario is then modified according to policy settings chosen by the user, with some exceptions in the transportation and electricity sectors.	Energy Policy Simulator Documentation (n.d.) *Energy Innovation LLC*. Web page. Available at: https://docs.energypolicy.solutions/.
IGEM (Integrated Green Economy Modelling) framework	Partnership for Action on Green Economy (PAGE)	United Nations agencies: UNEP, UNDP, ILO, UNIDO, UNITAR	SD, CGE, IO	Single country (global)	A methodology to integrate system dynamics and general equilibrium models with an input-output social accounting matrix, to enable combining the strengths of different modeling approaches.	PAGE (2017) *The Integrated Green Economy Modelling Framework.* Technical Document. Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/21863/Green_Economy_Modelling_Framework.pdf?sequence=1&amp%3BisAllowed=.

Model name	Principal institution/ lead developer	Partner institution/ developer	Model type	Geographical scope	Description	Documentation and further resources
EUROGREEN	University of Pisa		SD	France	An SD, ecological macroeconomic model that simulates policies and scenarios for low-carbon transition with social equity based on initial values and parameters of the French economy (2014–2050). It assesses the direct and indirect consequences of policy interventions on income distribution, unemployment, economic growth, energy demand, greenhouse gas emissions, and the government budget.	D'Alessandro S, Cieplinski A, Distefano T, et al. (2020) Feasible alternatives to green growth. *Nature Sustainability* 3: 329–335. D'Alessandro S (n.d.) *Eurogreen Model.* Web page. Available at: https://people.unipi.it/simone_dalessandro/eurogreen-model/.
Green Economy Model (GEM)	World Resources Institute (WRI)	KnowlEdge Srl	SD	Single country (multiple)	Estimates the impacts of potentially simultaneous and reinforcing covariate shocks such as external economic downturns, natural disasters, and layoffs on household consumption and welfare, and provides estimates of 'socioeconomic resilience'.	Bassi AM, Garrido L, Harsono A, et al. (2024) *Informing National Climate Action with the Green Economy Model: A Technical Description of the Structures and Processes.* Technical Note. Washington, DC: World Resources Institute. Available at: https://doi.org/10.46830/writn.21.00051.
DiruptSupplyChain	International Institute for Applied Systems Analysis (IIASA)	World Bank	ABM	Single country	A spatial ABM that quantifies a disaster's indirect impacts by assessing the economic loss related to the perturbations of supply chains. It can be used to (1) evaluate the impact of a disaster, (2) run stress tests on the transport network to identify critical links, and (3) assess resilience-enhancing measures.	Colon C, Hallegatte S and Rozenberg J (2021) Criticality analysis of a country's transport network via an agent-based supply chain model. *Nature Sustainability* 4: 209–215. Colon C (2025) DisruptSC: Spatial Agent-Based Model for Supply Chain Disruption Analysis. Available at: https://github.com/ccolon/disrupt-sc.

Appendix B: Further resources

Topic	Type of resource	Institution/lead developer	Name	Link
Adaptation	Data	Coalition for Disaster Resilient Infrastructure	Global Infrastructure Resilience Index (GIRI)	https://giri.unepgrid.ch/facts-figures/multi-hazards
	Initiative	World Resources Institute (WRI)	RAMP	https://www.wri.org/initiatives/resilience-and-adaptation-mainstreaming-program-ramp
Adaptation investment	Initiative	European Investment Bank	Climate Adaptation Investment Advisory Platform	https://advisory.eib.org/about/adapt.htm
	Tool	International Institute for Sustainable Development (IISD)	Community-based Risk Screening Tool—Adaptation & Livelihoods (CRiSTAL)	https://www.iisd.org/cristaltool/
Appraisal	Handbook	HM Treasury, UK	The Green Book and accompanying guidance on how to appraise policies, projects and programs	https://www.gov.uk/government/collections/the-green-book-and-accompanying-guidance-and-documents
Economic impacts	Data	Climate Econometrics	Economic impact projections from Pretis, Schwarz, Tang, Haustein, and Allen (2018)	https://www.climateeconometrics.org/paris-impacts/
Emissions	Data	Our World in Data	CO_2 and Greenhouse Gas Emission	https://ourworldindata.org/co2-and-greenhouse-gas-emissions
	Data	World Resources Institute (WRI)/Climate Watch	CAIT—Climate Analysis Indicators Tool	https://www.wri.org/data/climate-watch-cait-country-greenhouse-gas-emissions-data
Energy	Data	International Energy Agency (IEA)	World Energy Balances	https://www.iea.org/data-and-statistics/data-product/world-energy-balances
	Data	International Renewable Energy Agency (IRENA)	Power generation costs	https://www.irena.org/Energy-Transition/Technology/Power-generation-costs
Modeling	Handbook	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)	Handbook on Macroeconomic Modelling for Climate Resilience	https://www.giz.de/en/downloads/giz2023-en-handbook-macromodelling-resilience.pdf
Physical risks	Data	Caribbean Catastrophe Risk Insurance Facility (CCRIF SPC)	CCRIF Country Risk Profiles	https://www.ccrif.org/ccrifs-country-risk-profiles
	Data	Fathom	[Multiple; related to flood risk]	https://www.fathom.global/
	Data	Organisation for Economic Co-operation and Development (OECD)	Climate risks and disasters	https://www.oecd.org/en/topics/climate-risks-and-disasters.html
	Data	Oxford Programme for Sustainable Infrastructure Systems, University of Oxford	Global Resilience Index (GRI) Risk Viewer	https://global.infrastructureresilience.org
	Data	Global Facility for Disaster Reduction and Recovery (GFDRR)	Risk data library	https://riskdatalibrary.org/
	Data	Rosen and Sartori	Rosen & Sartori Climate Damages Dataset	https://jgea.org/ojs/index.php/jgea/article/view/31
	Data	University of Louvain	Emergency Events Database (EM-DAT)	https://www.emdat.be

Topic	Type of resource	Institution/lead developer	Name	Link
Physical risks (*cont.*)	Data	World Bank	Disaster Risk Profiles	https://www.gfdrr.org/en/disaster-risk-profiles
	Data	World Bank	Country Risk Profile Viewer	https://riskviewer.worldbank.org/
	Handbook	James Rising, Azhar Hussain, Kevin Schwarzwald, Ana Trisovic	Weather Panel Tutorial	https://climateestimate.net/content/getting-started.html
	Project	Climate Change Centre Austria	Project COIN (Cost of INaction: Assessing the costs of climate change for Austria)	https://ccca.ac.at/en/climate-knowledge/coin
	Project	European Commission, Joint Research Centre (JRC)	Projection of Economic Impacts of Climate Change in Sectors of the EU based on bottom-up Analysis (PESETA project)	https://climate-adapt.eea.europa.eu/en/metadata/projects/peseta-projection-of-economic-impacts-of-climate-change-in-sectors-of-the-european-union-based-on-bottom-up-analysis
	Tool	European Commission	Dynamic Interactive Vulnerability Assessment model—DIVA	https://climate-adapt.eea.europa.eu/en/metadata/tools/dynamic-interactive-vulnerability-assessment-model-diva
	Tool	Food and Agriculture Organization (FAO)	CROPWAT	https://www.fao.org/land-water/databases-and-software/cropwat/en/
	Tool	World Bank—Financial Protection Forum	Disaster Risk financing (DRF) Analytics Tools	https://www.financialprotectionforum.org/disaster-risk-financing-drf-analytics-tools
Policy	Tool	International Monetary Fund	Climate Change Policy Assessment for Small States	https://www.imf.org/en/Topics/climate-change/resilience-building
	Data	Organisation for Economic Co-operation and Development (OECD)	Climate Actions and Policies Measurement Framework (CAPMF)	https://oe.cd/dx/capmf
Scenarios	Data	Network for Greening the Financial System (NGFS)	NGFS Climate Scenarios Portal	https://www.ngfs.net/ngfs-scenarios-portal/
Various	Data	International Monetary Fund	Macroeconomic Climate Indicators Dashboard	https://climatedata.imf.org
	Data	World Bank	Climate Change Knowledge Portal	https://climateknowledgeportal.worldbank.org
	Initiative	Intergovernmental Panel on Climate Change (IPCC)	IPCC Reports	https://www.ipcc.ch/reports/

The Coalition of Finance Ministers for Climate Action

www.financeministersforclimate.org
www.greenandresilienteconomics.org