Multi-model Comparison

PLCY-798K

Integrated Human-Earth System Modeling and Policy Assessment

March 29, 2023

Topics for Today

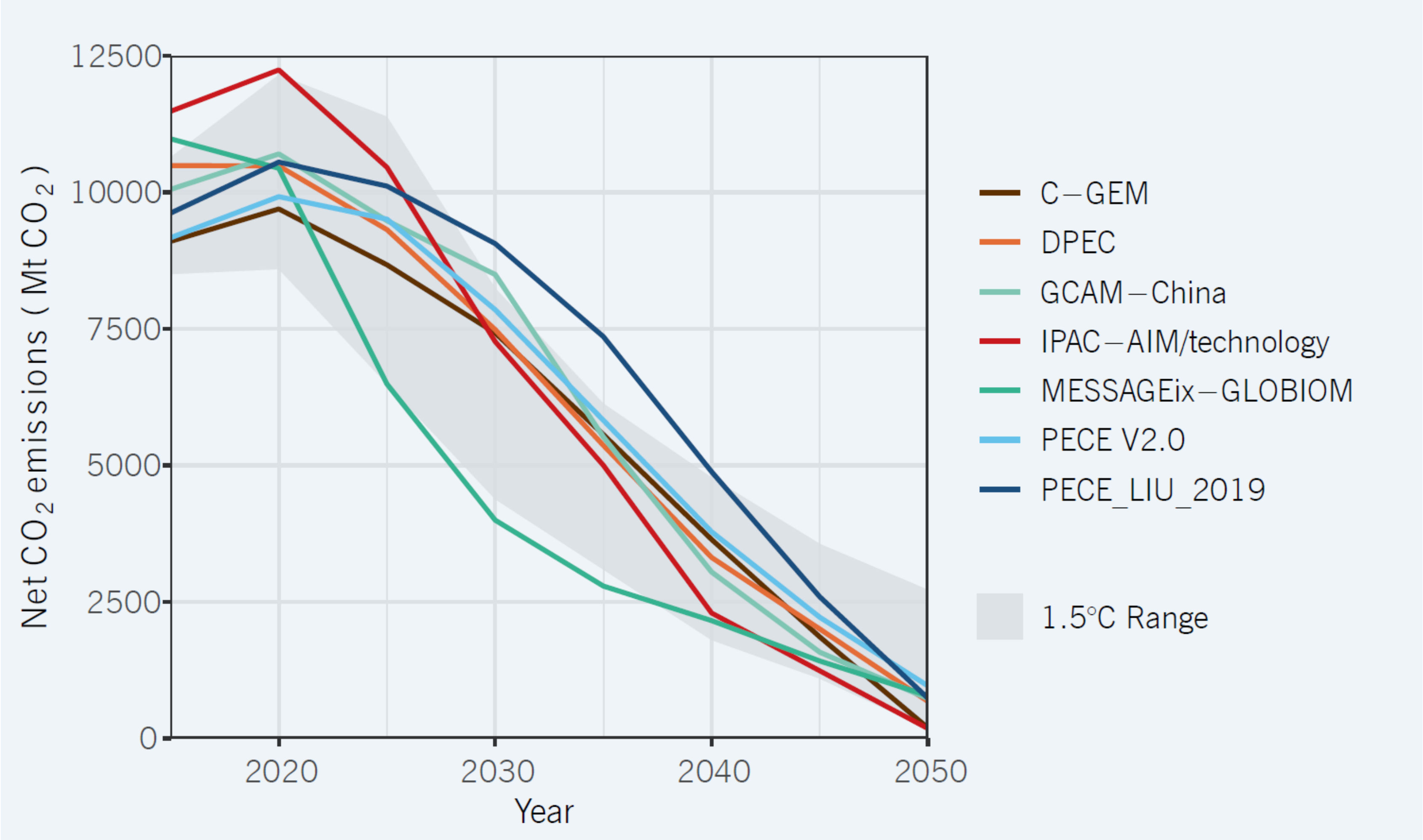
Why do we do model intercomparison?

What is model intercomparison?

How has it evolved over time?

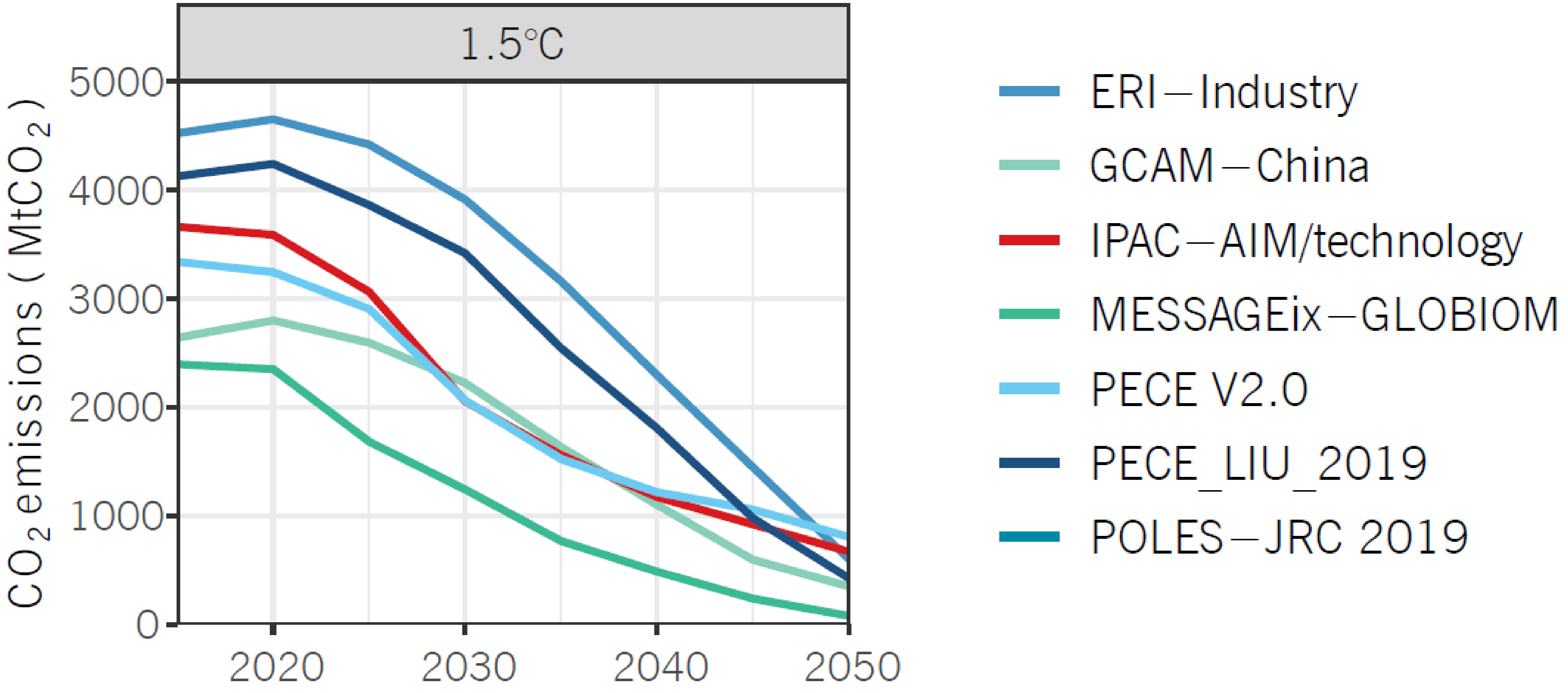
What are the main challenges in the process?

CO_2 Emissions (China)



Energy Foundation China (2020). "Synthesis Report 2020 on China's Carbon Neutrality: China's New Growth Pathway: from the 14th Five Year Plan to Carbon Neutrality." Energy Foundation China, Beijing, China. Available at: https://www.efchina.org/Reports-en/report-lceg-20201210-en.

Industrial CO_2 Emissions across Models (China)



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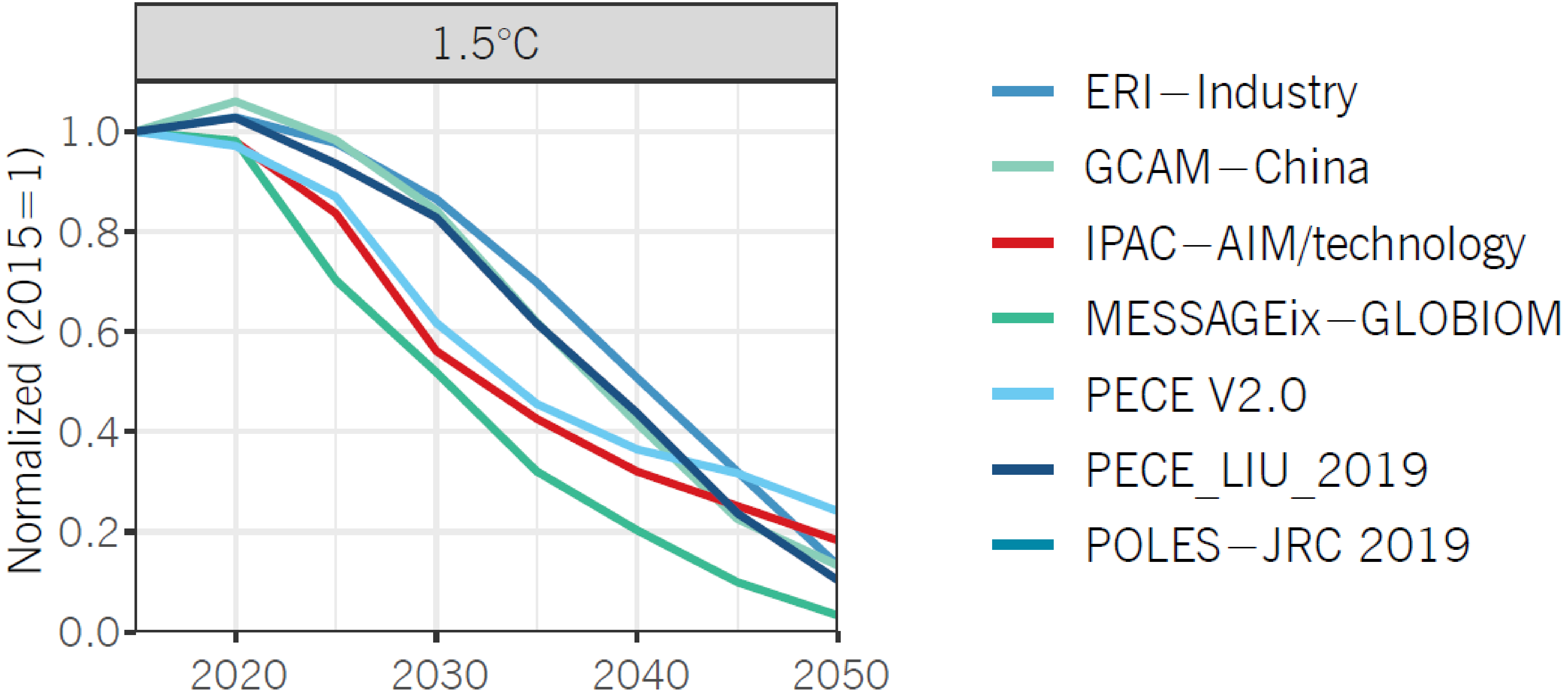


Energy Foundation China (2020). "Synthesis Report 2020 on China's Carbon Neutrality: China's New Growth Pathway: from the 14th Five Year Plan to Carbon Neutrality." Energy Foundation China, Beijing, China. Available at: https://www.efchina.org/Reports-en/report-lceg-20201210-en.

Why Model Intercomparison?

- Improve models

- Develop robust insights for policy makers

  "All models are wrong, but some are useful."

- Also provide guidance on how to interpret model results
  - Produce a sensitivity range
  - Identify key drivers and strategies
  - Identify areas of uncertainty

Improve Models

- Spot the outliers
- Most of the time, it is not a real insight but something to improve
- Some are easy to fix, others are inherent with model structure
  - Calibration data
  - Key input assumptions
  - …
  - Missing important sectors/technologies
  - …
  - Inter temporal optimization vs. recursive dynamic
  - GE vs. PE

What is Model Intercomparison? -- Models

Table 2
Models participating in the EMF 22 International Scenarios.

Model	Origin of Model	Participating Versions	Key supply technologies: New nuclear energy	Key supply technologies: CCS	Key supply technologies: Bio w/CCS	Model time step (years)	Last model year with no GHG price in delayed participation scenarios: Group 2	Last model year with no GHG price in delayed participation scenarios: Group 3	Intertemporal solution approach	Corresponding paper in this volume
ETSAP-TIAM	(Canada)	One Version	Yes	Yes	Yes	10	2020	2040	Intertemporal optimization	Loulou et al. (2009-this issue)
FUND	(E.U)	One Version	No specific technologies			1	2029	2049	Intertemporal optimization	Tol (2009-this issue)
GTEM	(Australia)	One Version	Yes	Yes	No	1	2029	2049	Recursive dynamic	Gurney et al. (2009-this issue)
IMAGE	(E.U.)	IMAGE IMAGE-BECS	Yes Yes	Yes Yes	No Yes	1	2029	2049	Recursive dynamic	van Vliet et al. (2009-this issue)
MERGE	(U.S.)	MERGE Optimistic MERGE Pessimistic	Yes Yes	Yes Yes	No No	10	2030	2050	Intertemporal optimization	Blanford et al. (2009-this issue)
MESSAGE	(E.U.)	MESSAGE MESSAGE-NoBECS	Yes Yes	Yes Yes	Yes No	10	2030	2050	Intertemporal optimization and dynamic recursive	Krey and Riahi (2009-this issue)
MiniCAM	(U.S.)	MiniCAM-Base MiniCAM-LoTech	Yes Yes	Yes No	Yes No	15	2035	2050	Recursive dynamic	Calvin et al. (2009a-this issue)
POLES	(E.U.)	One Version	Yes	Yes	Yes	1	2030	2050	Recursive dynamic	Russ et al. (2009-this issue)
SGM	(U.S.)	One Version	Yes	Yes	No	5	2026	2046	Recursive dynamic	Calvin et al. (2009b-this issue)
WITCH	(E.U.)	One Version	Yes	Yes	No	5	2025	2045	Intertemporal optimization	Bosetti et al. (2009-this issue)

Clarke, L., Edmonds, J., Krey, V., Richels, R., Rose, S., & Tavoni, M. 2009. “International climate policy architectures: Overview of the EMF 22 International Scenarios.” Energy Economics 31(S2):S64–S81.

What is Model Intercomparison: A scenario protocol

Table 1
The ten climate-action cases explored in the EMF 22 International Scenarios.

		Full participation	Delayed participation
450 CO_2-e	Not-to-exceed	X	X
	Overshoot	X	X
550 CO_2-e	Not-to-exceed	X	X
	Overshoot	X	X
650 CO_2-e	Not-to-exceed	X	X
	Overshoot	Not modeled	Not modeled

Clarke, L., Edmonds, J., Krey, V., Richels, R., Rose, S., & Tavoni, M. 2009. "International climate policy architectures: Overview of the EMF 22 International Scenarios." Energy Economics 31(S2):S64–S81.

What is Model Intercomparison

- *A question*
- *Models*
- *Scenario design*
- Funders
- Steering committee
- A schedule
- A facility to collect data
- A process for producing comparison charts to compare models
- Meetings for discussion of results
- Time to allow teams to make improvements and adjust
- A process for getting the results published

History and Types of IAM Modeling Intercomparison

Energy Modeling Forum https://emf.stanford.edu/

- EMF 37: Deep Decarbonization & High Electrification Scenarios for North America
- EMF 36: Carbon Pricing After Paris (CarPri)
- EMF 35: Japan model intercomparison project (JMIP) on long-term climate policy
- EMF 34: North American Energy Trade and Integration
- EMF 33: Bio-Energy and Land Use
- EMF 32: US GHG and Revenue Recycling Scenarios
- EMF 31: North American Natural Gas Markets in Transition
- EMF 30: Short Lived Climate Forcers / Air Quality
- EMF 29: The Role of Border Carbon Adjustment in Unilateral Climate Policy
- EMF 27: Global Model Comparison Exercise
- EMF 24: U.S. Technology and Climate Policy Strategies
- EMF 22: Climate Change Control Scenarios
- EMF 21: Multi-Gas Mitigation and Climate Change
- EMF 19: Climate Change: Technology Strategies and International Trade
- EMF 16: The Costs of the Kyoto Protocol
- EMF 1: Energy and the Economy (1977)

European Studies

- AMPERE
- COMMIT
- ENGAGE
- CD-LINKS
- NDC-ASPECTS
- ADVANCE
- ELEVATE…

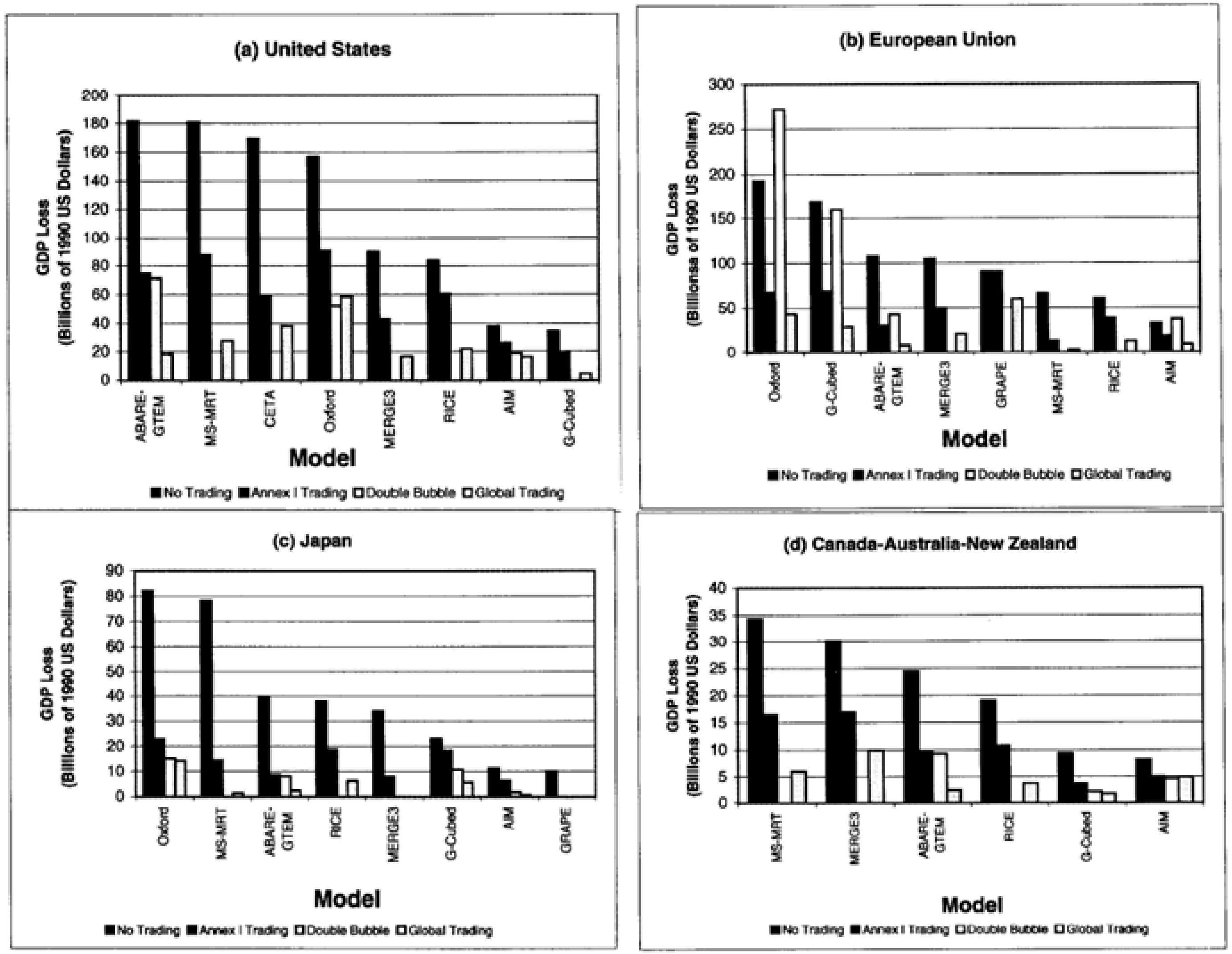
Targeted Studies

- Latin American Modeling Project
- Climate Change Science Program Scenarios
- Asian Modeling Exercise….

Multi-Model Papers and Reports

IPCC Assessment and Special Reports

EMF 16 on the Costs of the Kyoto Protocol (1999)



Emissions Trading

- Economic Efficiency
- Emissions Trading
- Hot Air

Weyant, John P., and Jennifer N. Hill. "INTRODUCTION AND OVERVIEW." The Energy Journal Vol. 20, Special Issue: The Costs of the Kyoto Protocol: A Multi-Model Evaluation (1999), pp. vii-xliv (38 pages). http://www.jstor.org/stable/23296903

2009: The Copenhagen Climate Conference

EMF 22: Second-Best International Policy Structures (2009)

Table 1
The ten climate-action cases explored in the EMF 22 International Scenarios.

		Full participation	Delayed participation
450 CO_2-e	Not-to-exceed	X	X
	Overshoot	X	X
550 CO_2-e	Not-to-exceed	X	X
	Overshoot	X	X
650 CO_2-e	Not-to-exceed	X	X
	Overshoot	Not modeled	Not modeled

How do we achieve long-term climate goals if countries do not all act at once? How does overshoot influence these dynamics?

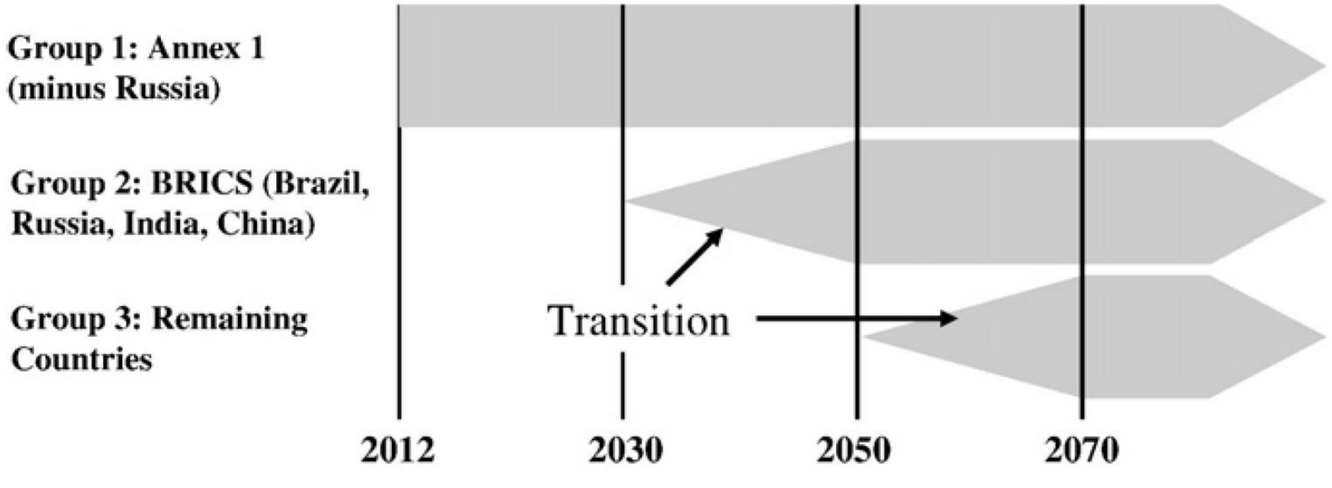


Fig. 1. The delayed participation architecture explored in EMF 22 International Scenarios.

Clarke, L., Edmonds, J., Krey, V., Richels, R., Rose, S., & Tavoni, M. 2009. "International climate policy architectures: Overview of the EMF 22 International Scenarios." Energy Economics 31(S2):S64–S81.

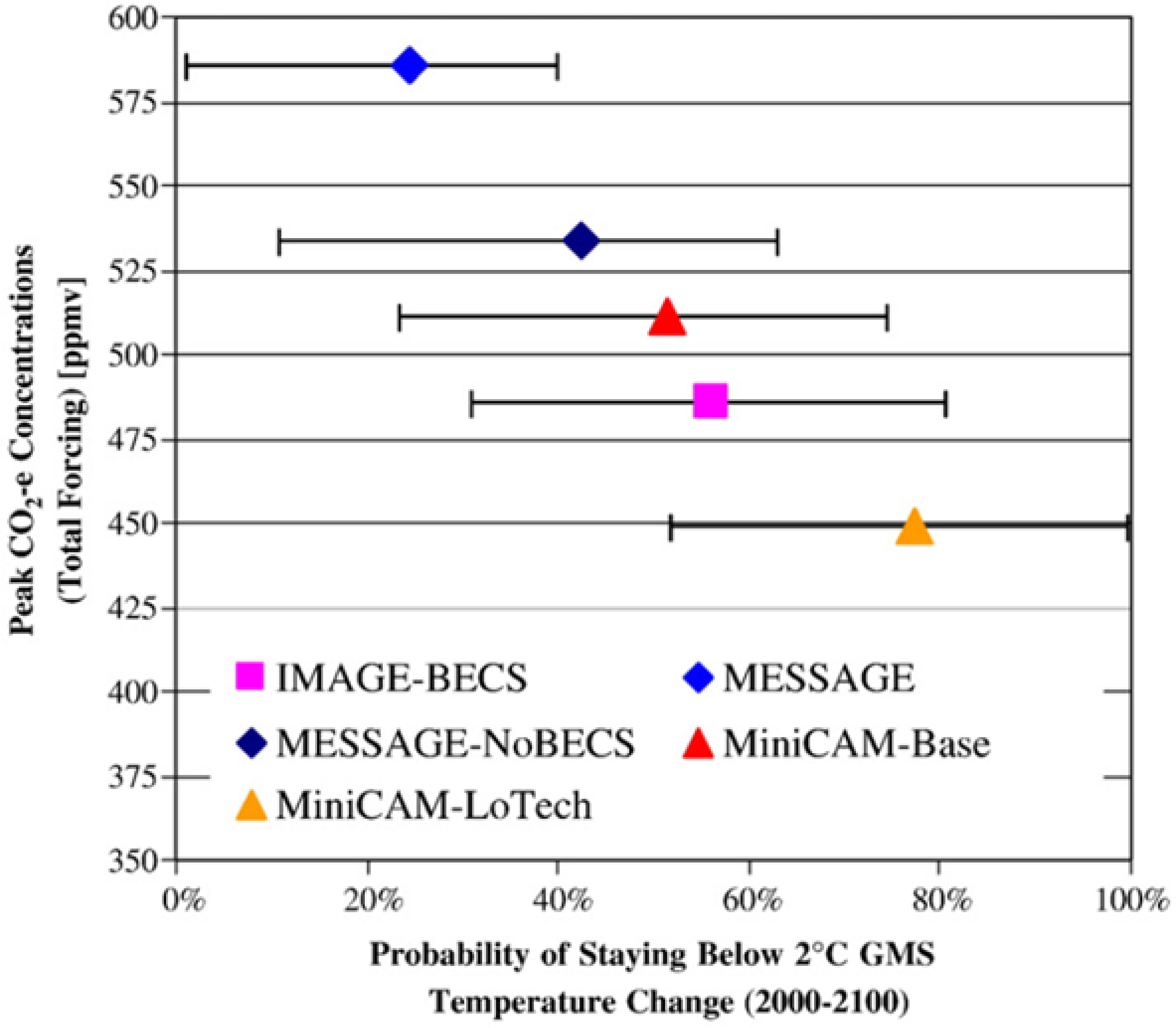
EMF 22: Second-Best International Policy Structures (2009)

Table 5
Carbon prices in Group 1 in 2020 (2005\$/tCO_2) across scenarios.

	650 CO2-e		550 CO2-e				450 CO2-e			
	Full	Delay	Full		Delay		Full		Delay	
	Not-to-exceed	Not-to-exceed	Overshoot	Not-to exceed	Overshoot	Not-to-exceed	Overshoot	Not-to exceed	Overshoot	Not-to-exceed
ETSAP-TIAM	\$3	\$5	\$8	\$10	\$13	\$24	\$77	\$214	\$1,297	X
FUND	\$20	\$43	\$51	\$52	\$147	\$239	\$260	X	X	X
GTEM	\$14	\$16	\$27	\$27	\$28	X	\$48	X	X	X
IMAGE	\$1	\$1	\$11	\$16	\$12	\$92	X	X	X	X
IMAGE-BECS	N/A	N/A	N/A	N/A	N/A	N/A	\$62	X	X	X
MERGE Optimistic	\$13	\$27	\$43	\$52	X	X	X	X	X	X
MERGE Pessimistic	\$9	\$13	\$29	\$35	\$154	\$256	X	X	X	X
MESSAGE	\$6	\$35	\$7	\$26	\$35	X	\$15	X	X	X
MESSAGE-NoBECS	\$6	N/A	\$12	\$27	N/A	N/A	\$70	X	X	X
MiniCAM-Base	\$4	\$7	\$8	\$14	\$10	X	\$20	\$101	\$53	X
MiniCAM-LoTech	\$12	\$19	\$34	\$34	\$169	X	\$263	X	X	X
POLES	\$7	\$9	\$27	\$41	\$51	X	X	X	X	X
SGM	\$10	\$11	\$40	\$40	\$67	\$67	X	X	X	X
WITCH	\$3	\$6	\$4	\$22	\$36	\$131	X	X	X	X

2020 carbon prices for Group 2 and 3 are the same as those in the table for the full participation scenarios and zero in the delayed participation scenarios. Darkened cells with an "X" mean that the team was not able to produce the scenario. "N/A" means that the scenario was not attempted with the given model or model version.

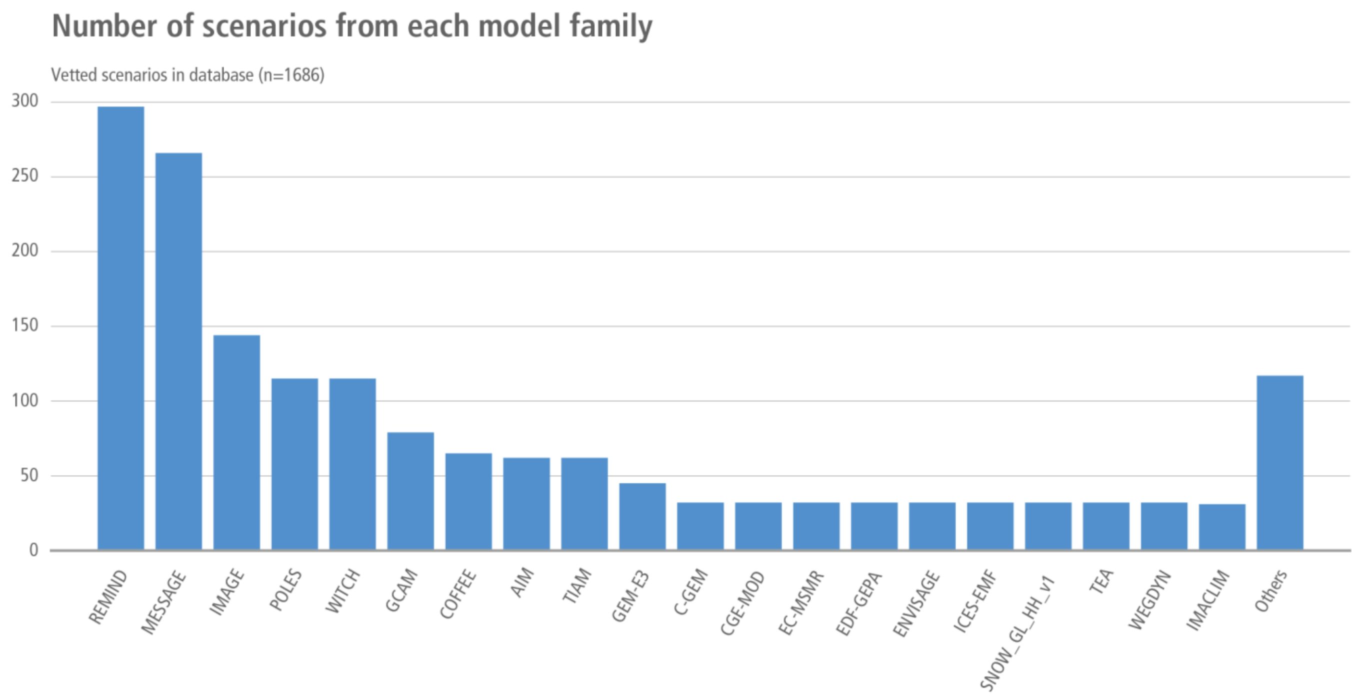
EMF 22: Second-Best International Policy Structures (2009)

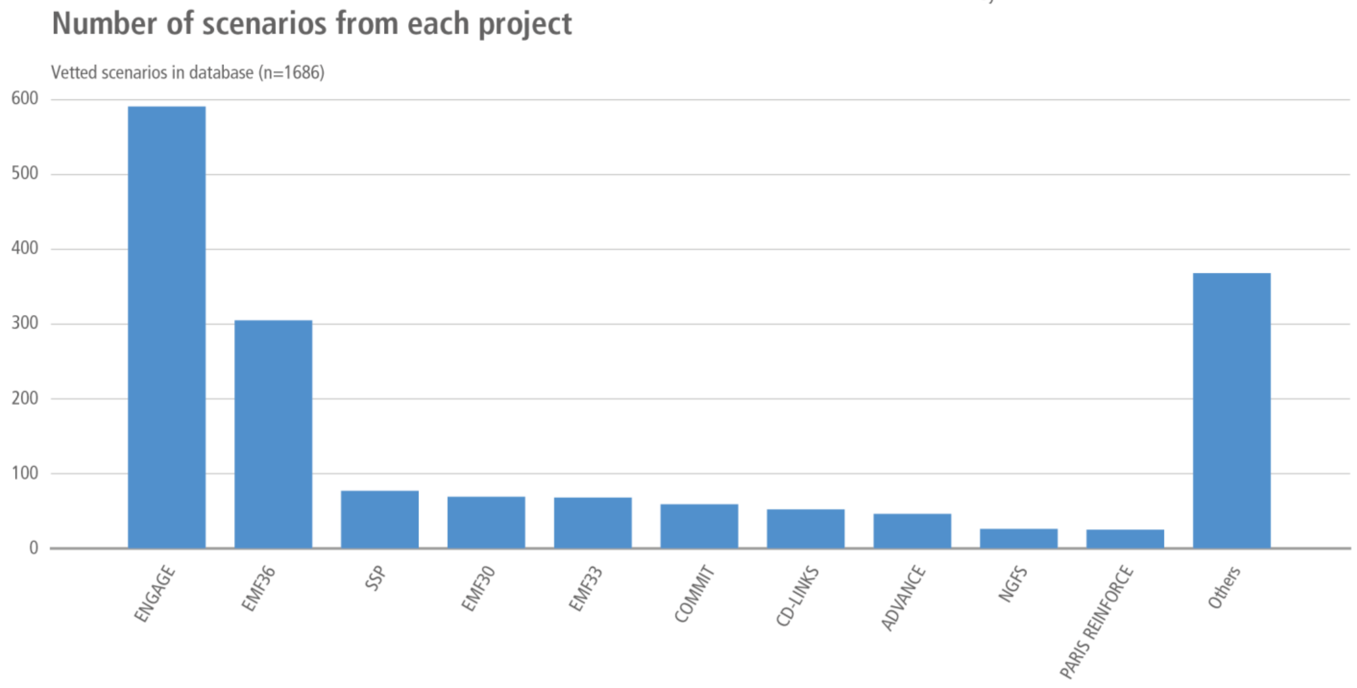


"Second Best" Mitigation

- Delayed Accession
- Probabilistic Temperature
- Annex 1 Mitigation
- BECCS
- 450 ppmv CO2e
- "Feasibility"
- Overshoot

Multi-model studies contribute to a large portion of IPCC scenarios





[AR6 Scenario Explorer and Database hosted by IIASA]

Riahi, K., R. Schaeffer, J. Arango, K. Calvin, C. Guivarch, T. Hasegawa, K. Jiang, E. Kriegler, R. Matthews, G.P. Peters, A. Rao, S. Robertson, A.M. Sebbit, J. Steinberger, M. Tavoni, D.P. van Vuuren, 2022: Mitigation pathways compatible with long-term goals. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.005

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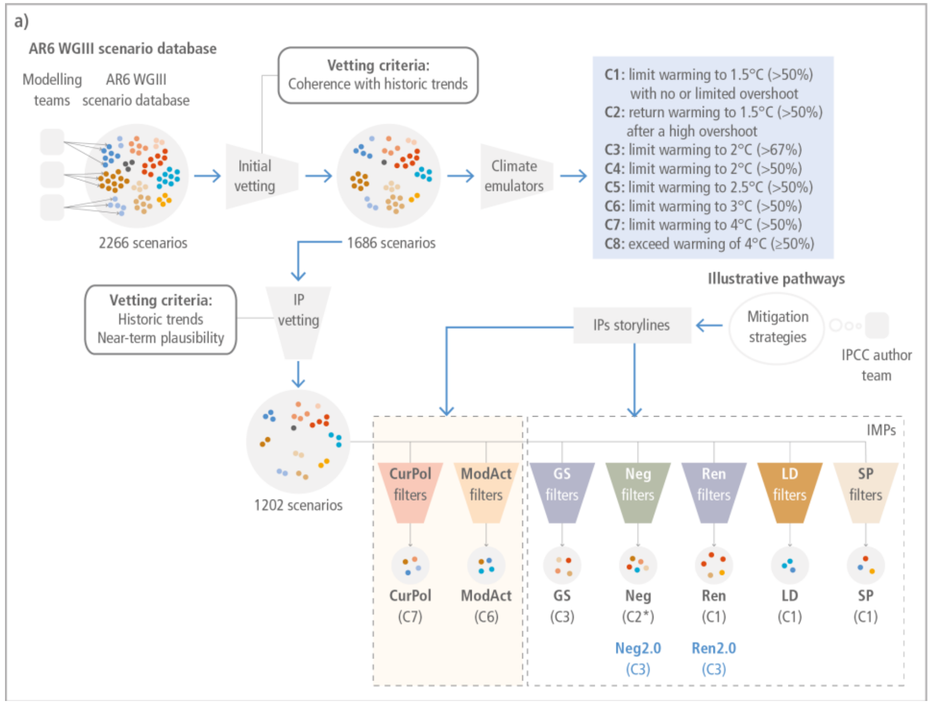
Table 3.1 | Classification of emissions scenarios into warming levels using MAGICC

Category	Description	WGI SSP	WGIII IP/IMP	Scenarios
C1: Limit warming to 1.5°C (>50%) with no or limited overshoot	Reach or exceed 1.5°C during the 21st century with a likelihood of ≤67%, and limit warming to 1.5°C in 2100 with a likelihood >50%. Limited overshoot refers to exceeding 1.5°C by up to about 0.1°C and for up to several decades.	SSP1-1.9	IMP-SP, IMP-LD, IMP-Ren	97
C2: Return warming to 1.5°C (>50%) after a high overshoot	Exceed warming of 1.5°C during the 21st century with a likelihood of >67%, and limit warming to 1.5°C in 2100 with a likelihood of >50%. High overshoot refers to temporarily exceeding 1.5°C global warming by 0.1°C–0.3°C for up to several decades.		IMP-Neg[a]	133
C3: *Limit warming to 2°C (>67%)*	Limit peak warming to 2°C throughout the 21st century with a likelihood of >67%.	SSP1-2.6	IMP-GS	311
C4: Limit warming to 2°C (>50%)	Limit peak warming to 2°C throughout the 21st century with a likelihood of >50%.			159
C5: Limit warming to 2.5°C (>50%)	Limit peak warming to 2.5°C throughout the 21st century with a likelihood of >50%.			212
C6: Limit warming to 3°C (>50%)	Limit peak warming to 3°C throughout the 21st century with a likelihood of >50%.	SSP2-4.5	ModAct	97
C7: Limit warming to 4°C (>50%)	Limit peak warming to 4°C throughout the 21st century with a likelihood of >50%.	SSP3-7.0	CurPol	164
C8: Exceed warming of 4°C (≥50%)	Exceed warming of 4°C during the 21st century with a likelihood of ≥50%.	SSP5-8.5		29
C1, C2, C3: limit warming to 2°C (>67%) or lower	All scenarios in Categories C1, C2 and C3			541

[a] The Illustrative Mitigation Pathway 'Neg' has extensive use of carbon dioxide removal (CDR) in the AFOLU, energy and the industry sectors to achieve net negative emissions. Warming peaks around 2060 and declines to below 1.5°C (50% likelihood) shortly after 2100. Whilst technically classified as C3, it strongly exhibits the characteristics of C2 high-overshoot pathways, hence it has been placed in the C2 category. See Box SPM.1 for an introduction of the IPs and IMPs.



Multi-model studies contribute to a large portion of IPCC scenarios

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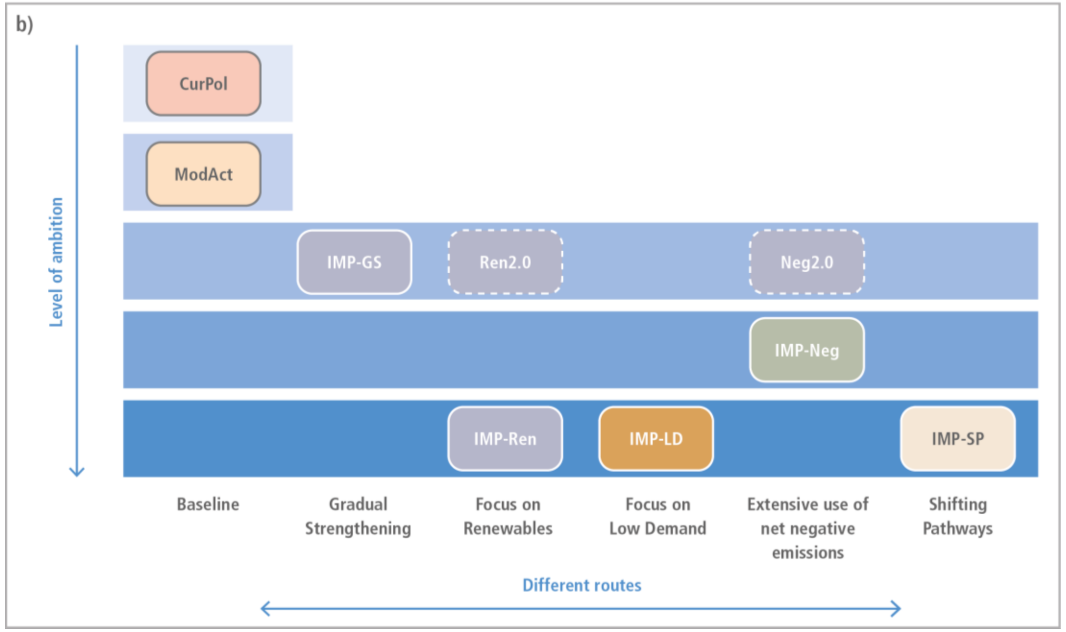

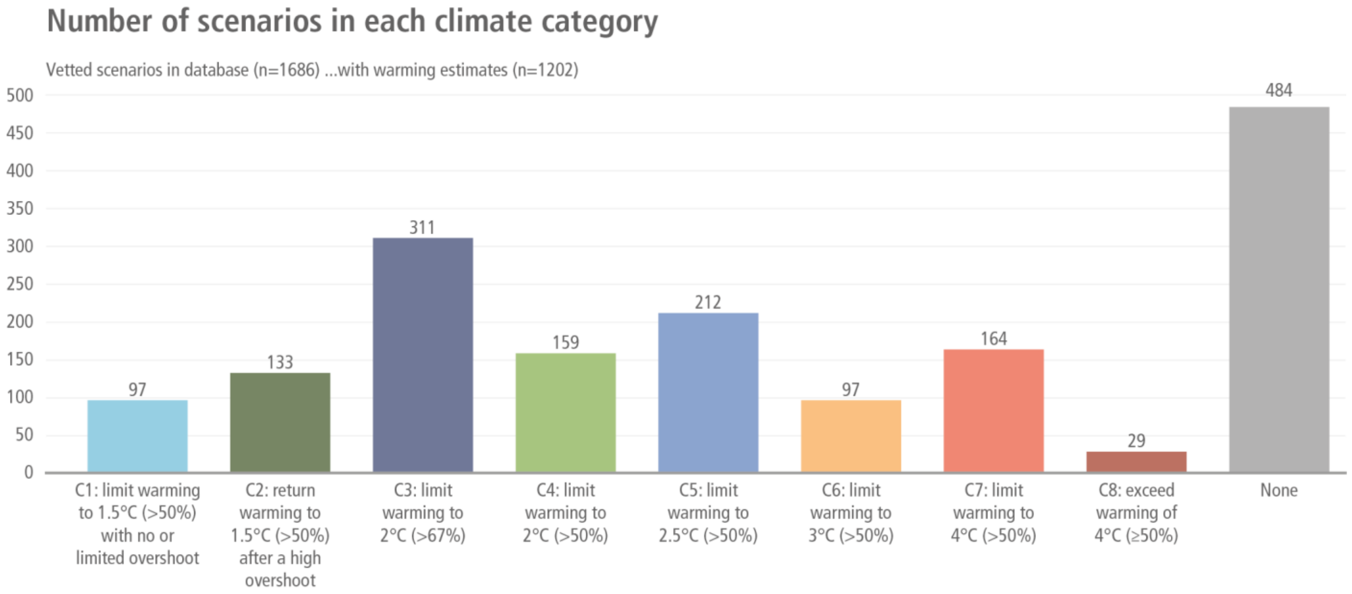

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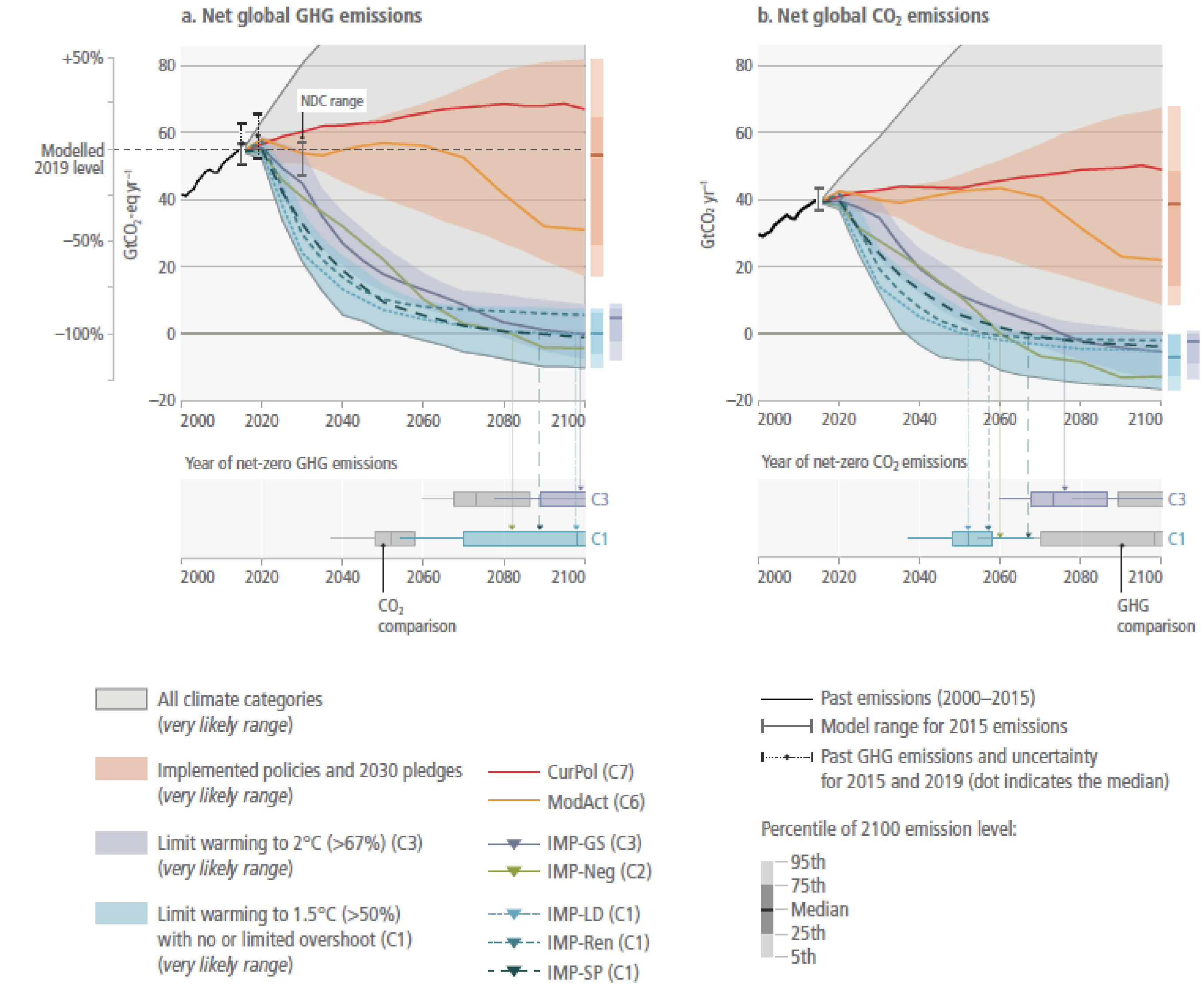


Figure 3.6 | Overview of the net CO_2 emissions and Kyoto greenhouse gas (GHG) emissions for each Illustrative Mitigation Pathway (IMP).

Riahi, K., R. Schaeffer, J. Arango, K. Calvin, C. Guivarch, T. Hasegawa, K. Jiang, E. Kriegler, R. Matthews, G.P. Peters, A. Rao, S. Robertson, A.M. Sebbit, J. Steinberger, M. Tavoni, D.P. van Vuuren, 2022: Mitigation pathways compatible with long-term goals. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.005

The Evolution of Model Intercomparison

- Grown in size and scope
- An increasingly accepted part of the analysis process
- Has evolved from EMF leadership to a broad set of different efforts
- Has evolved from just one overview paper to multiple subgroups writing their own papers
- **The topics have changed**

CD-LINKS Overview

The CD-LINKS project explored the complex interplay between climate action and development through both global and national perspectives, providing information to aid the design of complementary climate-development policies.

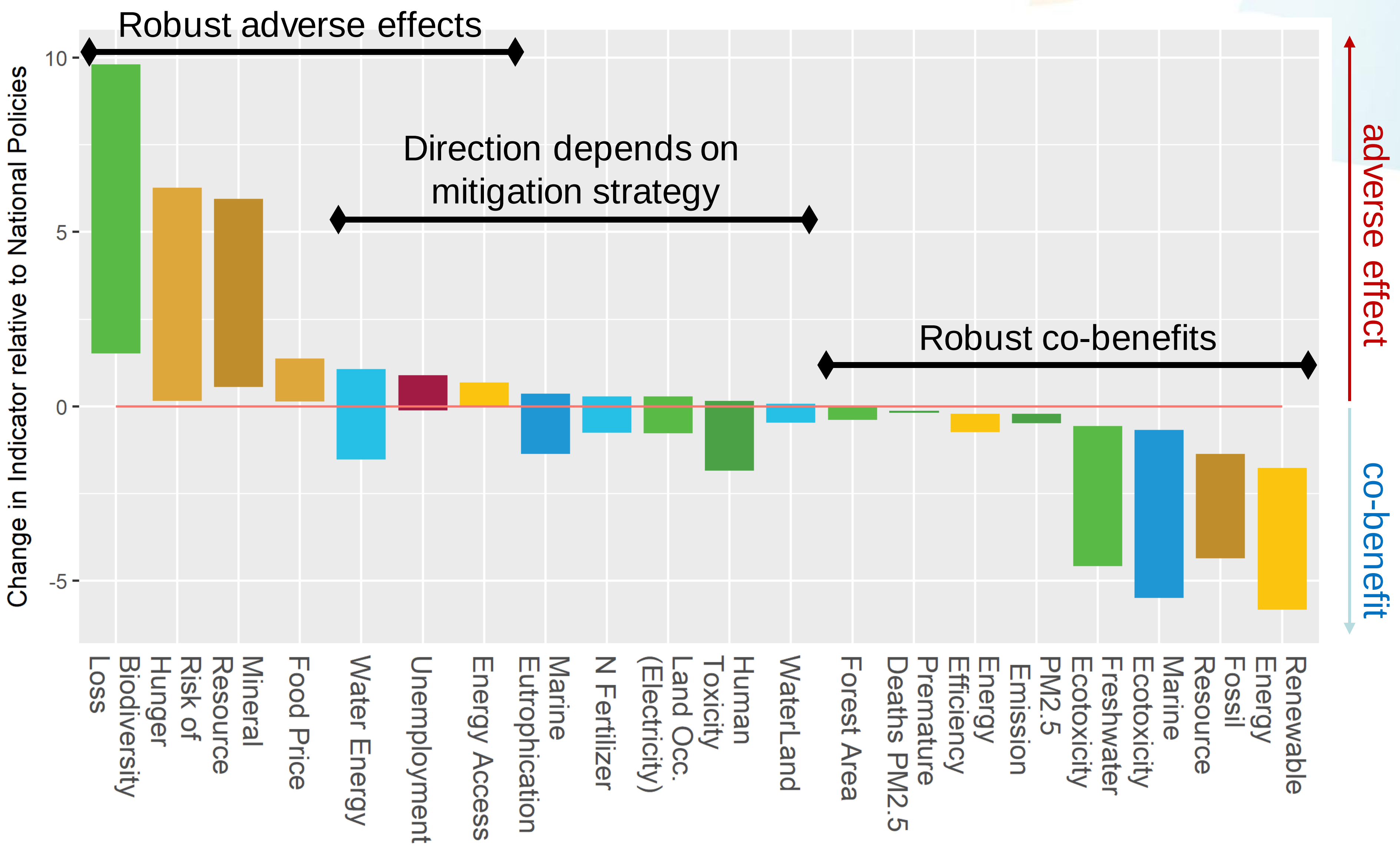
As a four-year project (September 2015-September 2019) with 19 partners and collaborators from around the world, CD-LINKS brought together expertise from the areas of integrated assessment modelling, human development, climate adaptation, economics, energy geo-politics, atmospheric chemistry and human health, land use and agriculture, and water, among others.

Project Goals

The project aimed to:

- gain an improved understanding of the linkages between climate change policies (mitigation/adaptation) and multiple sustainable development objectives;
- broaden the evidence base in the area of policy effectiveness by exploring past and current policy experiences;
- develop the next generation of globally consistent, national low-carbon development pathways; and
- establish a research network and capacity building platform to leverage knowledge exchange among institutions.

CD-Links: 1.5°C and SDGs

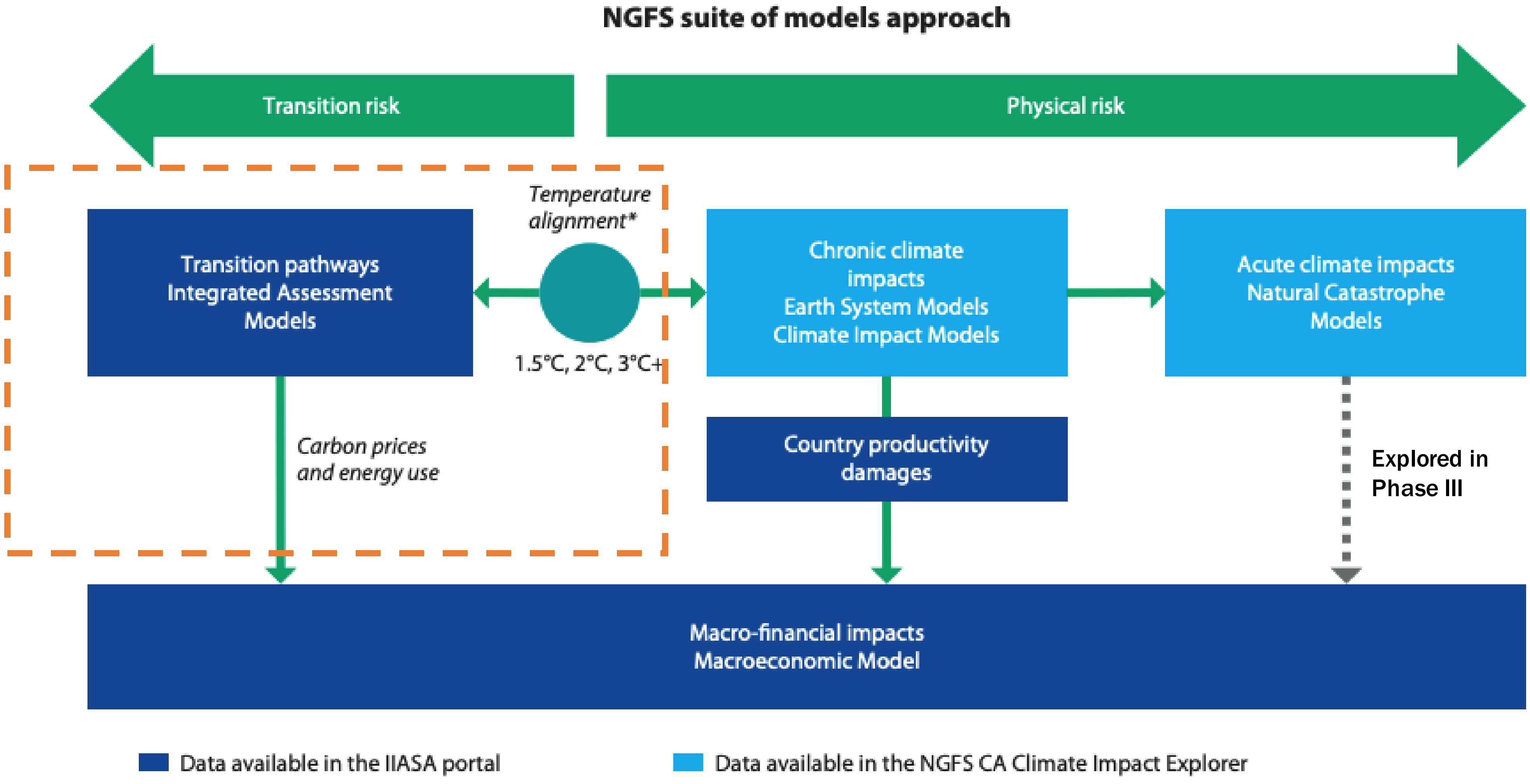


NGFS Scenarios for Central Banks and Supervisors

- The NGFS scenarios have been developed to provide **a common starting point** for analyzing climate risks to the **economy and financial system**.
- These are detailed scenarios that analyze both the **physical** and **transition risks** from climate change and their economic impacts.
- These have been created through **a suite of models**, supported by a consortium of world leading climate scientists and modeling teams.
- Key users of the NGFS scenarios include a growing number of **central banks, supervisors, governments, and private firms** to better understand risks to financial systems, economies and their own businesses and balance sheets.

NGFS
Central Banks and Supervisors
Network for Greening the Financial System

The scenarios have been created through a suite of models, aligned in a coherent way



https://www.ngfs.net/sites/default/files/media/2021/08/27/ngfs_climate_scenarios_phase2_june2021.pdf

NGFS Scenarios are supported by a consortium of world leading climate scientists and modeling teams

Research Consortium

PIK

SCHOOL OF PUBLIC POLICY
CENTER FOR GLOBAL SUSTAINABILITY

International Institute for Applied Systems Analysis
IIASA www.iiasa.ac.at

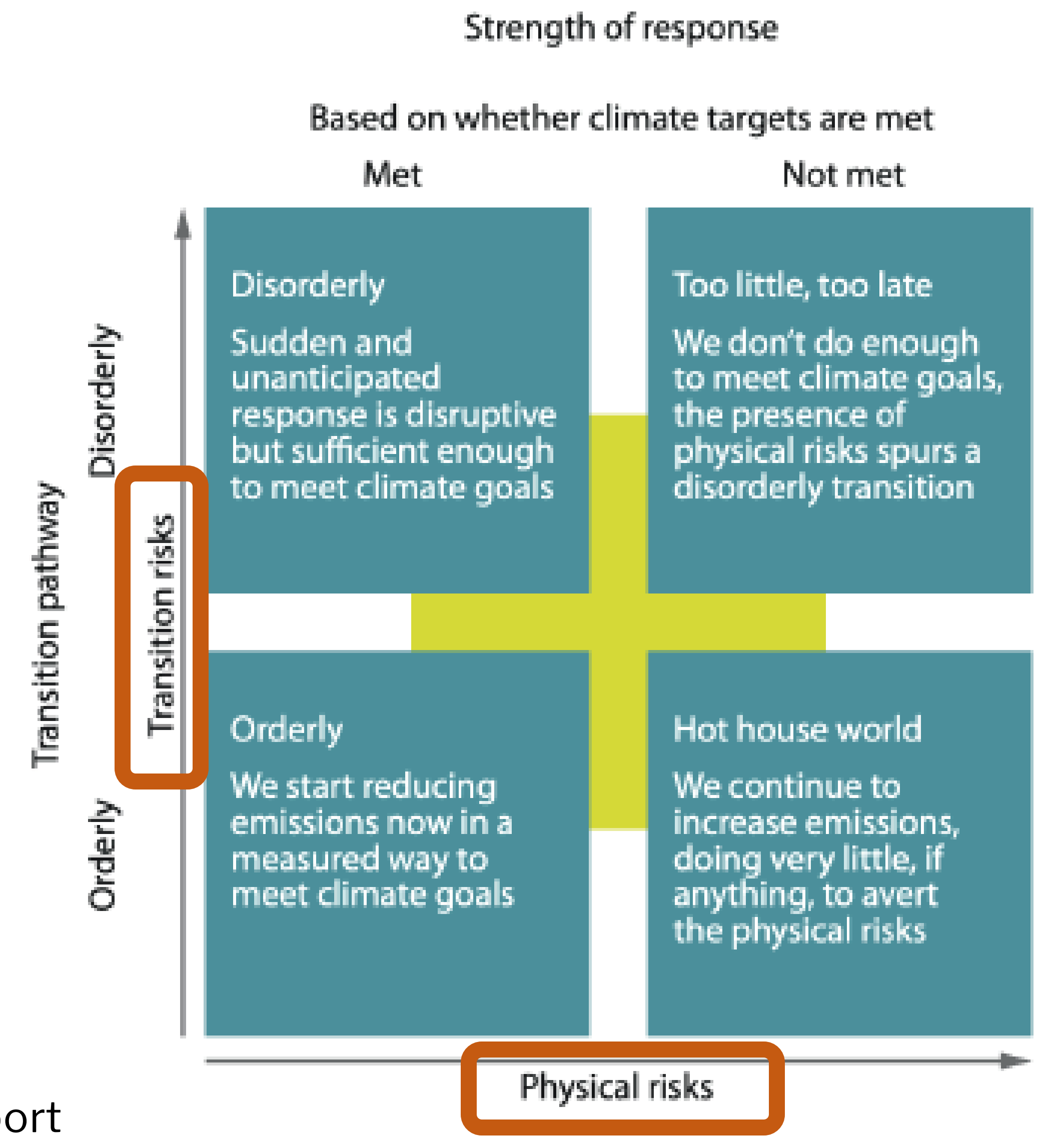
CLIMATE ANALYTICS

National Institute of Economic and Social Research
Quarterly Statistical Macroeconomic Model

Bloomberg Philanthropies

climateworks FOUNDATION

Financial Support



Source: NGFS (2019a).

Challenges

- *What do we make of the variation in the model results? How do we handle uncertainty?*
- *How do we compare models with very different characteristics*
- Untangling why models give different results
- Identifying "good" results – assessing models
- Models that don't solve.
- Data collection and consistency
- Funding and getting interest from the modelers
- Different model capabilities (regions, sectors, etc.)

IIASA databases

- [AR6 Scenario Explorer and Database hosted by IIASA]
- [IAMC 1.5°C Scenario Explorer hosted by IIASA]

Questions