Human Systems in Sustainability Science: Institutions, Markets & Incentives

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MIT Center for Sustainability Science and Strategy

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Center for Sustainability Science and Strategy


SUSTAINABLE DEVELOPMENT GOALS
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS

Earth's Future

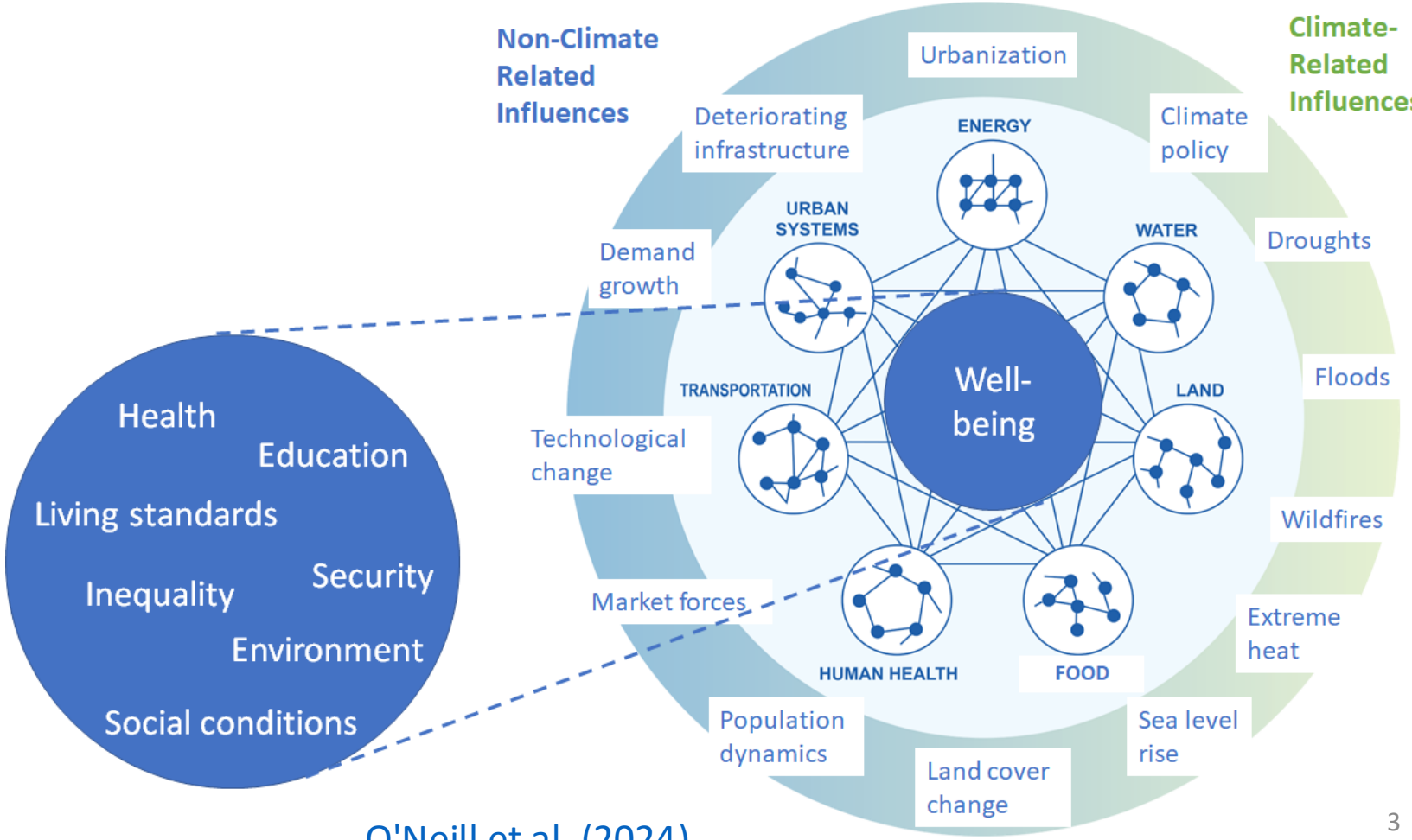
COMMENTARY

A Framework for Multisector Scenarios of Outcomes for Well-Being and Resilience

Brian C. O'Neill[1], Jennifer Morris[2], Jonathan Lamontagne[3], Marshall Wise[1], John Weyant[4]

Special Collection:
Multi-Sector Dynamics:
Advancing Complex Adaptive
Human-Earth Systems Science in
a World of Interconnected Risks

We propose an outcome-based scenario development approach focused on well-being & resilience that could cut across issues, scales and sectors



O'Neill et al. (2024)

Challenges for Studying Broader Dimensions of Sustainability:

What scales/metrics should we be looking at?

Example: Economic Security

- **GDP:** Global, National, State, County, City
- **Household Income:** average, income deciles…within country, state, county, city
- **Inequality:** Gini index, Palma ratio, 80-20 ratio, etc.
- **Wealth**
- **Poverty**
- **Unemployment**

Which scale & metric is most relevant depends on question being asked

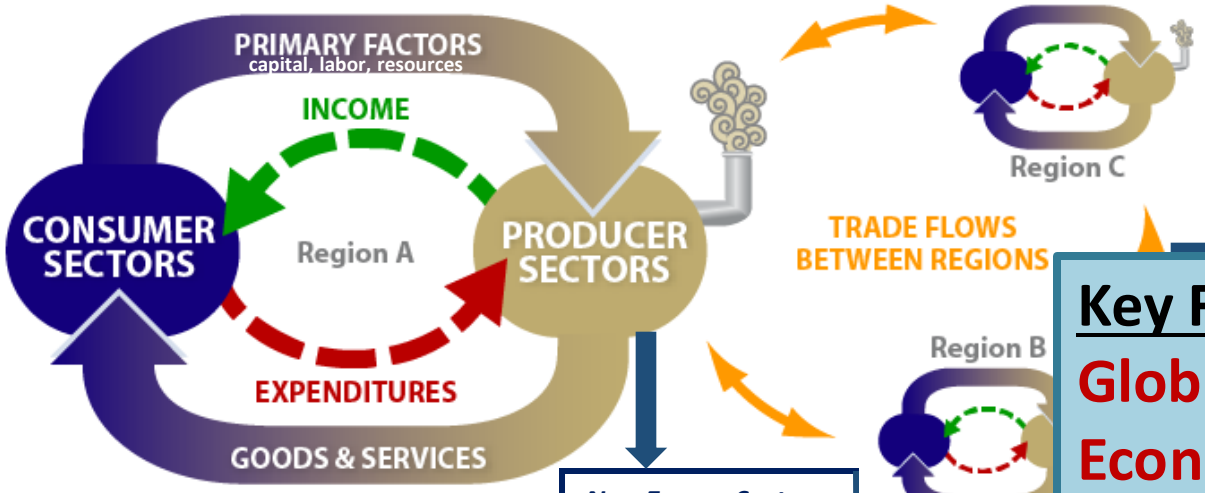
Higher resolution does not automatically mean better/more appropriate

Interactions and feedbacks across different sectors, regions and scales can be very important, and influence more local issues

MIT Economic Projection and Policy Analysis (EPPA) Model

"The best model in the world"
-Sergey Paltsev

Multi-sector, multi-region global economy-wide model for projections of energy, land use, economy and emissions



Technical Features
Written in GAMS using MSPGE
Recursive-Dynamic
Uses GTAP Database
Calibrated to current

Full Input-Output Data for Every Region

			INTERMEDIATE USE by Production Sectors				FINAL USE				OUTPUT
			1	2	j	n	Private Consump.	Government Consumption	Investment	Export	
Domestic Production	1										
	2										
	i		A				B				C
	n										
Imports	1										
	2										
	i		D				E				F
	n										
Value added:	-labor										
	-capital		G				H				I
	- natural resources										
INPUT			J								

Non-Energy Sectors
- Crops
- Livestock
- Forestry
- Food
- Energy-Intensive Industry
- Manufacturing
- Services
- Commercial Transport
- Household Transport

Energy Sectors
- Crude Oil
- Refined Oil
- Liquid Fuel from Biomass
- Oil Shale
- Coal
- Natural Gas (conv., shale, tight)
- Electricity
- DAC

New Technologies Continually Added

**Regions added fo*

Gas with Advanced CCS
Nuclear
Biomass
Biomass with CCS

Key Inputs
Policy Assumptions
Population Growth
Capital/Labor Productivity Growth
Energy Efficiency Improvements
Technology Costs
Rate of Technology Penetration
Elasticities of Substitution
(related to labor, capital, energy, fuels, etc.)
Fossil Fuel Resource Availability
Urban Pollutant Initial Inventories & Trends
Land Productivity

Key Features

Global Coverage & International Trade

Economy-Wide Coverage & Inter-Industry Linkages

Feedbacks Across Regions & Sectors

Theory-Based (microeconomics with full input-output data)

Endogenous Prices, Investments & Capital Accumulation

GDP and Welfare Effects

Policies (emissions limits/prices, sector/technology regulations…)

Distortions (taxes, subsidies, etc.)

Accounting for Physical Quantities (energy, electricity, land)

****Links to MIT Earth System Model (MESM)****

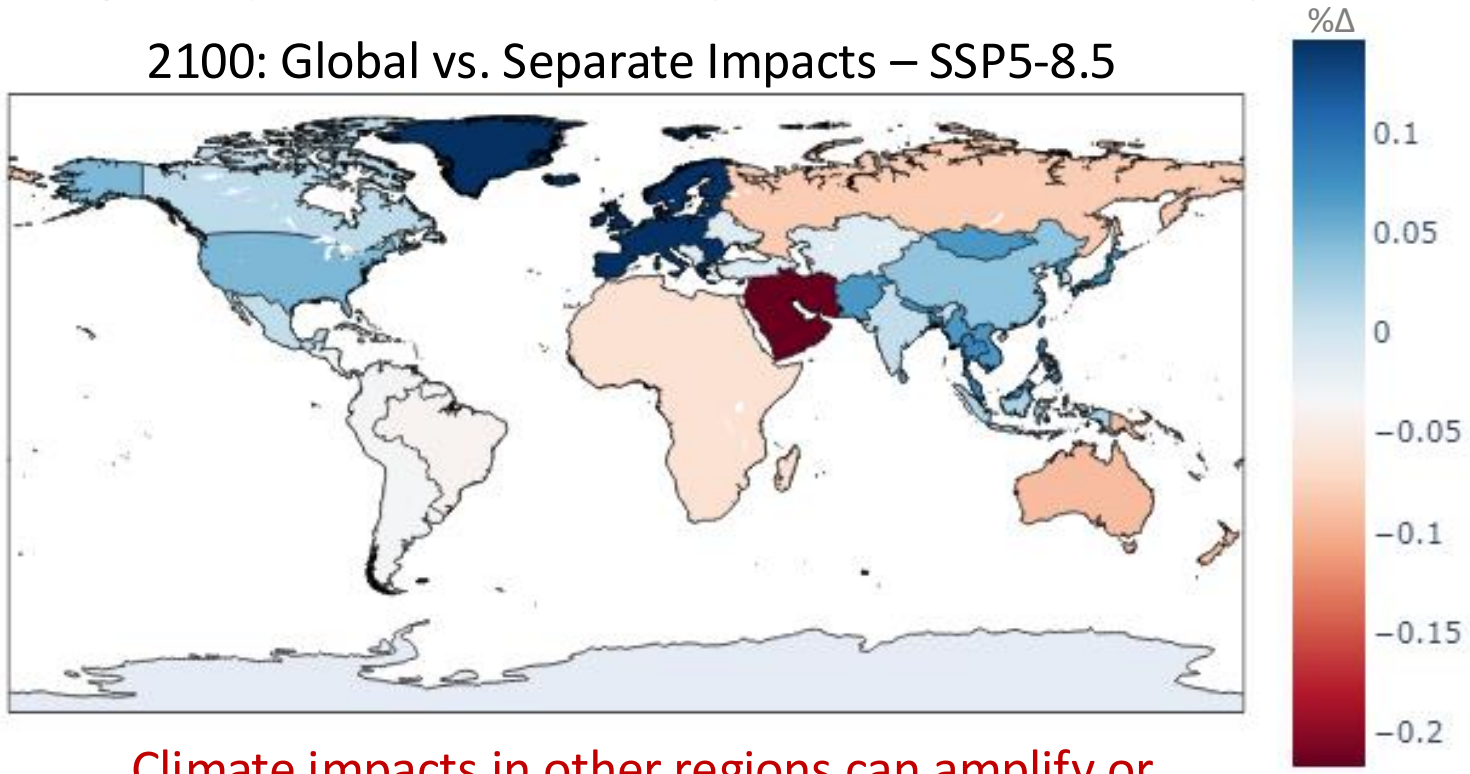
to budget constraint

Equilibrium Conditions: Market-Clearing, Zero-Profit, Income Balance

Example: Economic Impacts of Climate Change

- Applied econometrically-estimated country-level climate-driven **Total Factor Productivity (TFP)** shocks from Casey et al. (2023) and assessed **% change in GDP** (vs. no climate impacts)
- Applied shocks **globally** AND to each country **one at a time**, and compared the GDP impacts

2100: Global vs. Separate Impacts – SSP5-8.5



Countries' economies are impacted by climate change directly as well as via terms of trade effects driven by climate impacts in other places

Climate impacts in other regions can amplify or dampen direct domestic impacts

(in many places in the +/- 5-10% range)

Example: Using Trade Policy (Tariffs) to Align Economic Incentives with Sustainability Goals, e.g. Halting Deforestation

Led by CS3 postdoc **Etienne Berthet**

- Extend Nordhaus' concept of a Climate Club to a "Forest Club" by **linking deforestation footprints to tariffs**, with membership dynamically updated based on welfare changes
- Novel game-theoretic framework; integrates spatially disaggregated land-use dynamics into global economy-wide trade model

Global Reduced Deforestation (Ha)

EU-only Sanctions

58,615

Forest Club: Targeted Diplomacy

14,953,477

For additional examples of the importance of markets, at different scales, see the following posters at 5pm:

Dominic White

The Impacts of Extreme Weather Events in the Mississippi River Basin: Enhancing Agriculture Modeling

Etienne Berthet

Food Security in Africa under a Changing Climate–Navigating the Energy and Agricultural Transition to Net Zero

Yichun Fan

Levees and levies: Local financing of climate infrastructure maintenance and housing market dynamics

Challenges for Studying Broader Dimensions of Sustainability:

Are we capturing the needed dynamics in our models?

Need to assess model dynamics to determine if a metric would be meaningful

Image Source: Food Navigator (Getty Images)

Example: Food Security

- Food consumption
  - Calories/person/day

    → ***How sensitive is model in terms of food consumption? Is hunger allowed?***

- Food Expenditures as share of income

  →***How does model capture changes in food prices? Global or regional? Food prices vs. crop prices?***

  →***How is trade represented? Can global trade mediate shocks to regional food supply? Is there regional variation in global market integration?***

Different metrics may require different types of models focused on different dynamics at different scales

Example: Energy Security

- Energy Expenditures as share of income → **Energy-economic model**
- Energy Access (physical connection) → **Model of infrastructure expansion / networks w/ high geospatial resolution**
- Reliability → **Electricity dispatch / operations model w/ high temporal resolution**

Using a model for a metric it's not designed for could lead to very misleading results

What often-missing dynamics might be important?

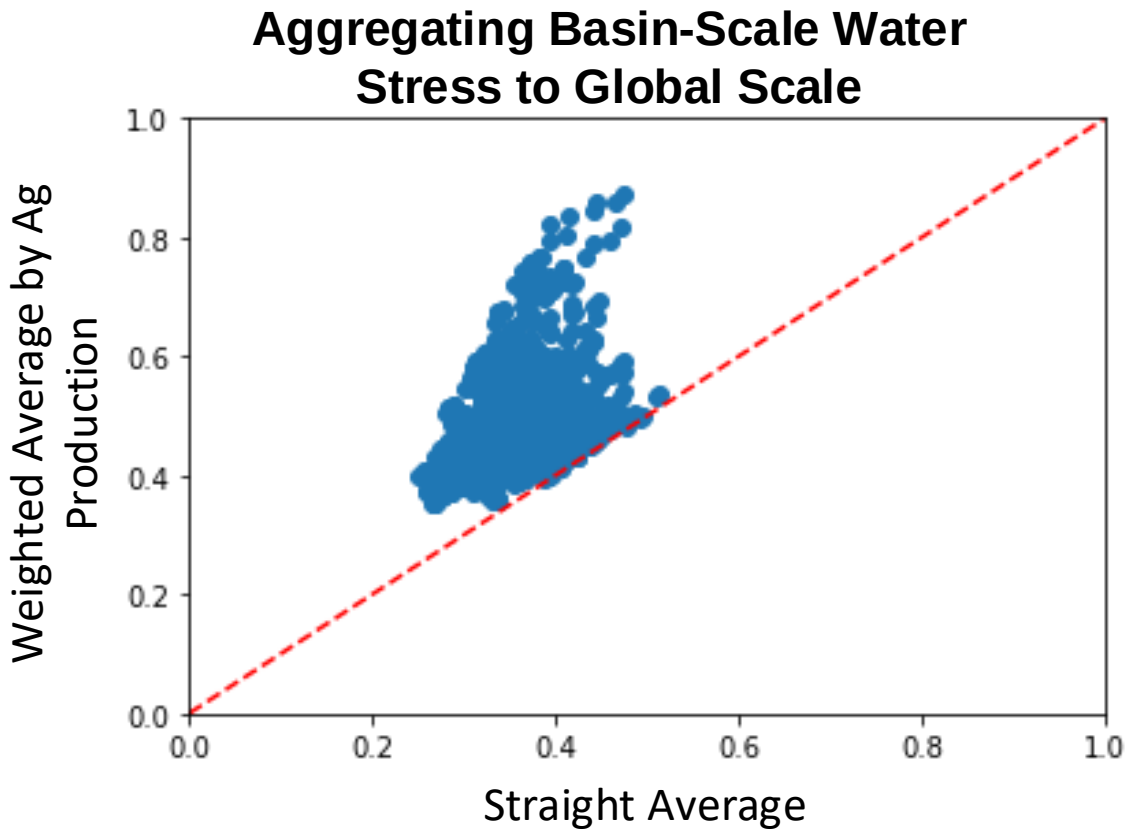
- Household behavior
- Migration
- Demographic changes
- Economic sectoral shifts
- Infrastructure investments
- Institutions
- Risk management
- …

Challenges for Studying Broader Dimensions of Sustainability:

How to connect models of different scales?

Need to carefully think through:

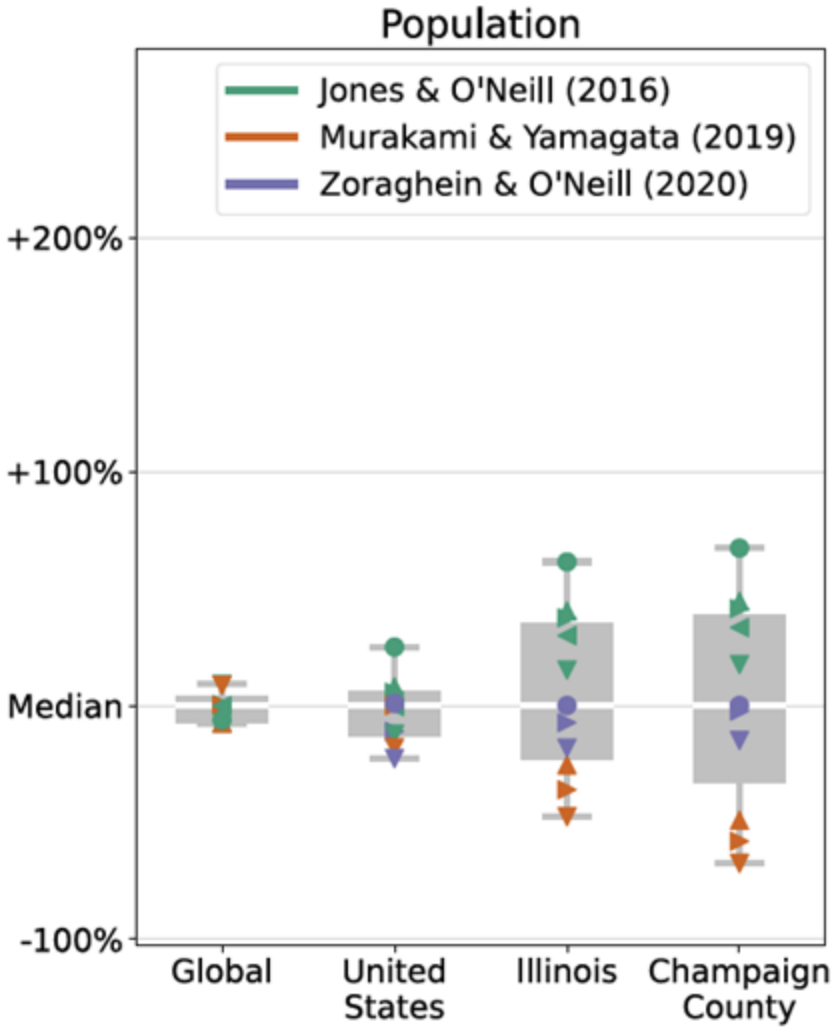
- Aggregation
  - Average?
  - Weighted Average?
    - By population?
    - By GDP?
    - By Production? …
- Downscaling
  - What are the rules?
  - Value of community tools
- Linkages?
  - What information is being passed?
  - Full coupling vs. one-way?



Challenges for Studying Broader Dimensions of Sustainability:

How to balance treatment of uncertainty with model complexity and resolution?

Finer scales make uncertainty blow up



Earth's Future

REVIEW ARTICLE
10.1029/2021EF002644

Special Section:
Modeling MultiSector Dynamics to Inform Adaptive Pathways

Uncertainty Analysis in Multi-Sector Systems: Considerations for Risk Analysis, Projection, and Planning for Complex Systems

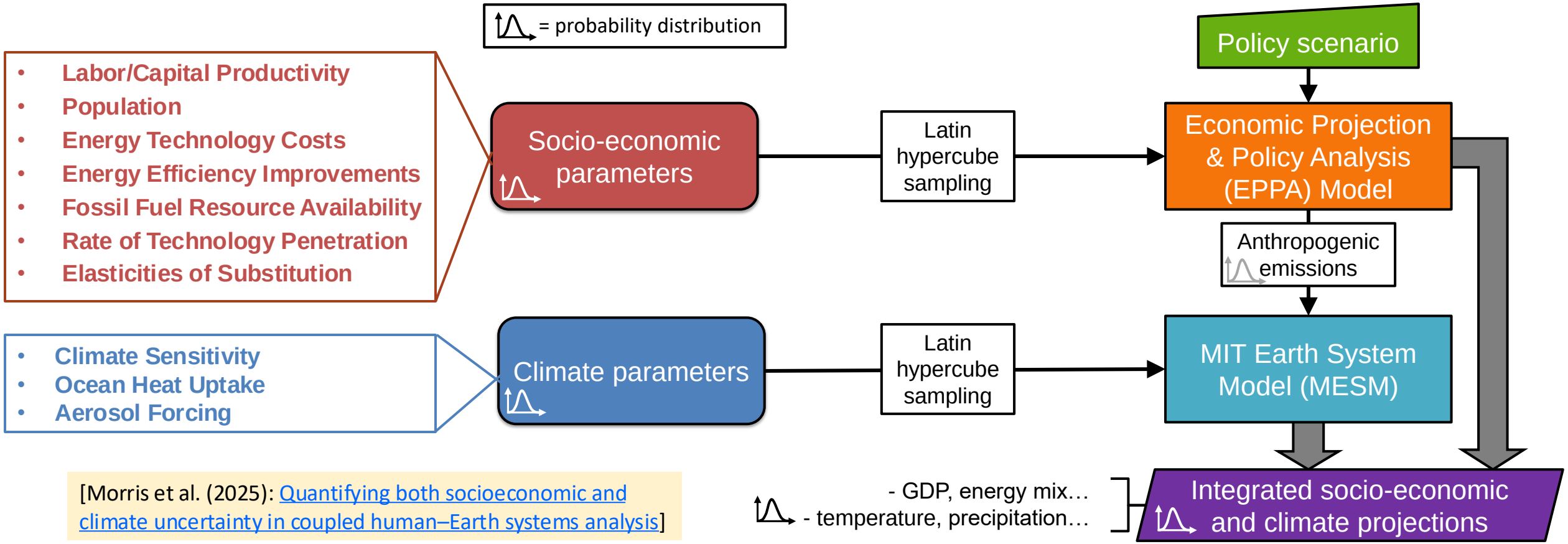
Vivek Srikrishnan[1], David C. Lafferty[2], Tony E. Wong[3], Jonathan R. Lamontagne[4], Julianne D. Quinn[5], Sanjib Sharma[6], Nusrat J. Molla[7], Jonathan D. Herman[7], Ryan L. Sriver[2], Jennifer F. Morris[8], and Ben Seiyon Lee[9]

Srikrishnan et al. (2022)

But fine scale models may be too computationally expensive to run many times…

Uncertainty means we need to explore a wide range of assumptions and scenarios

Exploratory modeling via probabilistic Monte Carlo analysis



[Morris et al. (2025): Quantifying both socioeconomic and climate uncertainty in coupled human–Earth systems analysis]

[Morris et al. (2022): Representing Socio-Economic Uncertainty in Human System Models]

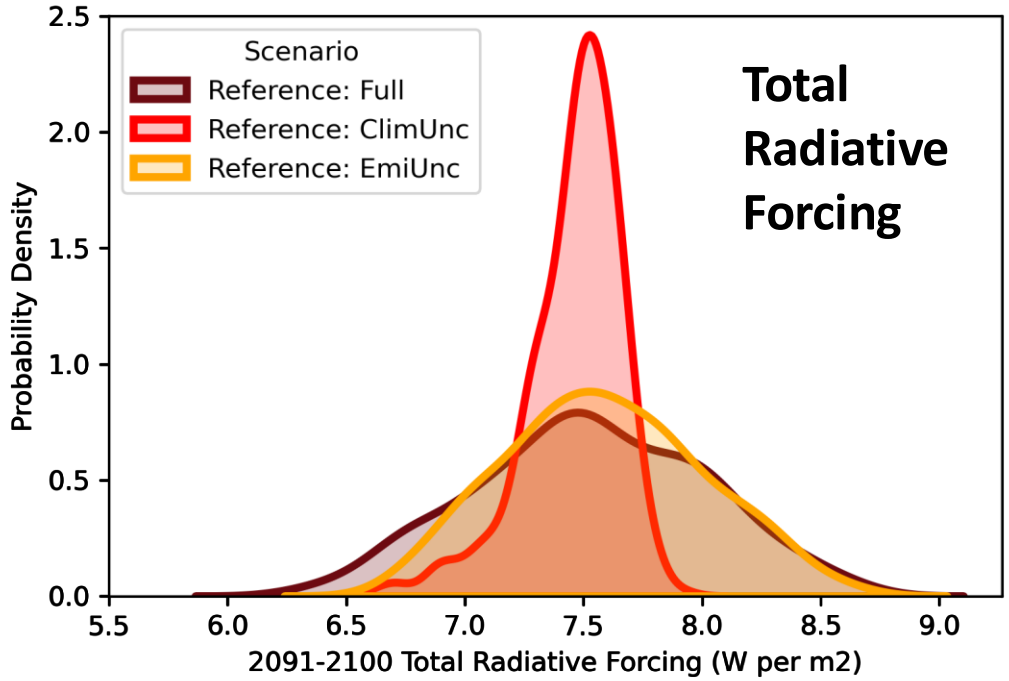
Combination of human and Earth system uncertainty is less than additive

Reference (unconstrained emissions) scenario

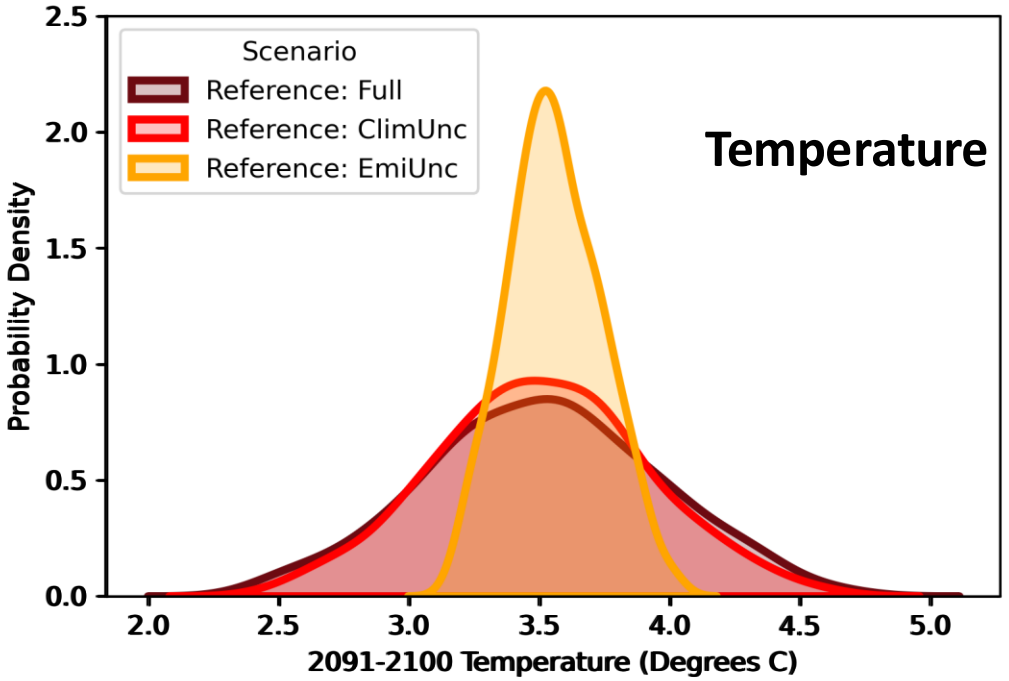
Full: both socio-economic and climate uncertainty

ClimUnc: just climate uncertainty, median emissions

EmiUnc: just socio-economic uncertainty, median climate



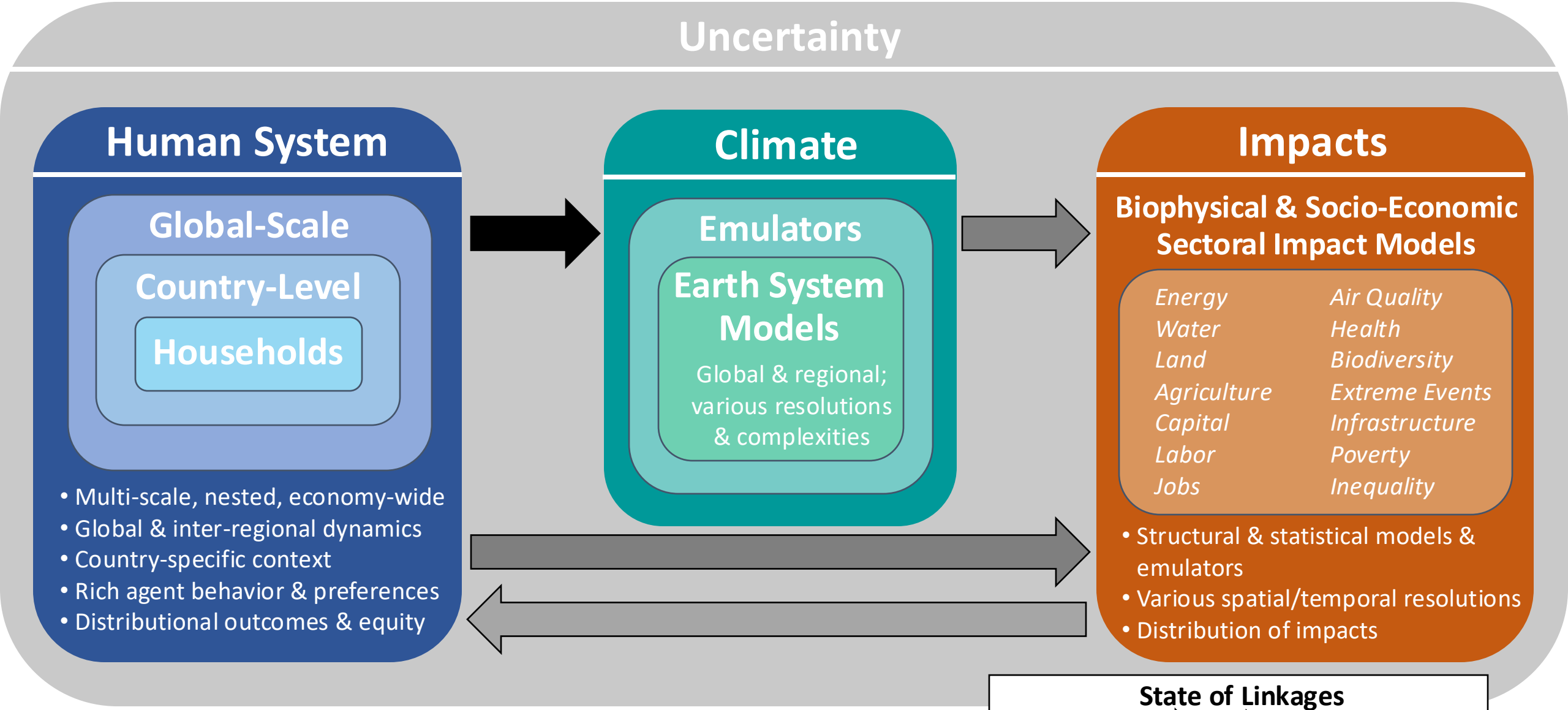
Human system uncertainties dominate uncertainty of radiative forcing

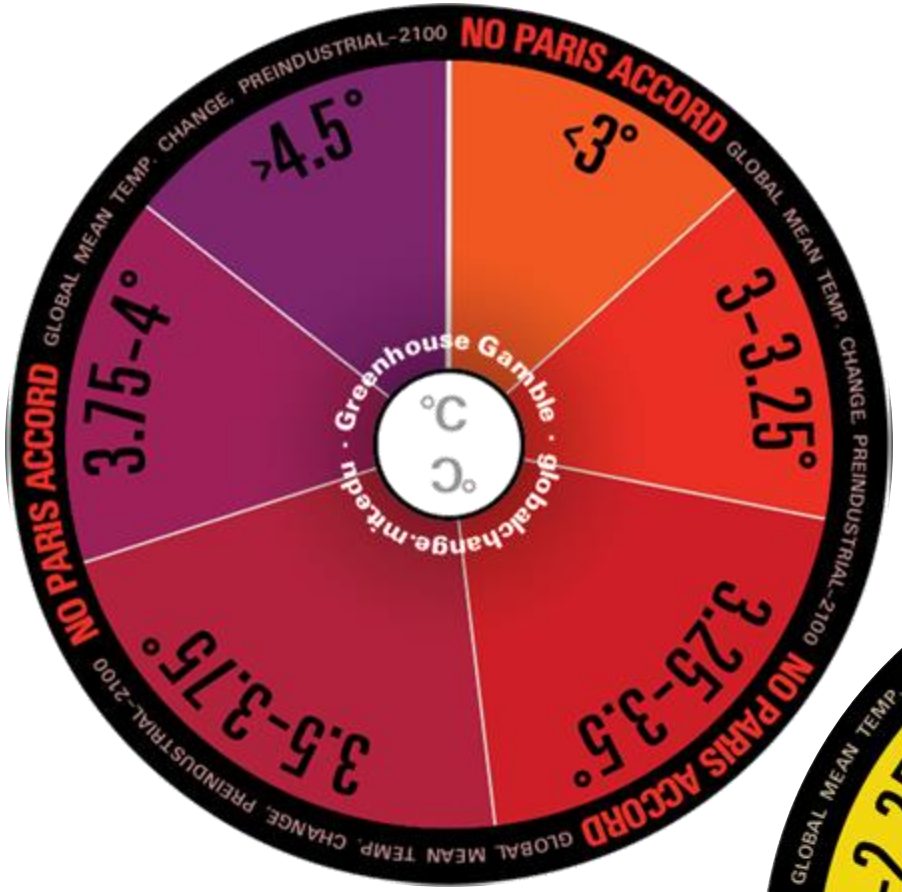


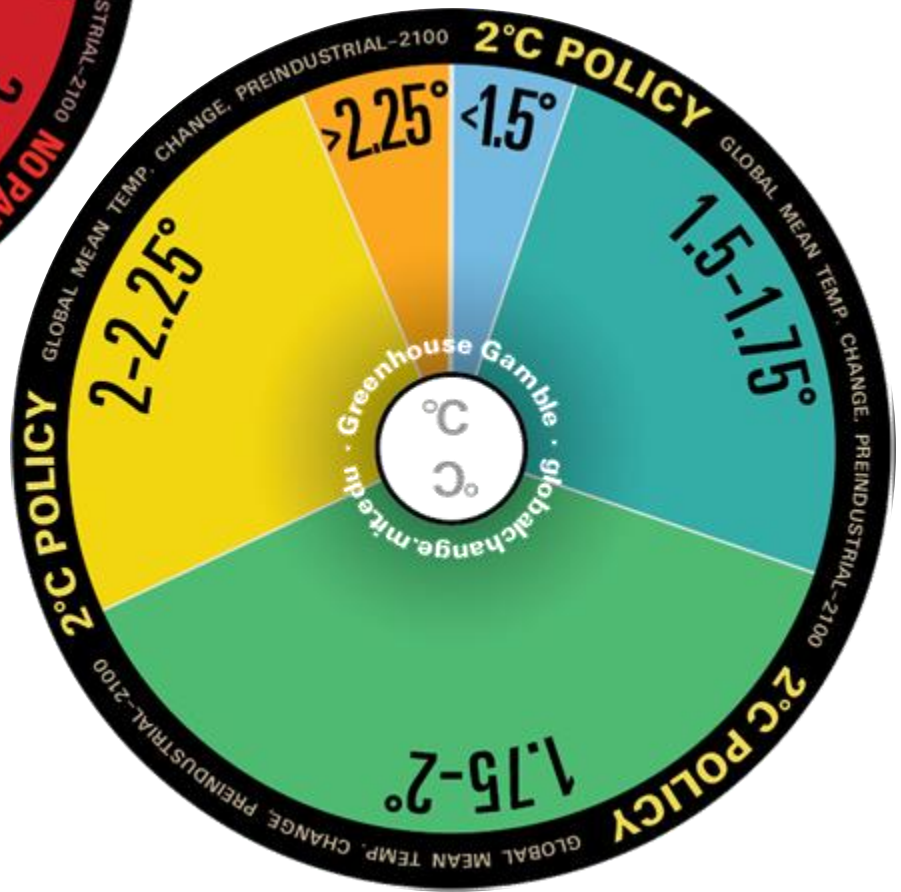
Earth system uncertainties dominate temperature uncertainty

Demonstrates need for integrated modeling for uncertainty analysis

Overcoming Challenges: Advancing components & flexible integration







Uncertainty is unavoidable… but we can quantify where possible and make decisions accordingly

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Thank you!

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