Quantifying uncertainty in global and sub-global socioeconomic and greenhouse gas emissions futures

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EIA Meeting on Challenges in Modeling International Climate Policies
June 29, 2022

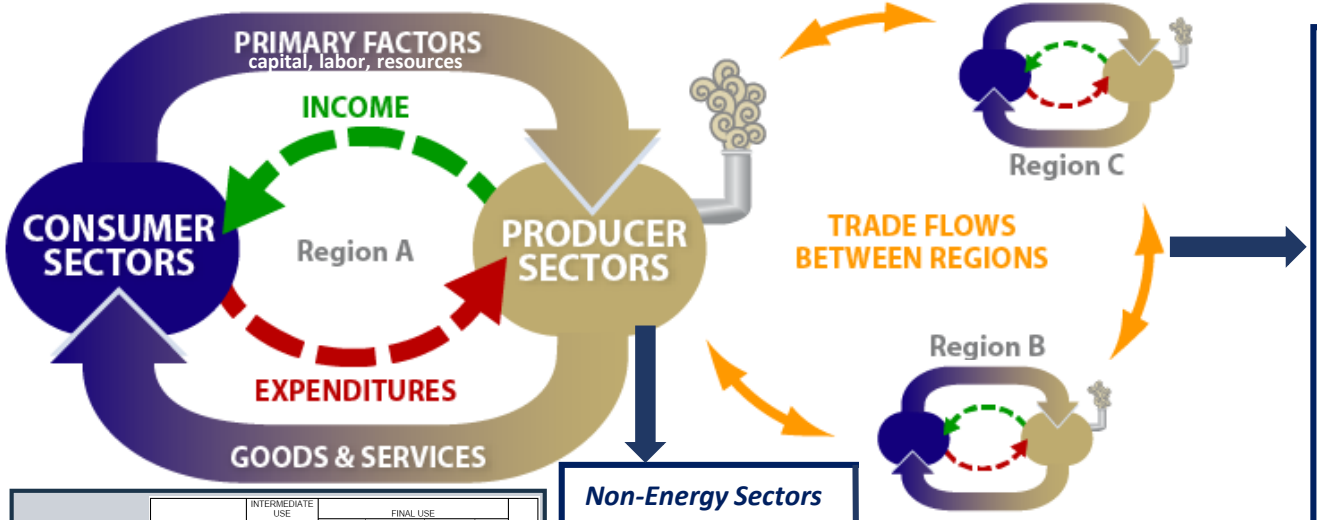
Uncertainty in Modeling International Climate Policies

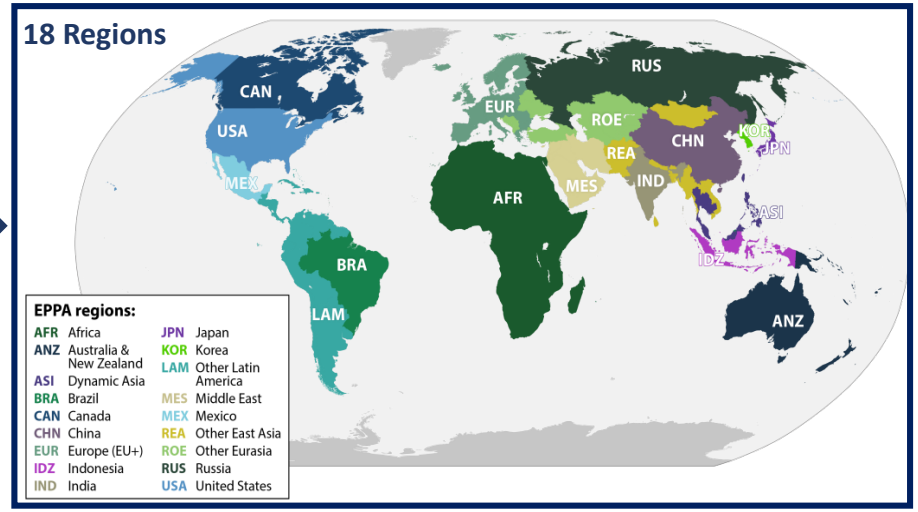
- Many uncertainties:
  - Human system: socioeconomic assumptions
  - Policy: level and design
  - Earth system: climate assumptions
- Uncertainty typically represented through sensitivity analysis, scenarios and model comparisons → No probabilistic interpretation
- Need for formal quantification of uncertainty about the future composition of society to inform climate policy and planning and risk management
  - At both global and sub-global levels… and coherency across scales

→ **GOAL:** Develop a **probabilistic** multi-region, multi-sector energy-economic model and explore both **parametric uncertainty** and **deep uncertainty about climate policy** and resulting distributions for potential future global and sub-global societies with and without additional climate policy

MIT Economic Projection and Policy Analysis (EPPA) Model

Multi-sector, multi-region computable general equilibrium (CGE) model of the world economy for energy, economy and emissions projections





Technical Features
- Written in GAMS using MSPGE
- Based on GTAP Database
- Calibrated to current economic and energy levels based on IMF and IEA
- Documented in peer-reviewed literature
- Publicly Available Version
- 2100+ (in 5-year steps)

Full Input-Output Data for Every Region

		INTERMEDIATE USE by Production Sectors				FINAL USE				OUTPUT
		1	2	...	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								

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

Non-Energy Sectors
- **Crops**
- **Livestock**
- **Forestry**
- **Food**
- **Energy-Intensive Industry** — Iron & Steel, Cement, Chemicals, Non-Ferrous Metals, *+ low-carbon options*
- **Manufacturing**
- **Service**
- **Commercial Transport**
- **Household Transport** — ICE (gasoline & diesel), Plug-in Electric, Battery Electric, Hydrogen

Energy Sectors
- **Crude Oil**
- **Refined Oil**
- **Liquid Fuel from Biomass** — Current Generation, Advanced Biofuel
- **Oil Shale**
- **Coal**
- **Natural Gas (conv., shale, tight)**
- **Electricity** — Conv. Fossil (coal, gas, oil); Adv. Fossil (NGCC, Adv Coal); Coal with CCS; Coal + Bio Co-firing w/ CCS; Gas with CCS; Gas with Advanced CCS; Nuclear; Advanced Nuclear; Hydro; Solar; Wind; Renewables with Backup; Biomass; Biomass with CCS
- **Synthetic Gas (from Coal)**

New Technologies Continually Added

Regions and sectors can be added for special studies

Key Outputs
- GDP
- Consumption
- Emissions (GHGs, Air Pollutants)
- Primary/Final Energy Use
- Electricity Generation
- Technology Mix
- Commodity and Factor Prices
- Sectoral Output
- Land Use

At global and regional levels

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)**

Key Equations

Firms maximize profit: choose technology, level of output and inputs subject to production functions and costs

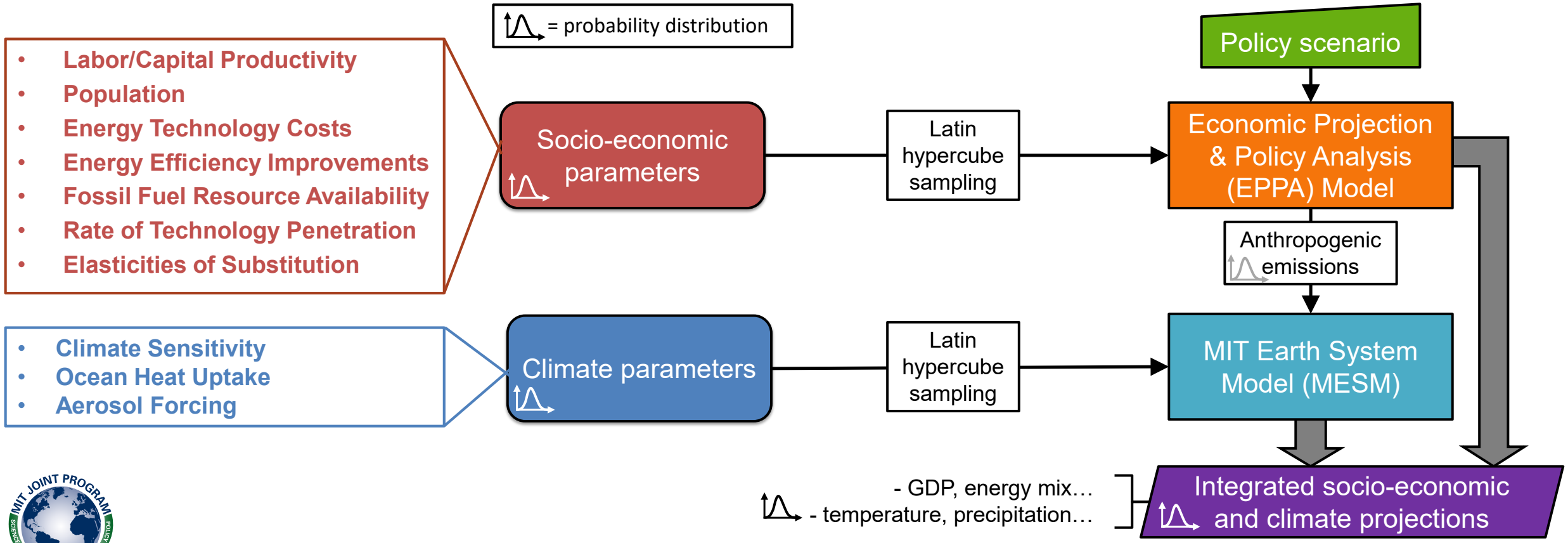
Household maximize welfare: choose savings and consumption subject to budget constraint

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

https://globalchange.mit.edu/research/research-tools/human-system-model

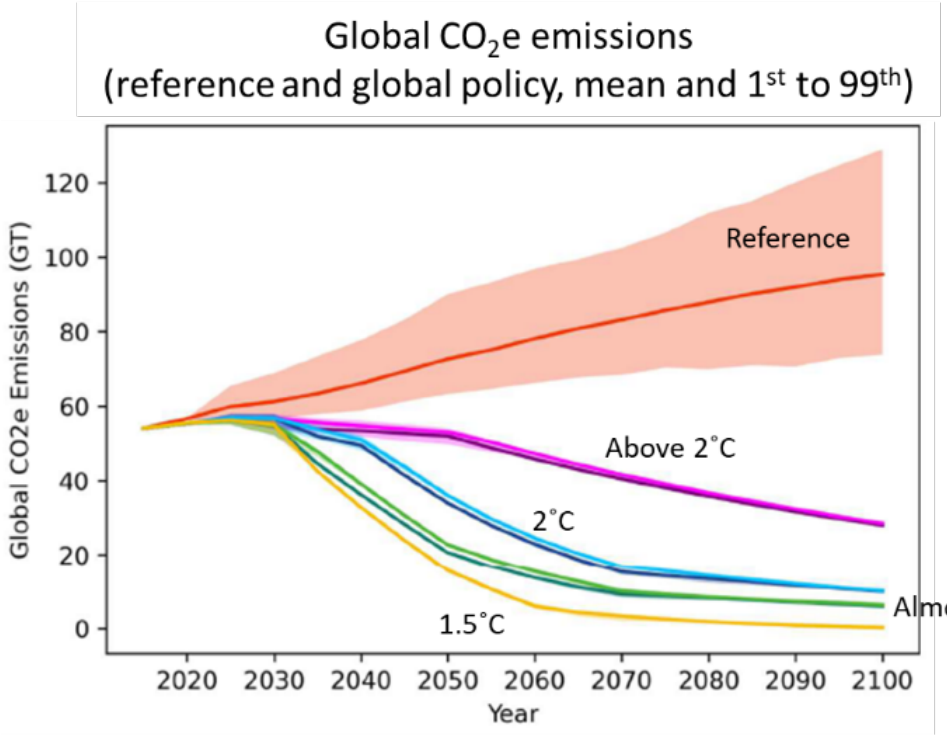
Uncertainty Quantification via Traditional Monte Carlo Approach

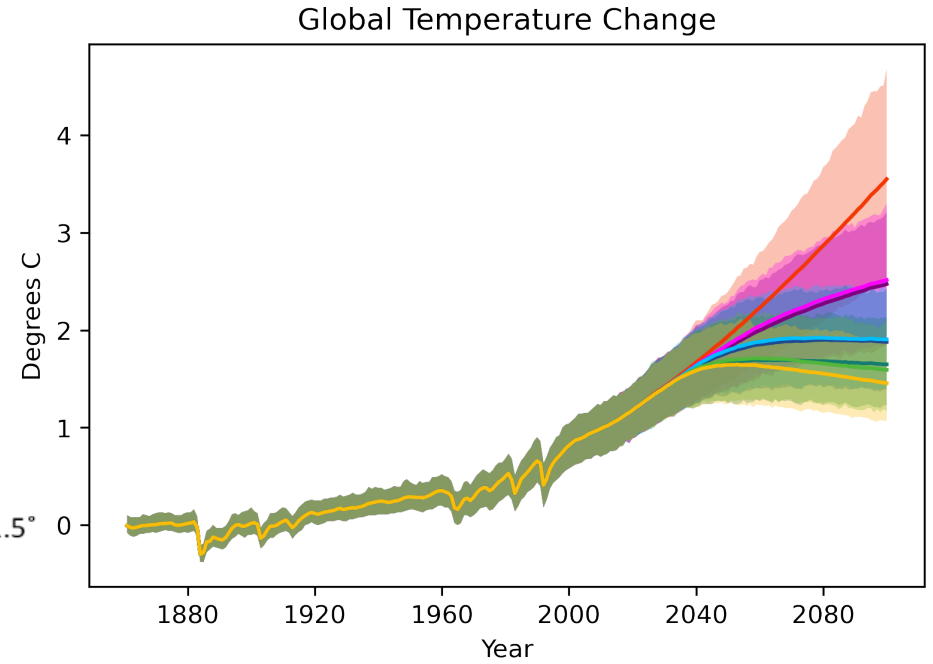
- Probability distributions for input parameters are developed & sampled
- Simulated through MIT integrated models to explore a range of possible future outcomes
- For a set of ensemble scenarios representing different policy levels and designs



Scenarios for Ensembles

- Increasingly stringent **global policies** comprised of increasingly stringent **regional GHG constraints**



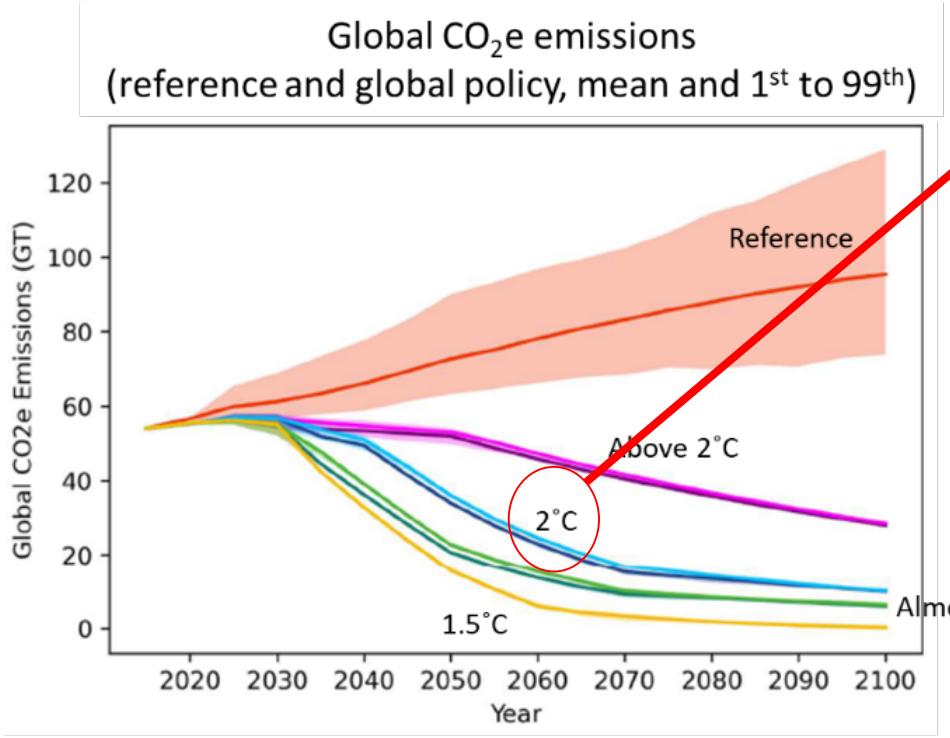


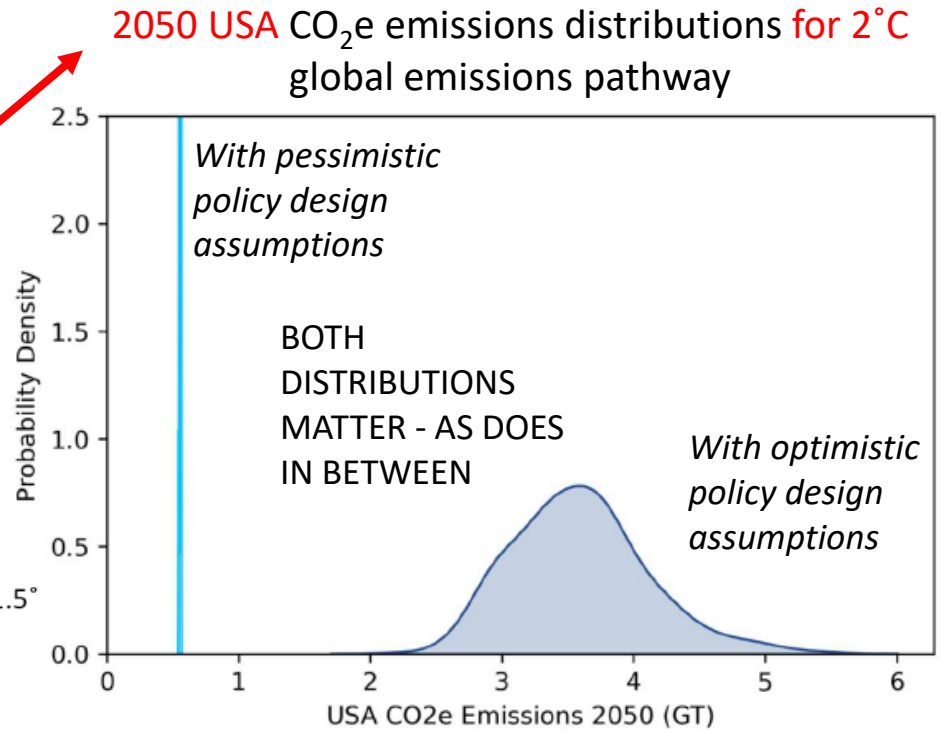
Global pathway definitions

Global pathway	Description
Reference	No additional future climate policy (median 2100 temp 3.4˚C)
Above 2˚C	Peak 2.5˚C w/ 45-60% chance (< 3˚C 92-98%)
2˚C	Peak 2˚C w/ 58-60%, 2100 61-64% < 2˚C
Almost 1.5˚C	Peak 1.5˚C w/ 8-15% (< 2˚C 86-90%), 2100 25-33% < 1.5˚C (94-98% < 2˚C)
1.5˚C	Peak 1.5˚C w/ 21%, 2100 58% < 1.5˚C

Scenarios for Ensembles

- Increasingly stringent **global policies** comprised of increasingly stringent **regional GHG constraints**
- **"Optimistic"** and **"Pessimistic"** GHG management conditions that represent deep uncertainties for climate strategy: international emissions cooperation, coverage of land use related emissions, and availability of carbon dioxide removal technologies

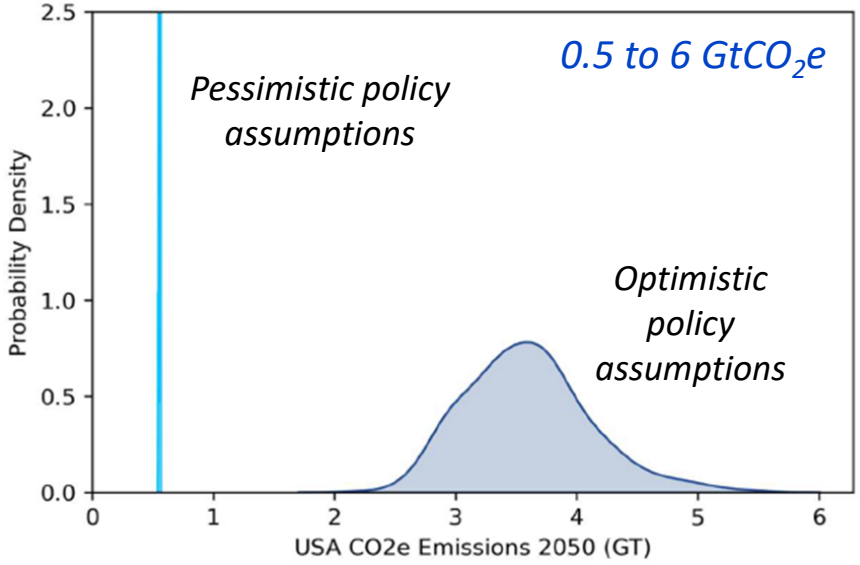




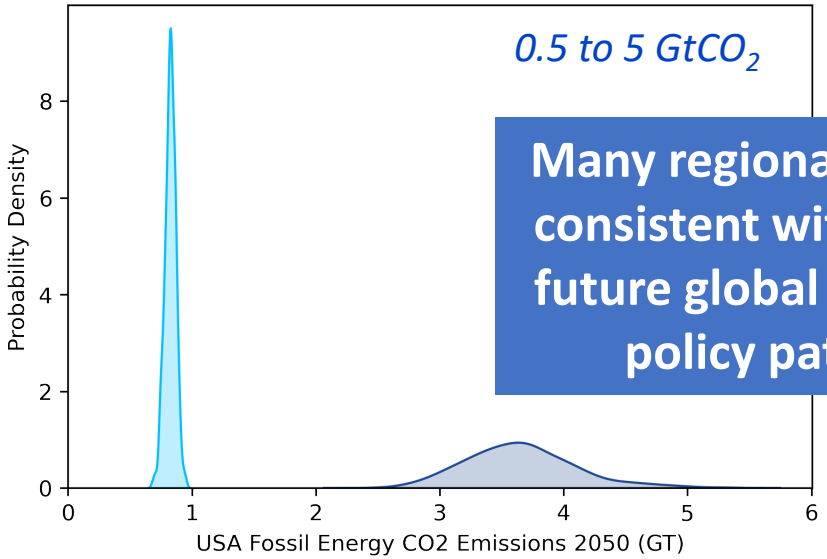
	CDR (BECCS & afforestation)	Land Mitigation Covered	International Permit Trading
Optimistic	**Yes**	**Yes**	**Yes**
Pessimistic	**No**	**No**	**No**

US 2050 uncertainty for a single 2˚C global emissions pathway

CO_2e Emissions

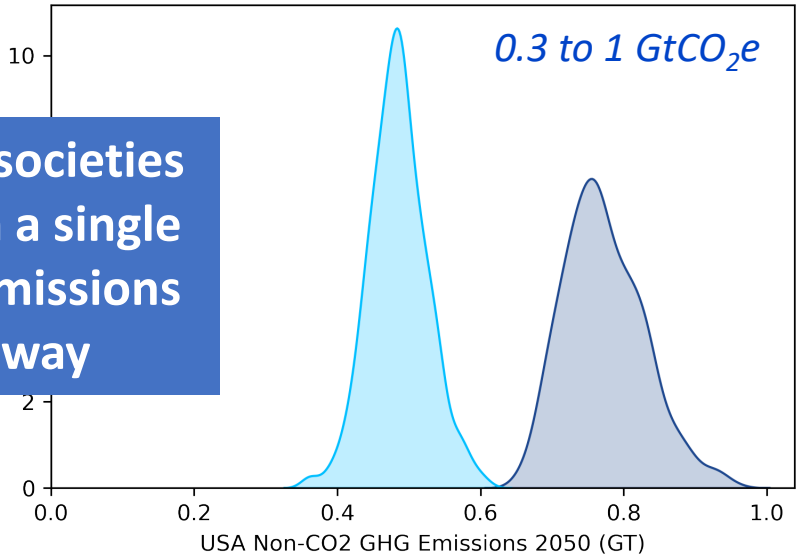


Fossil Energy CO_2 Emissions

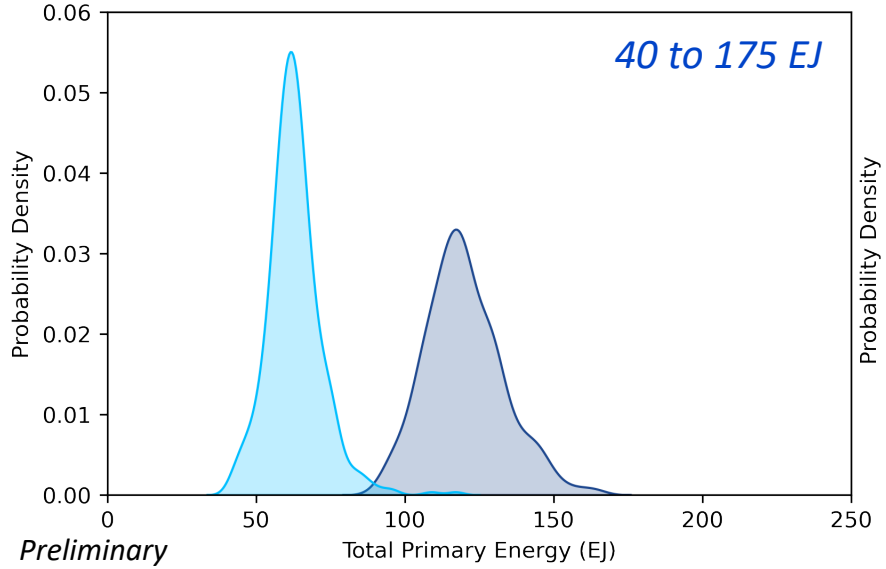


Many regional societies consistent with a single future global emissions policy pathway

Non-CO_2 GHG Emissions



Total Primary Energy



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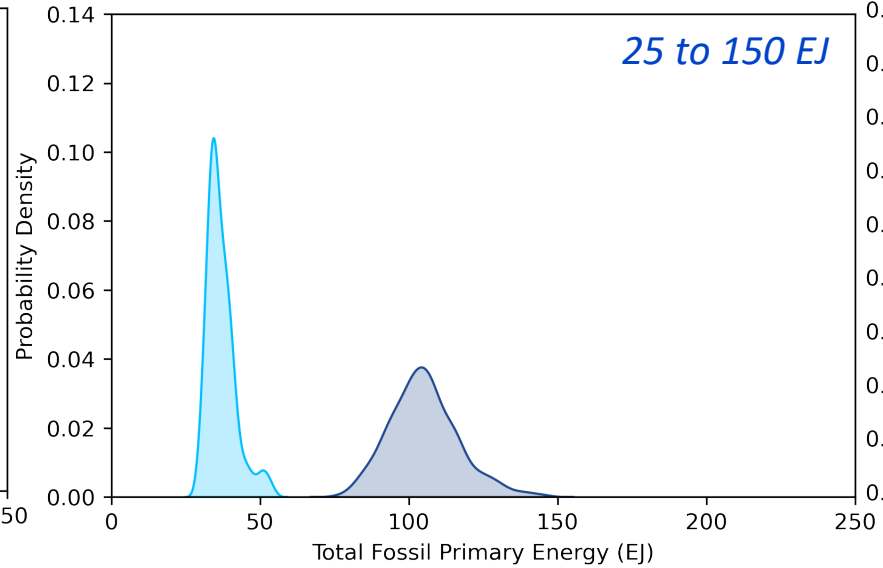
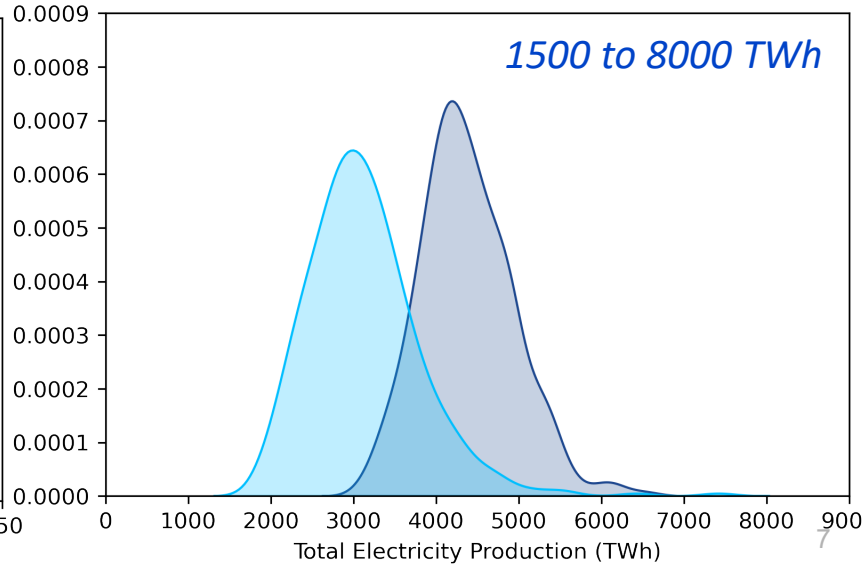
Fossil Primary Energy

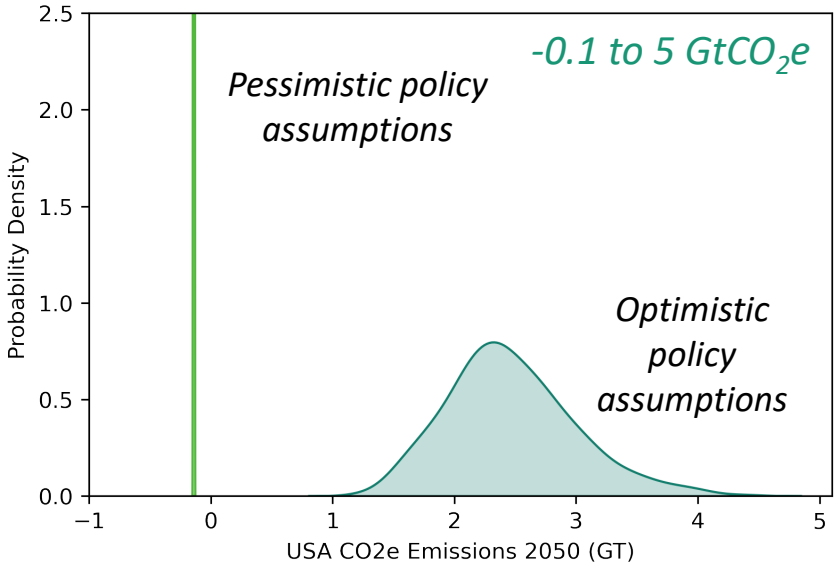


Electricity Generation



US 2050 uncertainty for a single Almost 1.5˚C global emissions pathway

CO_2e Emissions



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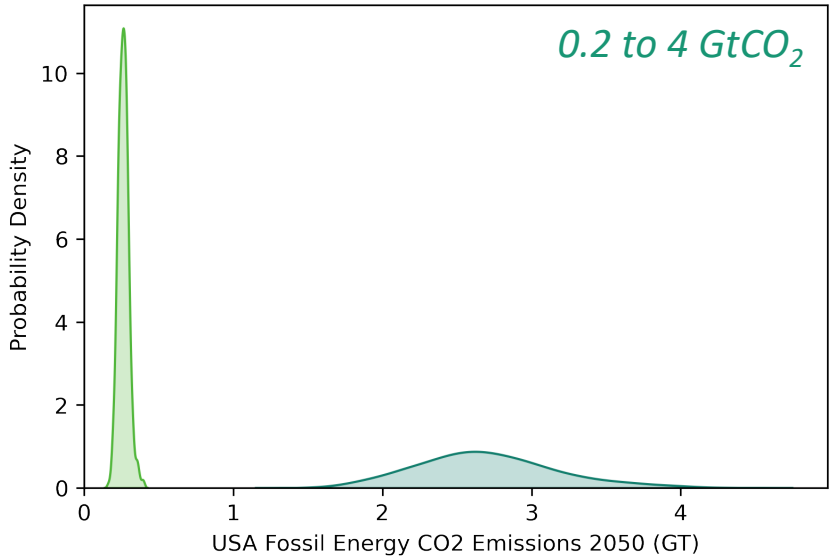

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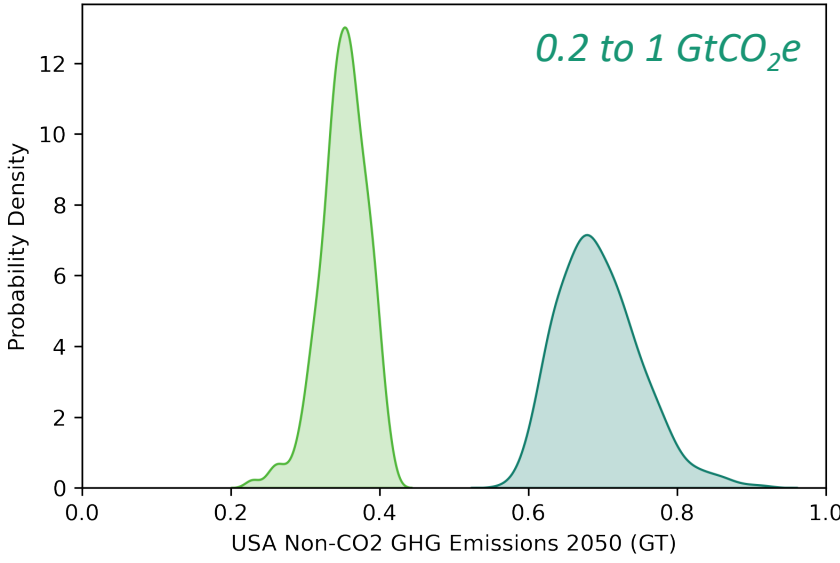

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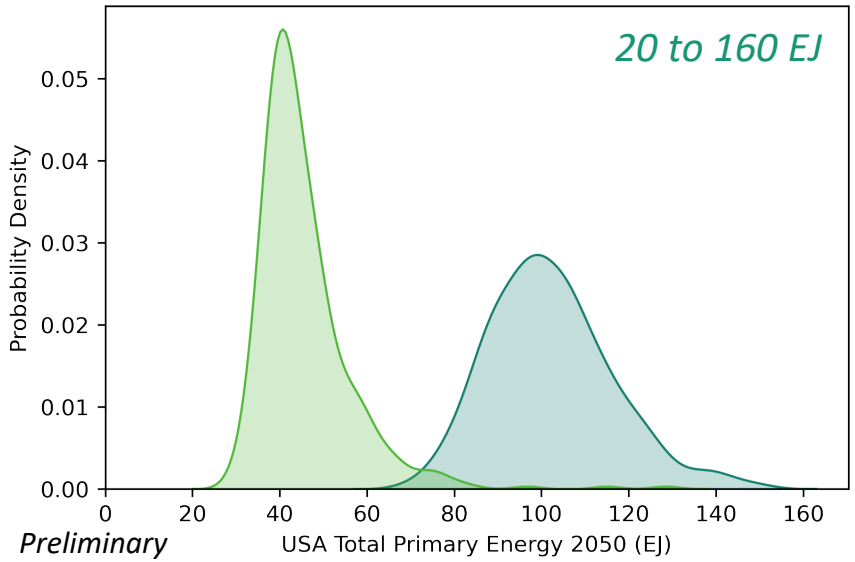

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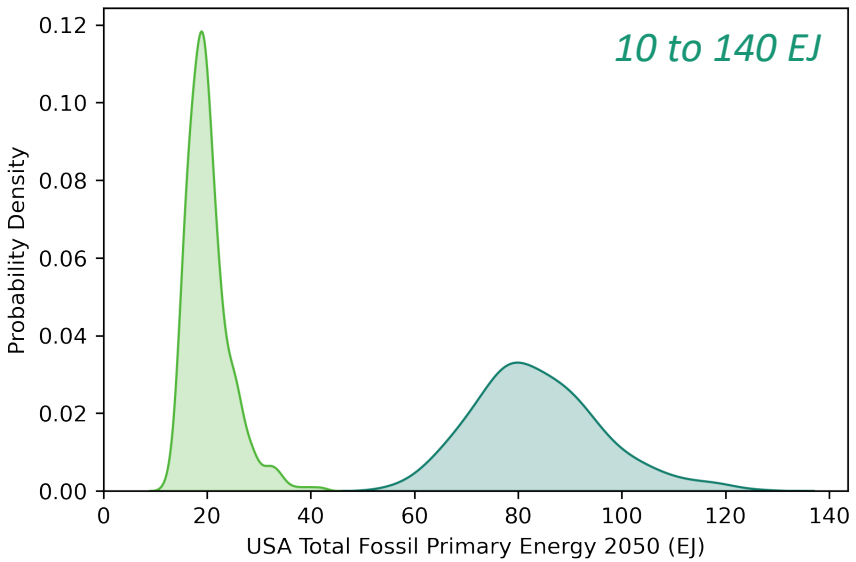

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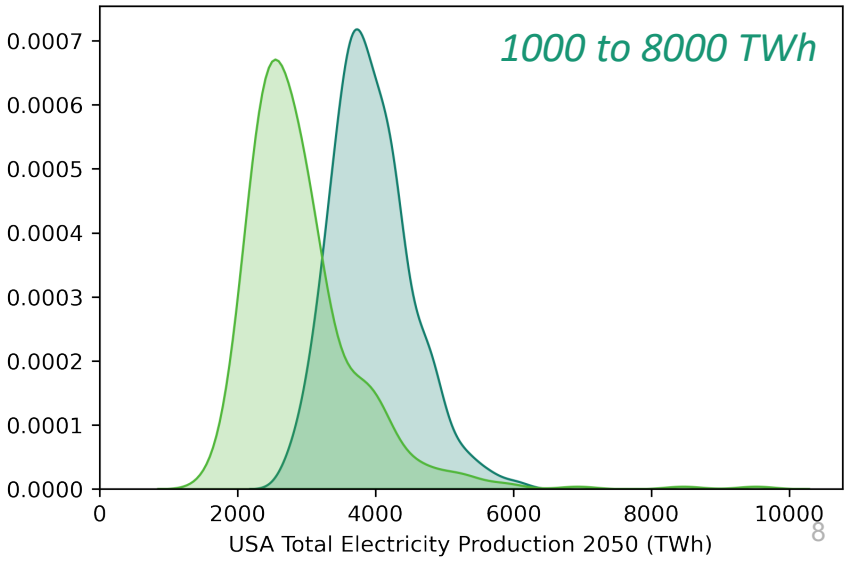

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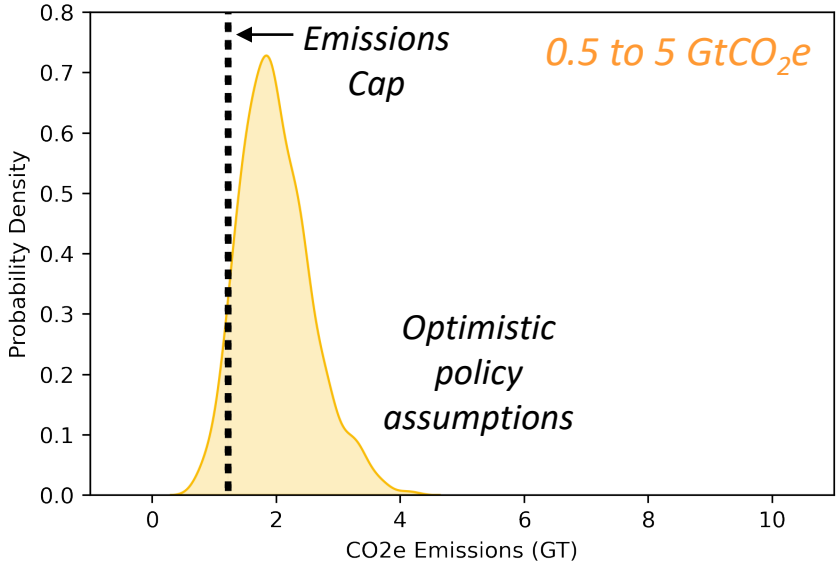

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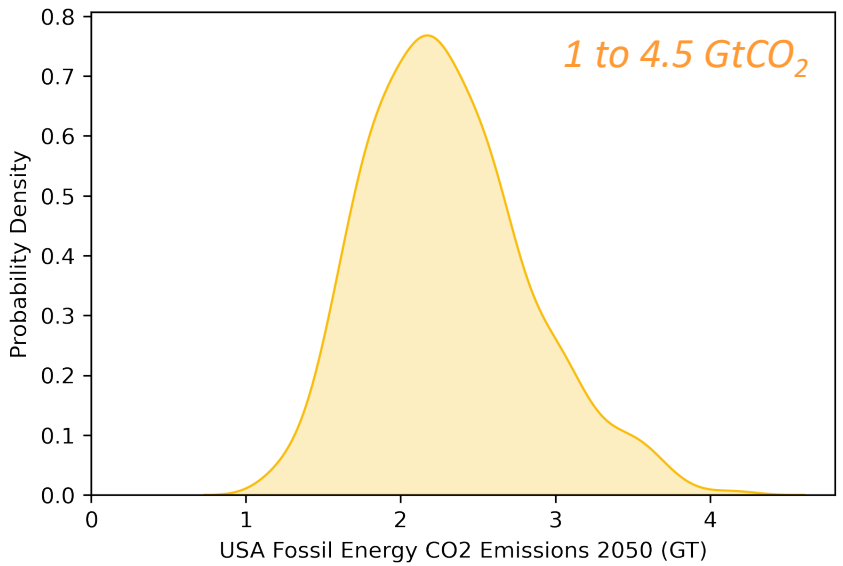

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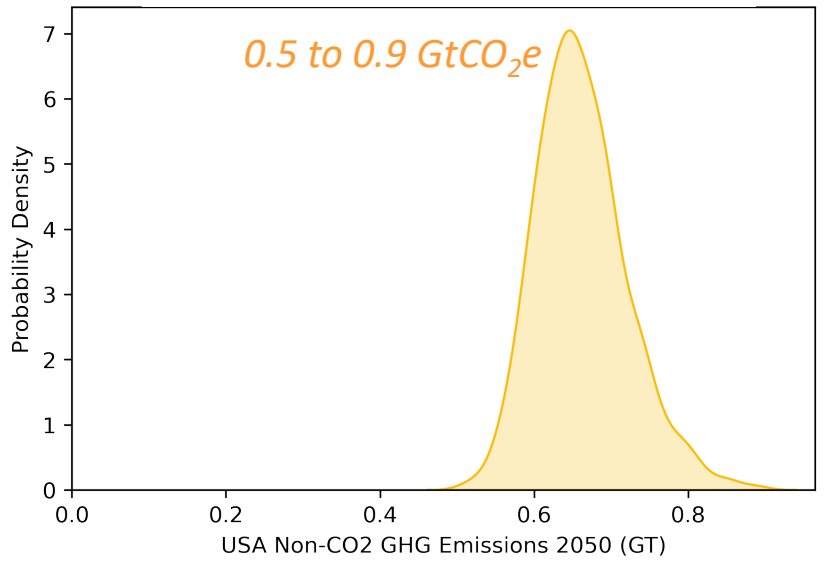

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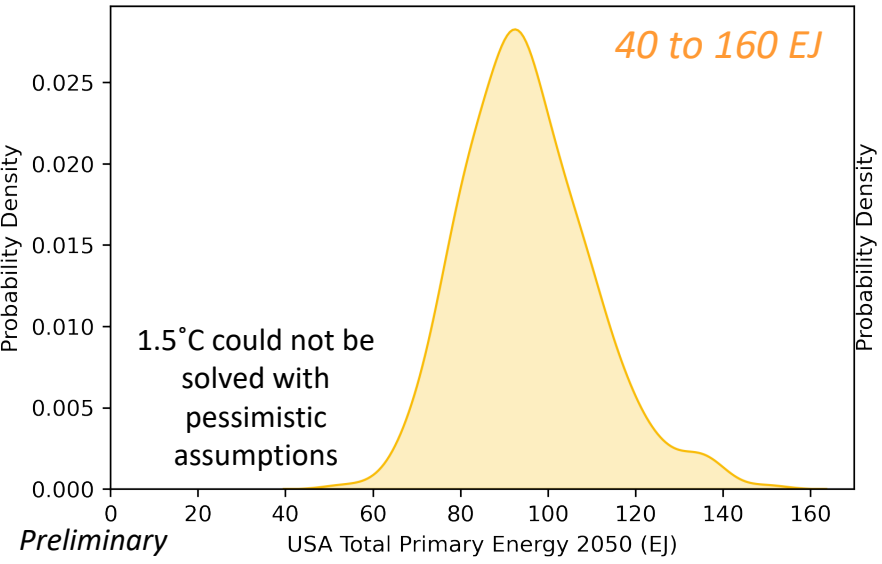
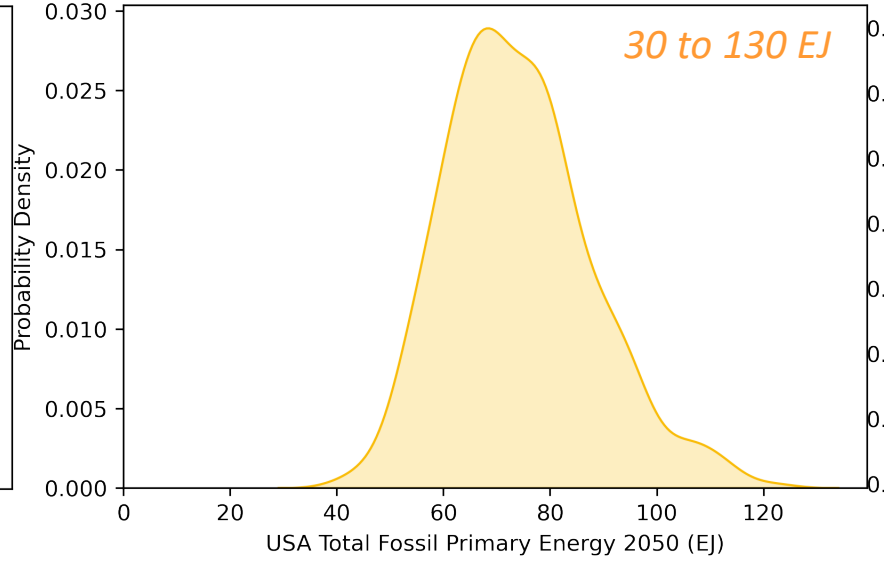


Fossil Primary Energy



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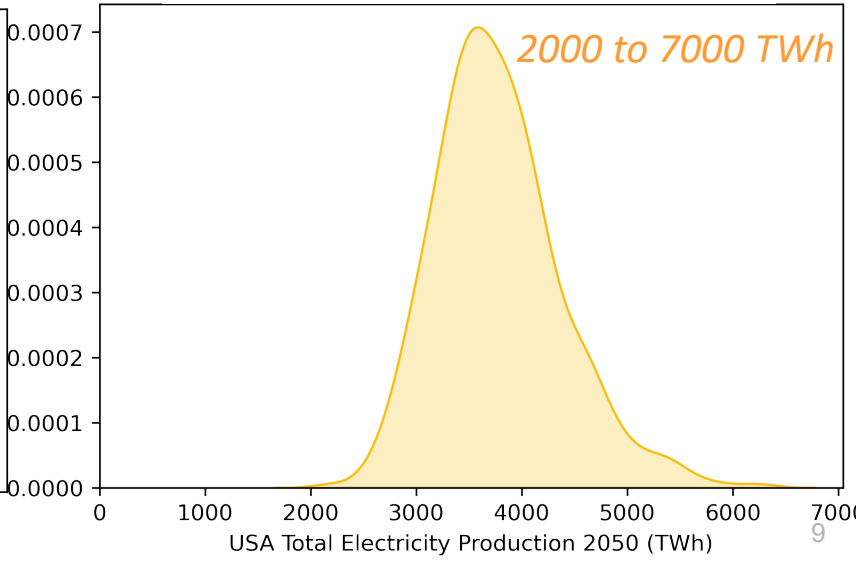
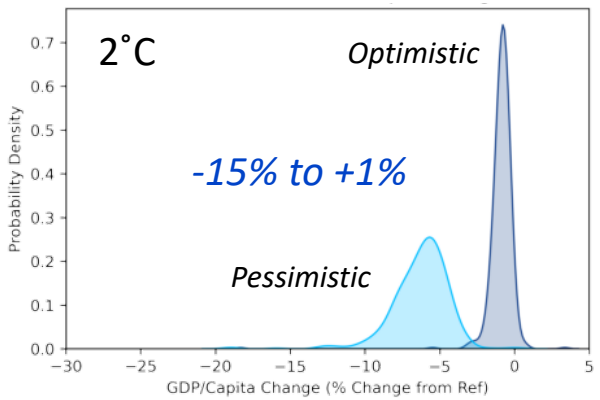


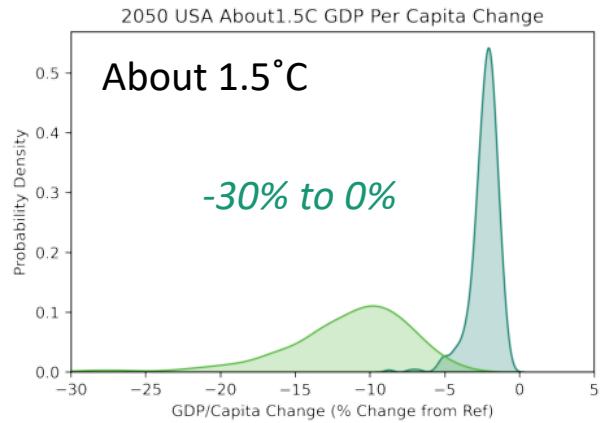
Preliminary

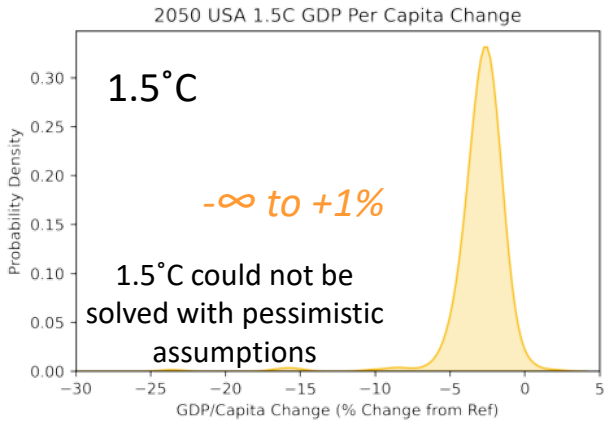
US 2050 cost uncertainty for different ˚C pathways

Substantial regional cost uncertainty – due primarily to pessimistic decarbonization policy context, and the uncertainty increases with policy ambition

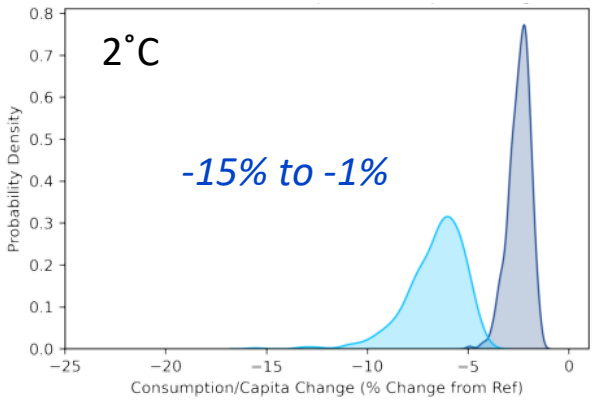
GDP per capita % change

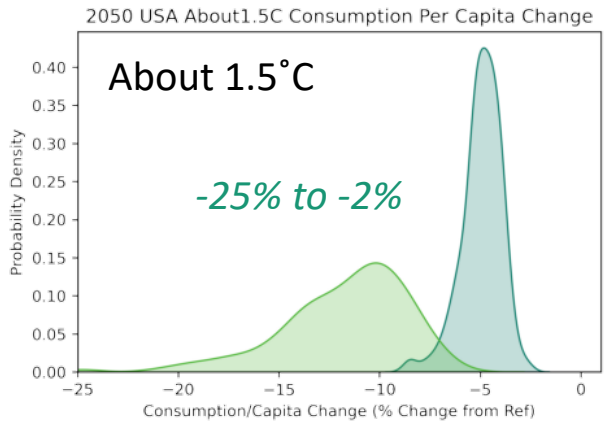


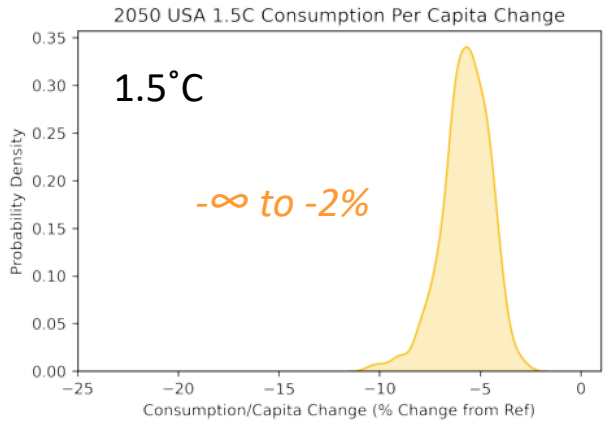




Consumption per capita % change

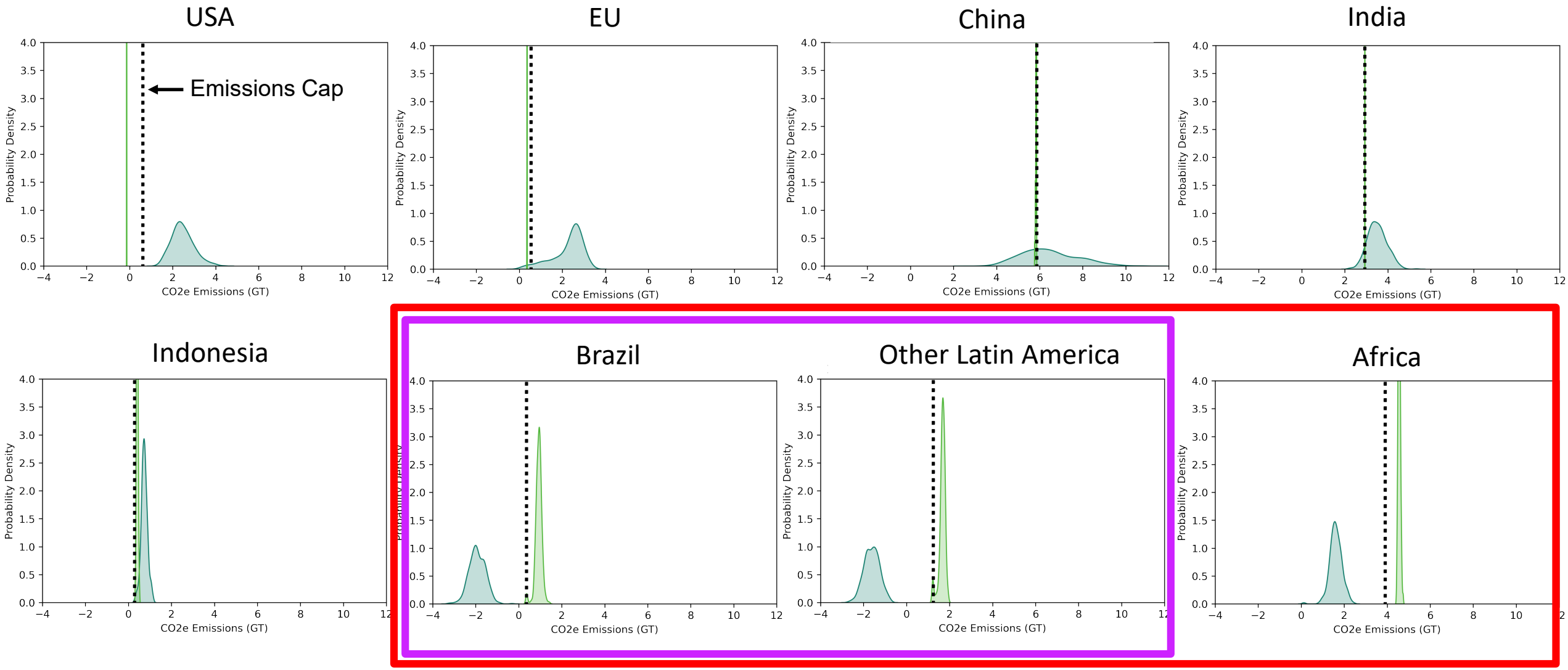






Preliminary

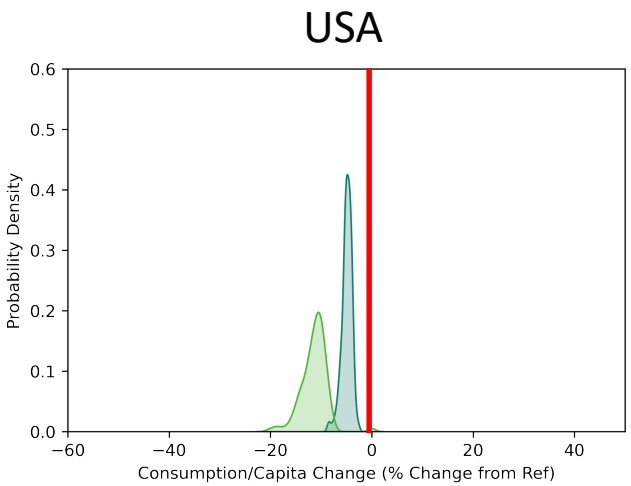
CO_2e emissions for selected regions under Almost 1.5˚C scenario

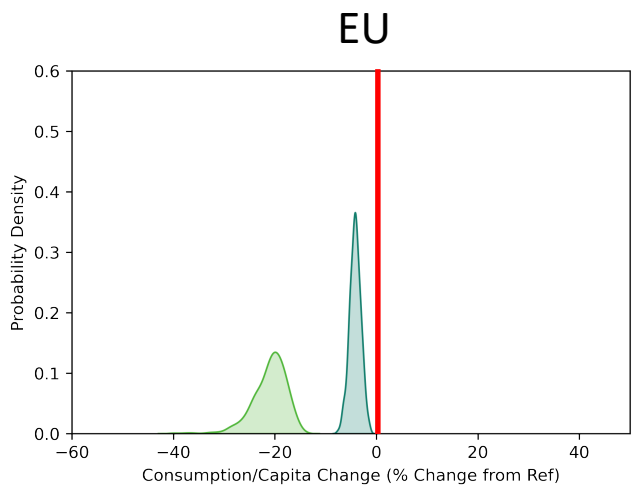


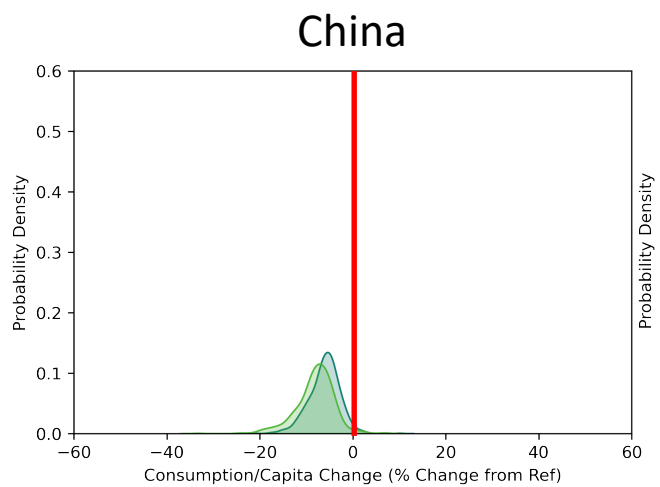
NET-NEGATIVE SELLERS

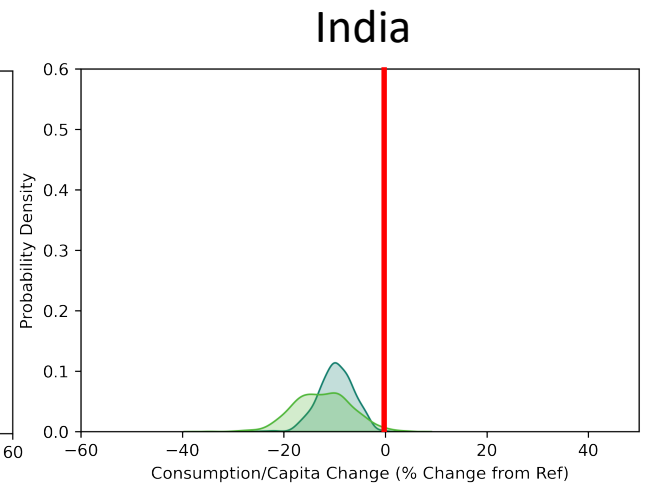
Preliminary

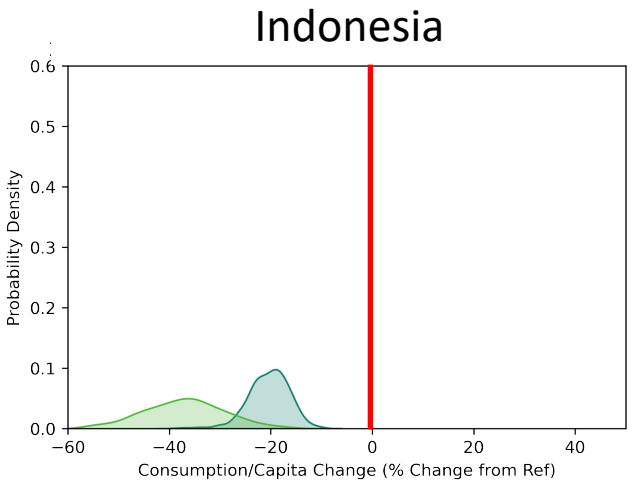
Consumption Impact for selected regions under Almost 1.5˚C scenario

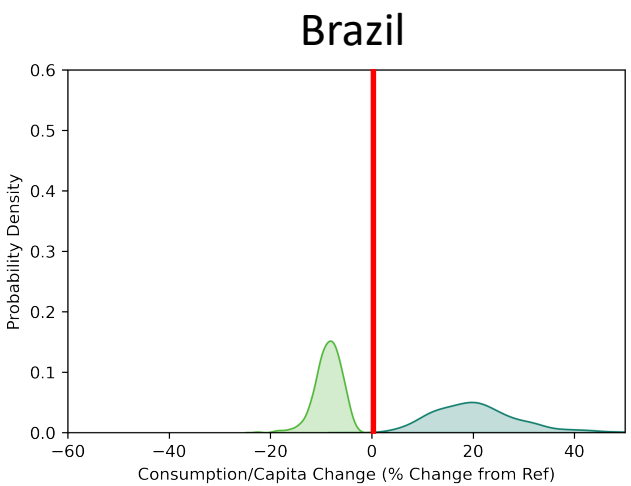


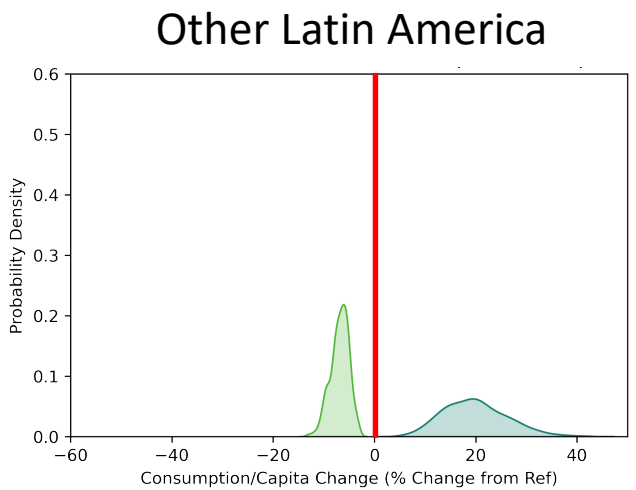


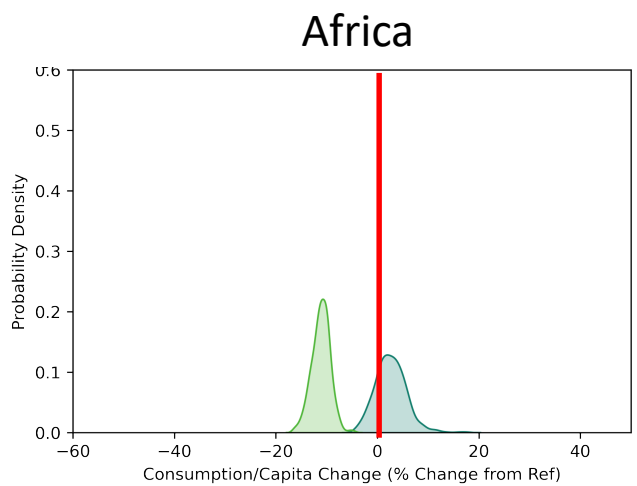












consumption/capita % change from Reference

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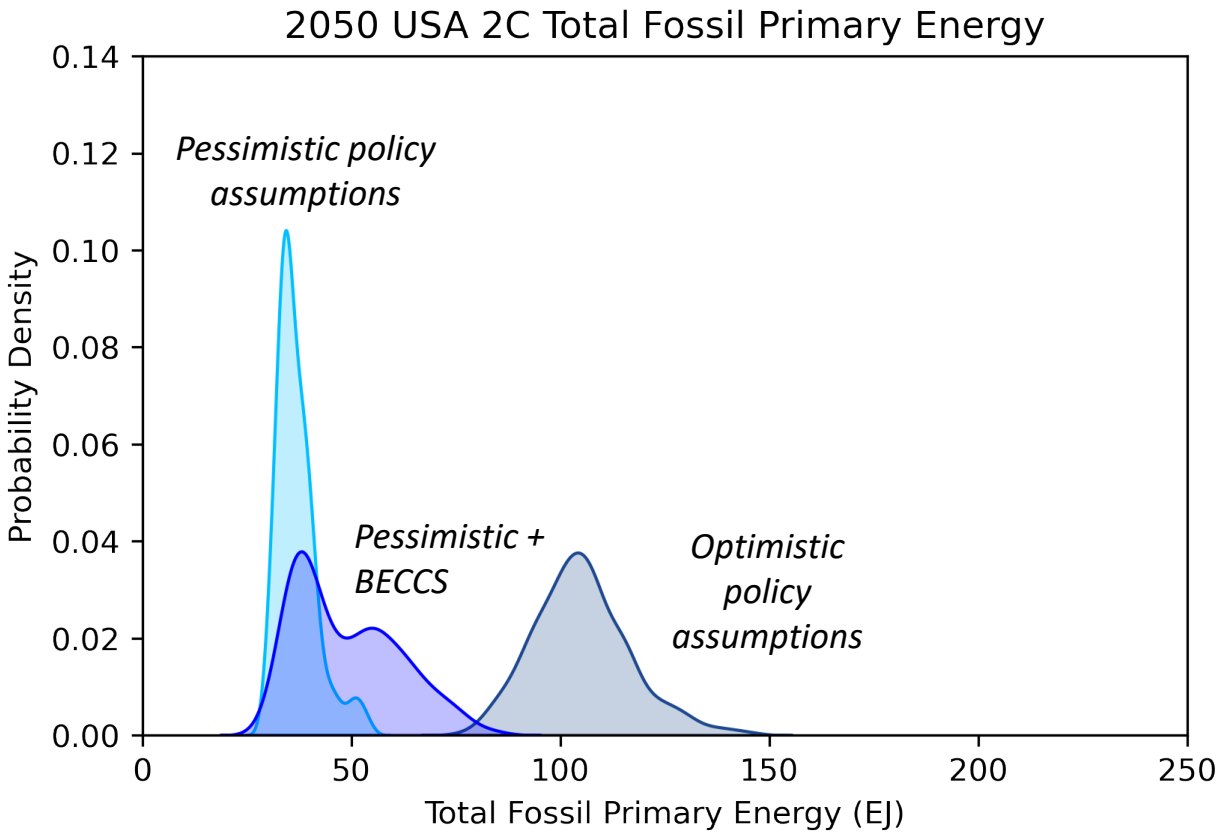
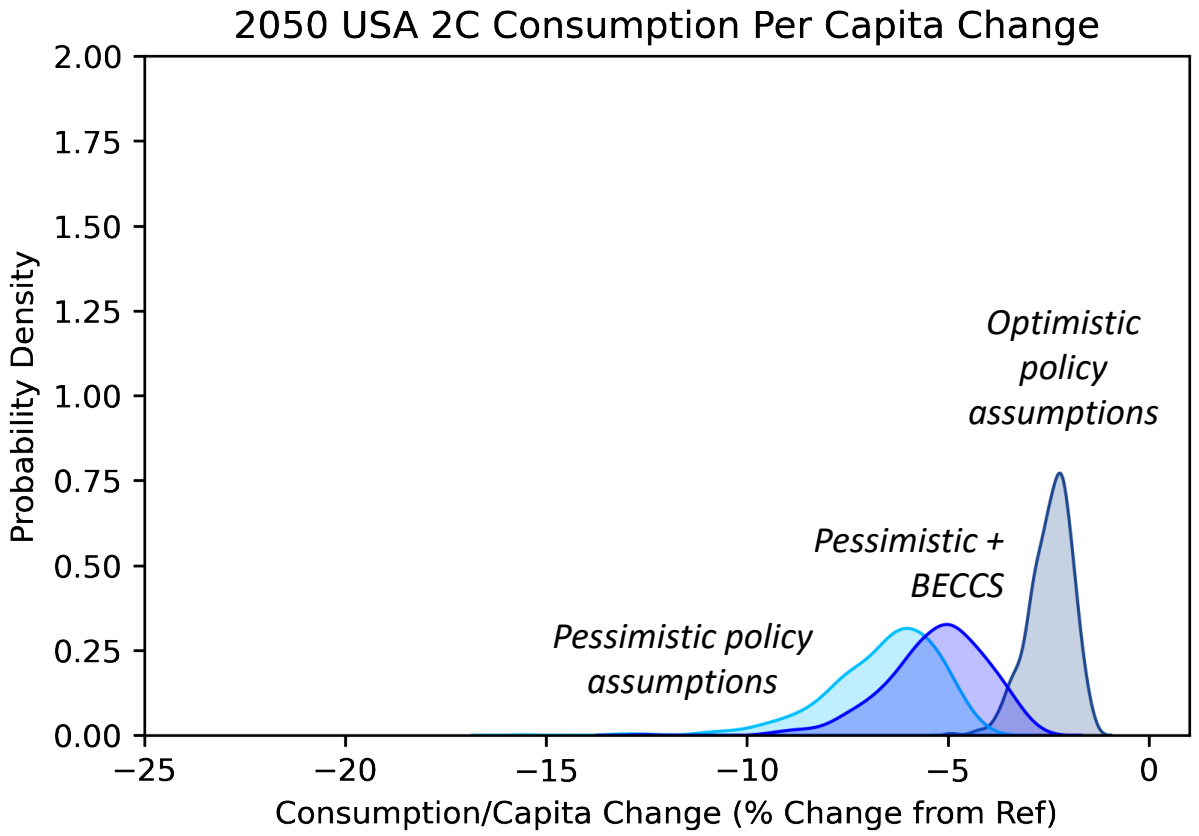
What about an intermediate scenario? Pessimistic + BECCS

US 2050 uncertainty for 2˚C global emissions pathway





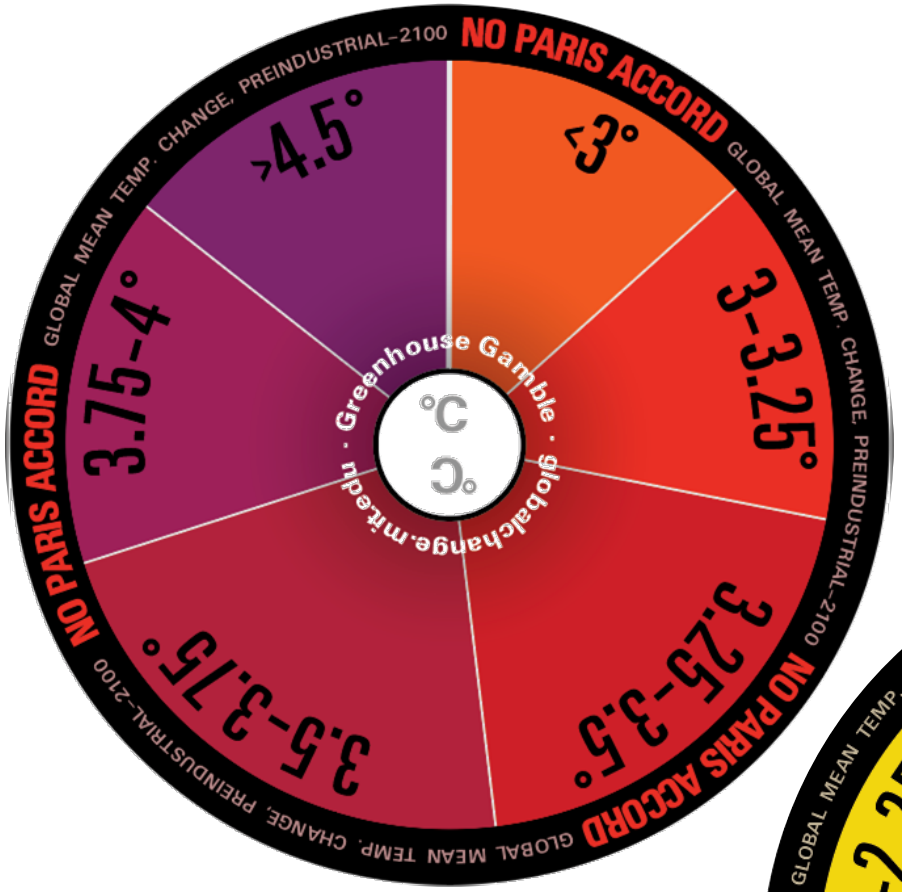
Preliminary

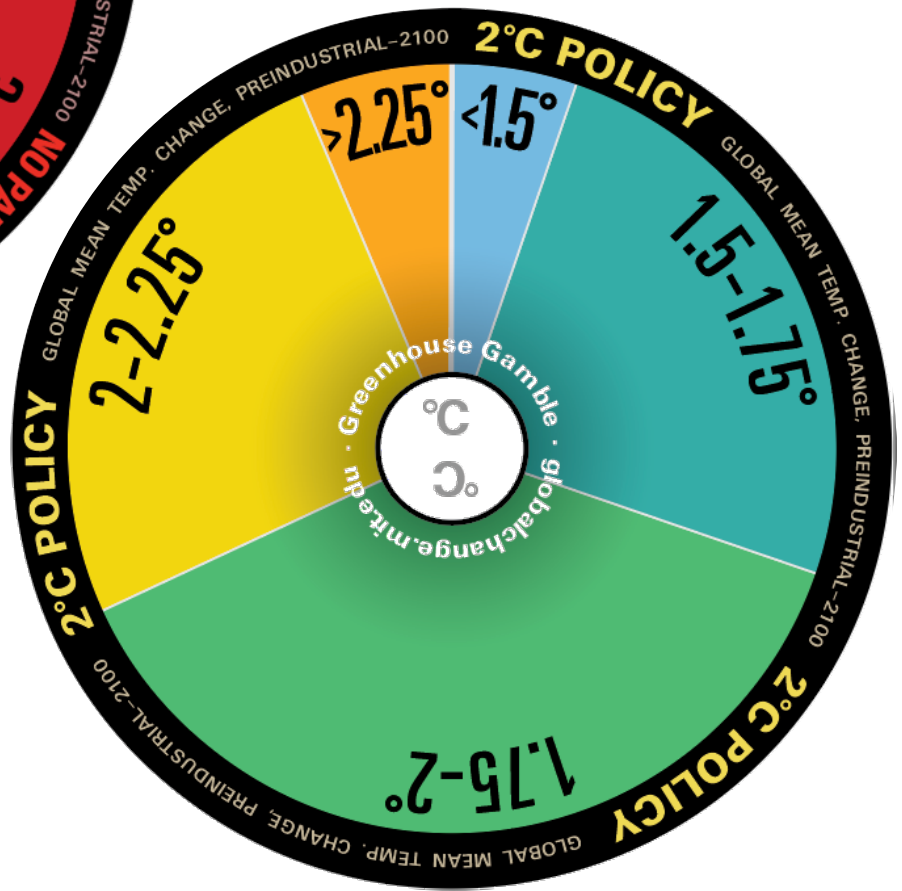
Key insights

- **Future socioeconomic structural uncertainty is significant** – at global, national and sectoral levels
- **Many societies** are consistent with a given global emissions climate policy pathway
- Results suggest that **uncertainty about the size of economies and their make-up** needs to be considered in climate risk assessment (transition and physical), social cost of carbon estimation, and GHG goal setting
- Results highlight that **both climate policy and non-policy uncertainties** represent risks that need to managed, and that planning for a single future (globally or sub-globally) is risky
- A **set of distributions representing wide ranges of possibilities** (e.g. optimistic & pessimistic, across policy stringency) is relevant to risk assessment & planning
    - Distribution overlap indicates that same condition are consistent with different global futures and climates – important for risk management
- Results could be used to **weight or rule out development pathways** in the literature

Selection of Recent MIT Work Relevant to Modeling International Climate Policies

- Representing socio-economic uncertainty in human system models (2022)
- Future energy: In search of a scenario reflecting current and future pressures and trends (2022)
- The MIT EPPA7: A Multisectoral Dynamic Model for Energy, Economic, and Climate Scenario Analysis (2022)
- 2021 Global Change Outlook (2021)
- Global Electrification of light-duty vehicles: Impacts of economics and climate policy (2021)
- Scenarios for the deployment of carbon capture and storage in the power sector in a portfolio of mitigation options (2021)
- The economics of bioenergy with carbon capture and storage (BECCS) deployment in a 1.5°C or 2°C world (2021)
- Projecting Energy and Climate for the 21st Century (2020)
- Representing the Costs of Low-Carbon Power Generation in Multi-region Multi-sector Energy-Economic Models (2019)
- Advanced Technologies in Energy-Economy Models for Climate Change Assessment (2019)
- MIT Scenarios for Assessing Climate-Related Financial Risk (2019)
- Can Tariffs be used to Enforce Paris Climate Commitments? (2018)
- Long-term economic modeling for climate change assessment (2016)





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

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Thank you!

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