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

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Formal characterization of uncertainty about the future composition of society is needed

- Consideration of uncertainty in global socioeconomic and greenhouse gas emissions projections is needed for climate policy and planning and risk management. Essential for, among other things…
    - Characterizing potential climates, impacts exposure and vulnerability, and mitigation strategies
    - Informing global climate goals and their benefit and cost trade-offs
    - Computing the social costs of carbon and other greenhouse gases
    - Assessing climate-related risks to economies and companies, as well as GHG goal setting
- Understanding of sub-global uncertainty is limited – absence of understanding and information regarding socioeconomic transformation uncertainty and risk implications relevant to federal, state, local and company decision-makers
- Projections to date arbitrary without probabilistic interpretation & coherency across variables and scales
    - Global emissions scenarios/projections (SRES, RCPs, SSPs, IPCC), and national scenarios /projections, without any means for weighting them, or even statistical interpretation (Rose and Scott, 2018, 2020)
- Furthermore, individual global emissions pathways are being prescribed to address climate change

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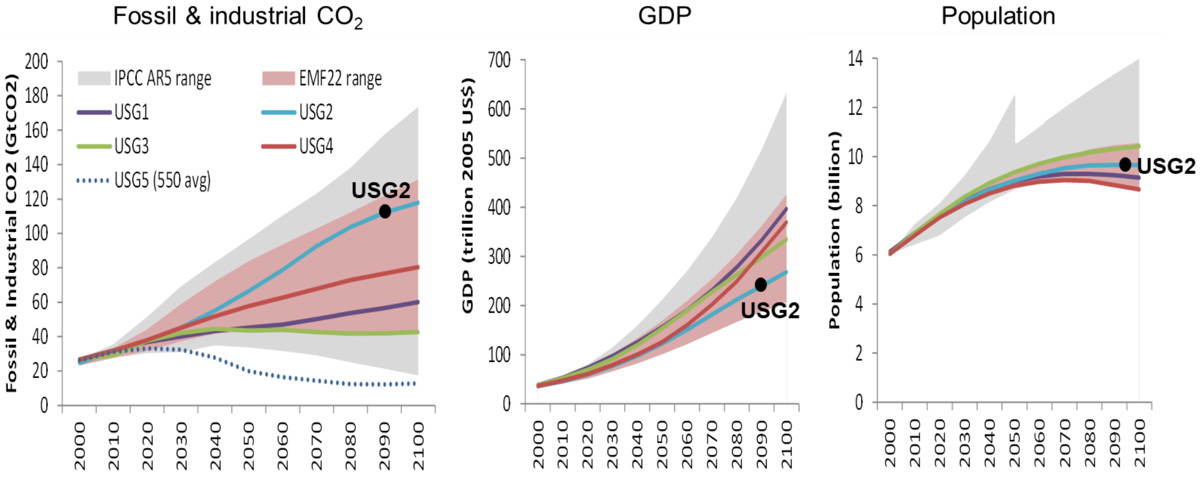
Examples of the need for probabilistic future societies

- **Social cost of carbon and other greenhouse gases (SC-GHGs)** – choosing and weighting global scenarios to estimate the marginal damages/benefits of emitting/reducing GHG emissions
  - To date, arbitrary weighting and lack of socioeconomic structural uncertainty
- **IPCC** – assessing scenario literature results
  - Challenging to synthesize or communicate variation in results. Lack of random samples in scenario databases, not amenable to statistical interpretation (Rose and Scott, 2018)

- **Assessing climate-related risk and evaluating national and company consistency with global temperature objectives**
  - Essential for national to company risk assessment and identification of strategies
- **SSPs** – set of alternative societies with varying mitigation and adaptation challenges
  - However, likelihood of futures and uncertainty in transitions important

In SC-GHG estimates, uncertainty not represented within and between projected variables (Rose et al., 2017)



Rose et al (2017)

IPCC SR1.5 scenario inventory by model

(total number of scenarios followed by number of scenarios after SR1.5 exclusions*)

Model	Total in database	1.5°C & 2°C scenarios
AIM	90 / 90	41 / 41
C-ROADS	6 / 6	5 / 5
GCAM	23 / 23	7 / 7
GENeSYS	1 / 1	0 / 0
IEA	2 / 2	1 / 1
IMAGE	61 / 61	26 / 26
MERGE-ETL*	3 / 0	2 / 0
MESSAGE	58 / 58	36 / 36
POLES	37 / 10	28 / 7
REMIND	93 / 93	62 / 62
WITCH	39 / 39	14 / 14
Total	413 / 383	222 / 199

Rose and Scott (2020)

Methods

Approach

- Develop a probabilistic multi-sector coupled human-natural system model and explore both parametric uncertainty and deep uncertainty about climate policy
- Results: distributions for potential global and sub-global societies without and with additional climate policy

Model and experimental design

- **Model**: Global computable general equilibrium model with economic production, consumption, and trade structure
- **Parameter distributions**: Latin hypercube sampling (n=400) from probability distributions for socioeconomic parameters

Scenario design

- Range of increasingly stringent global policies – reference to 1.5˚C
- Futures defined by increasingly stringent regional GHG constraints
- “Optimistic” and “pessimistic” GHG management conditions that represent deep uncertainties for climate strategy

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

Decarbonization conditions

	CDR (BECCS & afforestation)	Land mitigation overall	International permit trading	Regional economy-wide policies
Optimistic	Yes	Yes	Yes	Yes
Pessimistic	No	No	No	Yes

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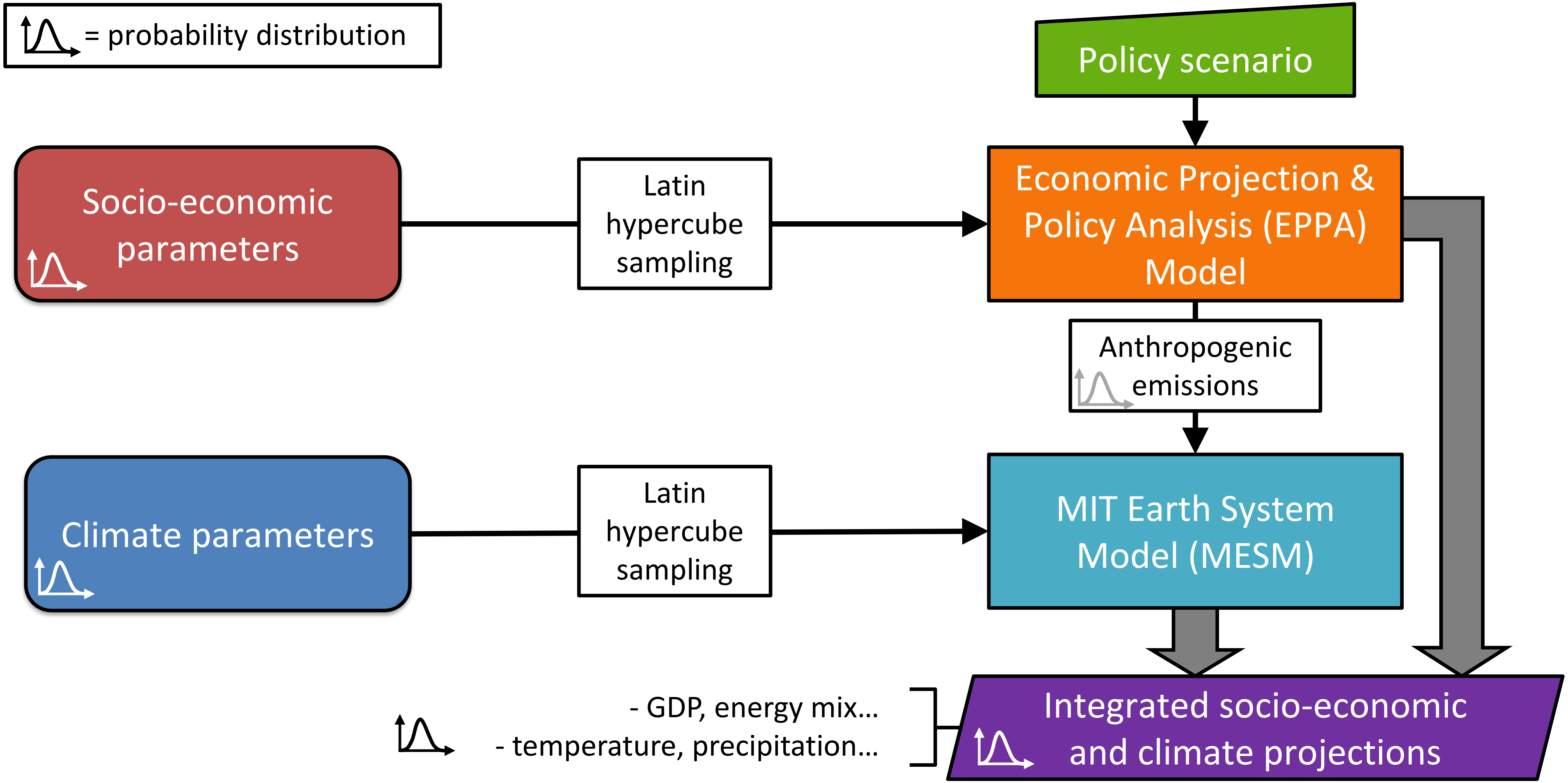
Methods

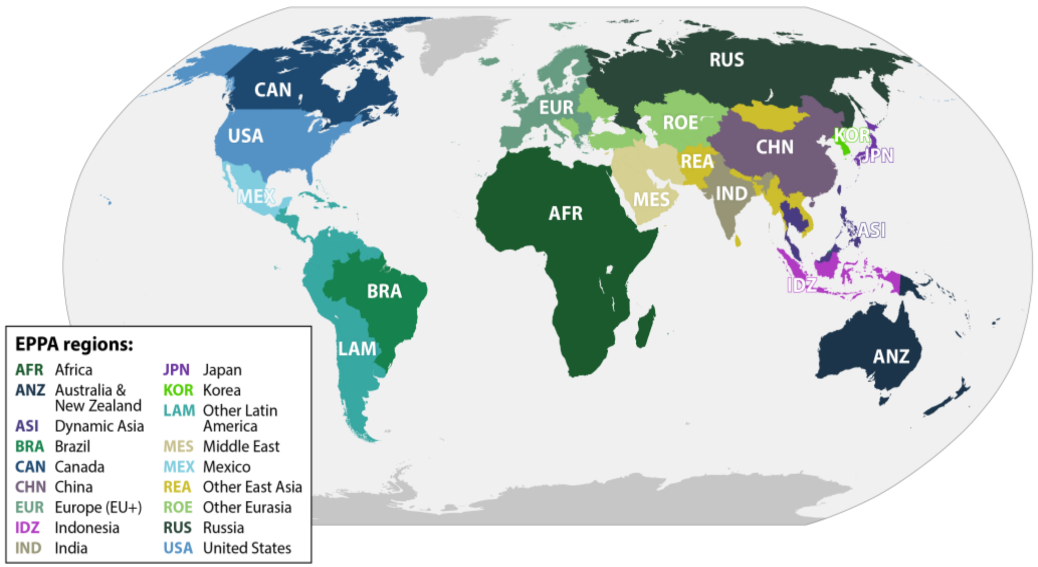

= probability distribution
Policy scenario
Socio-economic parameters
Latin hypercube sampling
Economic Projection & Policy Analysis (EPPA) Model
Anthropogenic emissions
Climate parameters
Latin hypercube sampling
MIT Earth System Model (MESM)
- GDP, energy mix...
- temperature, precipitation...
Integrated socio-economic and climate projections

The EPPA Model

A global multi-region, multi-sector general equilibrium model coupled with an Earth system model

Major goals: Energy, economy, emissions projections

Global Coverage (in 18 regions)



Includes Endogenous Land Use Change

Model Features: Theory-based; Prices are endogenous; International Trade; Inter-industry Linkages; Distortions (taxes, subsidies, etc.); GDP and Welfare effects

Trade-off: Aggregated representation of regions, sectors, technologies

Covers all sectors of economy, with additional detail in energy sectors

Non-Energy
- **Crops**
- **Livestock**
- **Forestry**
- **Food**
- **Energy Intensive Ind.**
- **Manufacturing**
- **Services**
- **Industrial Transport**
- **Household Transport**

Energy
- **Crude oil**
- **Refined oil**
- **Liquid fuel from biomass**
- **Oil Shale**
- **Coal**
- **Natural gas (conv., shale, tight, CBM)**
- **Electricity**
- **Synthetic gas (from coal)**

Vehicle Types
ICE (gasoline & diesel)
Plug-in Electric
Battery Electric
Hydrogen

Biofuels
Current generation (Ethanol from Biodiesel)

Advanced biofuel

Technologies
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

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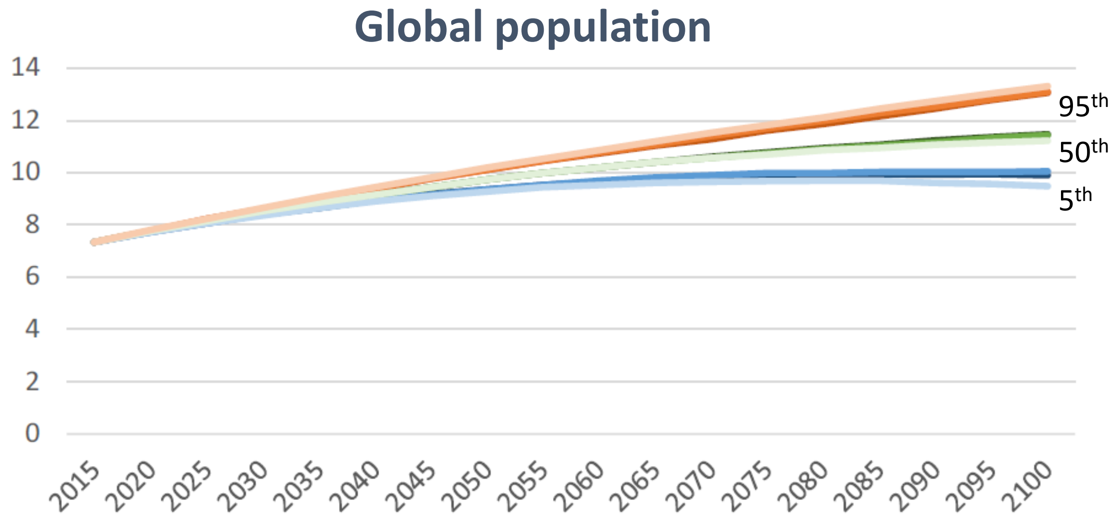
Examples of probabilistic inputs



Uncertain input parameters

- Population growth
- GDP growth (total factor productivity)
- Technology costs
- Elasticities of substitution (between capital and labor, between energy and other inputs)
- Energy efficiency trends
- Fossil fuel resource availability
- Urban pollutants initial inventory and trends
- Rate of technology penetration
- With some correlated

Regional per capita GDP growth

Table 5. Mean and Standard Deviation of Historical Per-Capita GDP Growth Rates, and the 5%, median, and 95% projected average annual growth rates for 2000-2100.

	Historical 1950-2000 (%)		Projected Annual Average Growth Rate (%) 2000-2100		
Region	***Mean***	***Std Dev***	***0.05***	***0.5***	***0.95***
USA	2.2	2.3%	1.7	2.1	2.5
CAN	2.3	2.3%	1.7	2.1	2.5
MEX	2.2	5.2%	1.2	2.1	2.9
JPN	4.9	3.5%	1.7	2.2	2.7
ANZ	2.0	1.8%	2.0	2.3	2.6
EUR	2.8	1.6%	1.9	2.1	2.4
EET	1.1	3.9%	2.1	2.8	3.3
FSU	1.1	5.3%	2.0	2.8	3.7
ASI	4.3	4.7%	1.8	2.6	3.3
CHN	4.3	3.7%	2.5	3.1	3.7
IND	2.3	2.7%	2.3	2.7	3.1
IDZ	2.7	5.0%	1.1	2.6	3.9
AFR	1.0	1.8%	2.0	2.3	2.6
MES	2.3	3.3%	1.5	2.1	2.6
LAM	1.7	2.0%	1.7	2.1	2.5
ROW	2.2	3.5%	1.7	2.3	2.8
GLOBAL			2.2	2.4	2.6

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Examples of probabilistic inputs

Estimating energy efficiency improvement (for regions and sectors)

Energy productivity

$$\ln E_t = \alpha(1-\lambda) + \lambda \ln E_{t-1} + \beta(1-\lambda)\ln P_{t-1} + \theta(1-\lambda)\ln GDP_{t-1} + \gamma(1-\lambda)t + \eta_t$$

<u>Uncertain input parameters</u>

- Population growth
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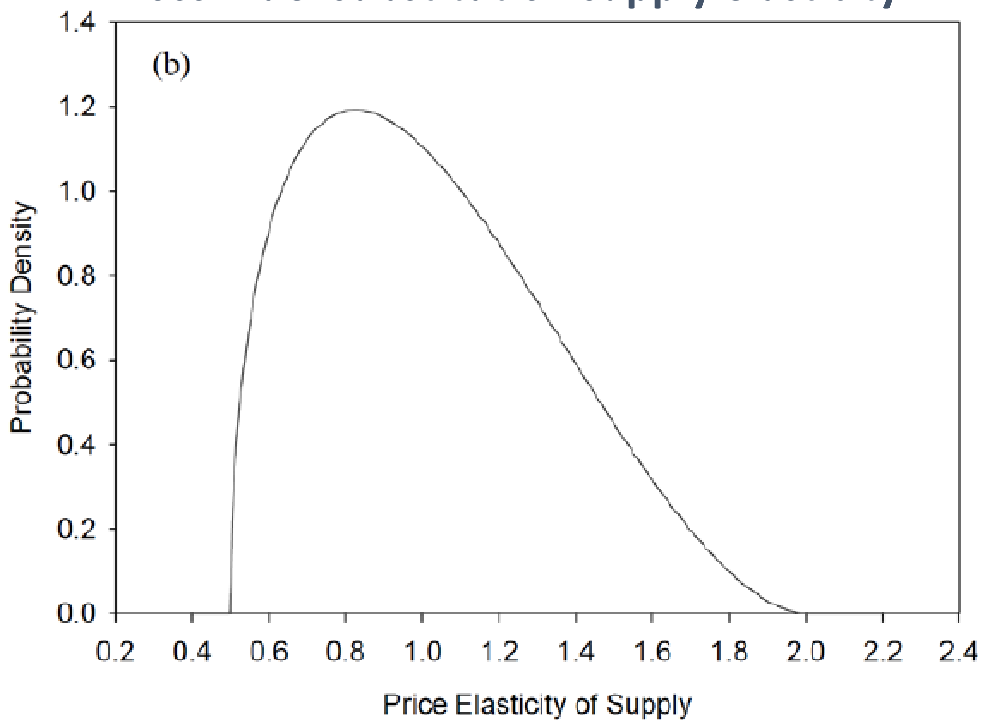
Fossil fuel substitution supply elasticity



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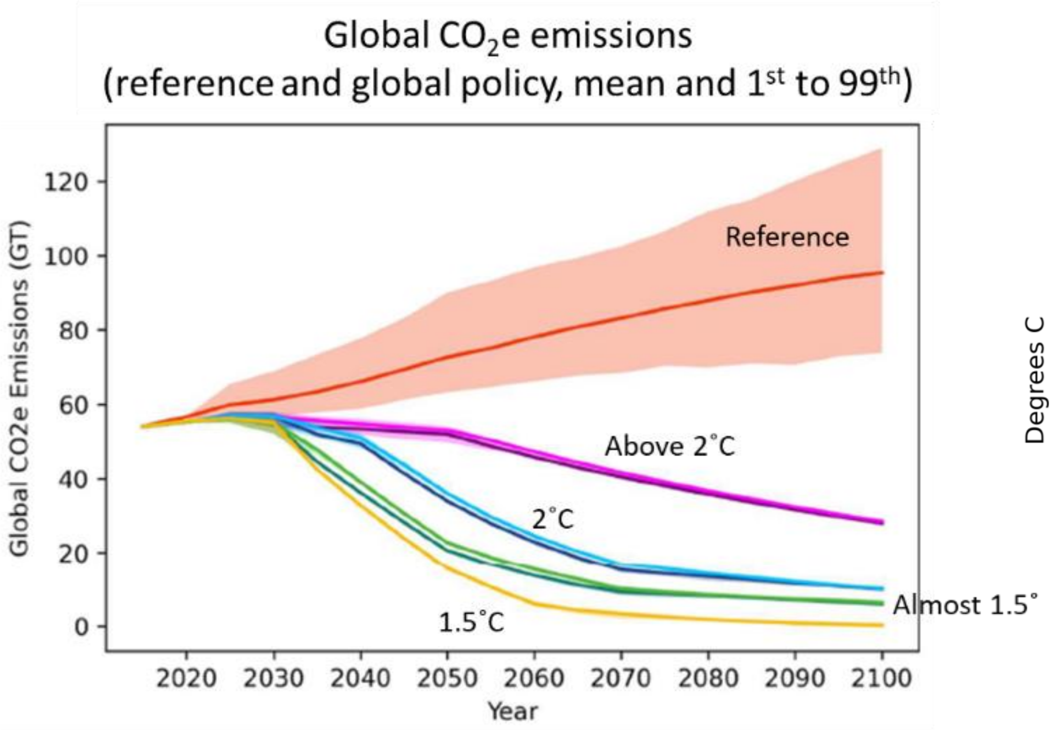
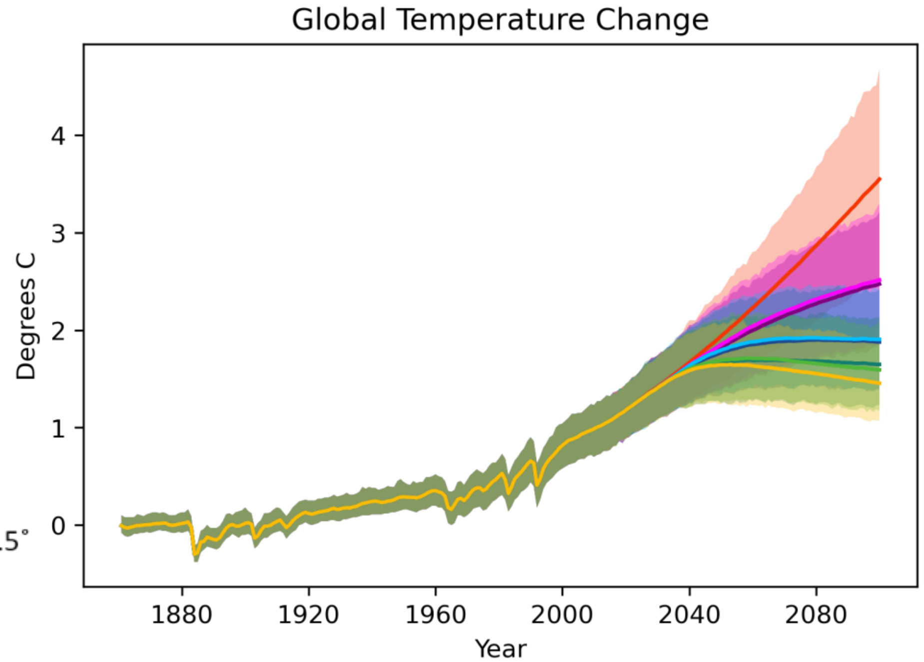
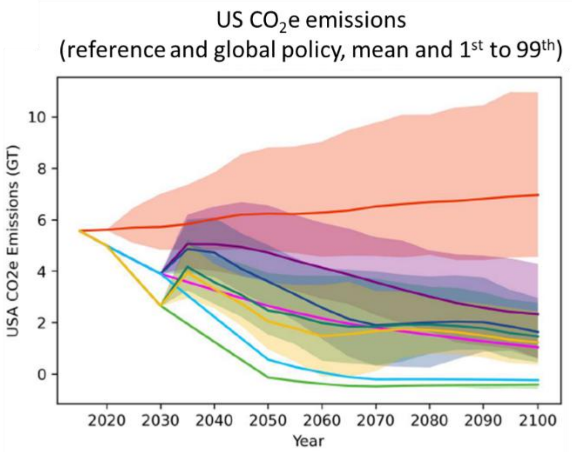
Scenarios







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

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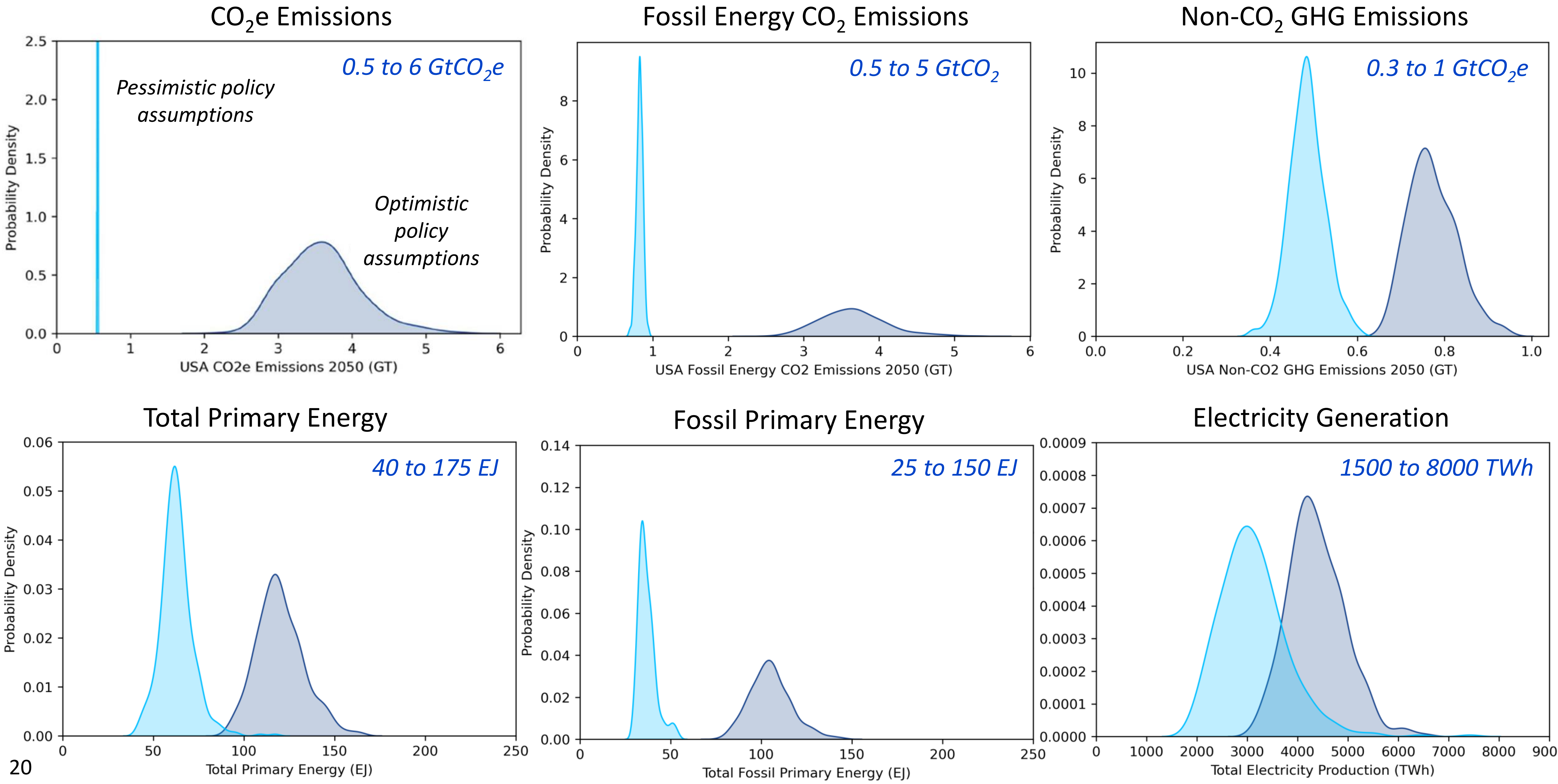
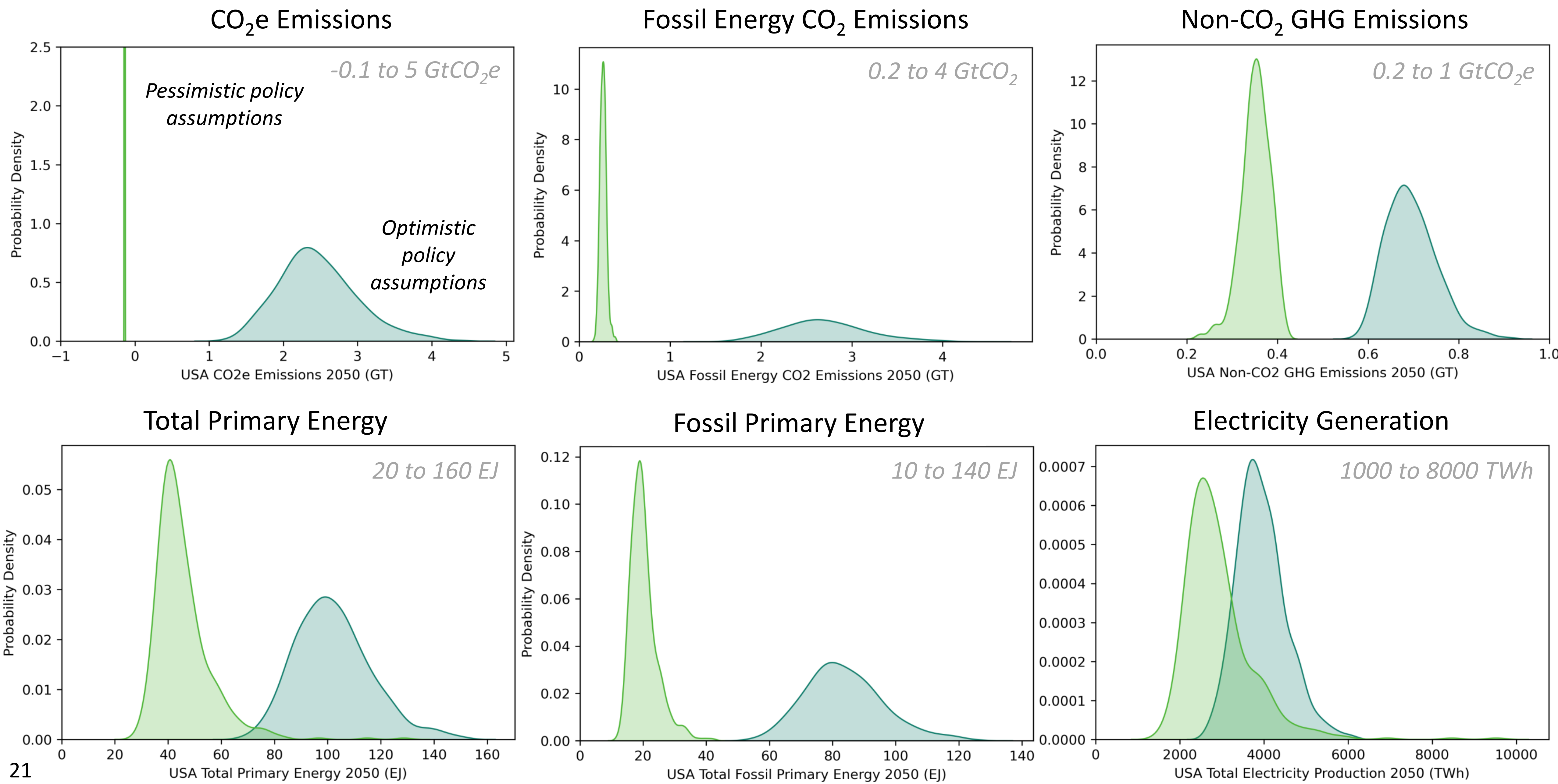
US 2050 uncertainty for a single 2˚C global emissions pathway

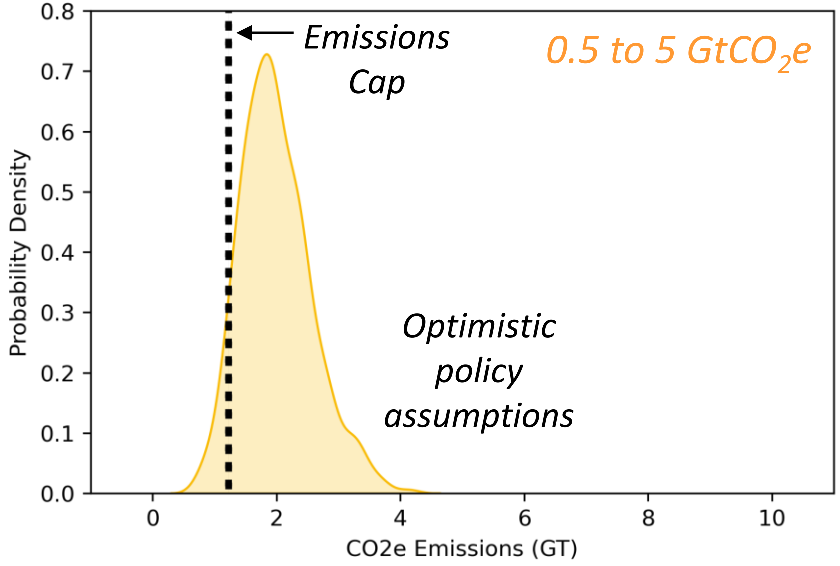


US 2050 uncertainty for a single Almost 1.5˚C global emissions pathway

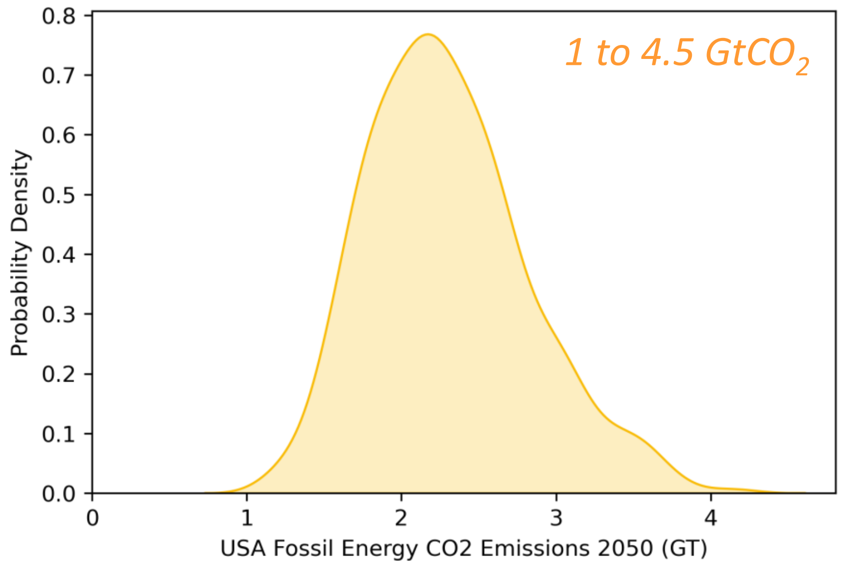


US 2050 uncertainty for a single 1.5˚C global emissions pathway

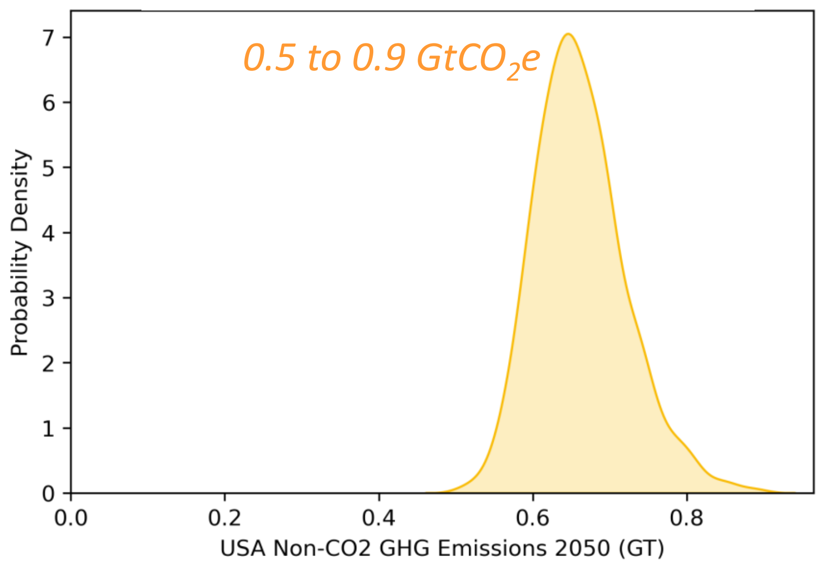
CO_2e Emissions



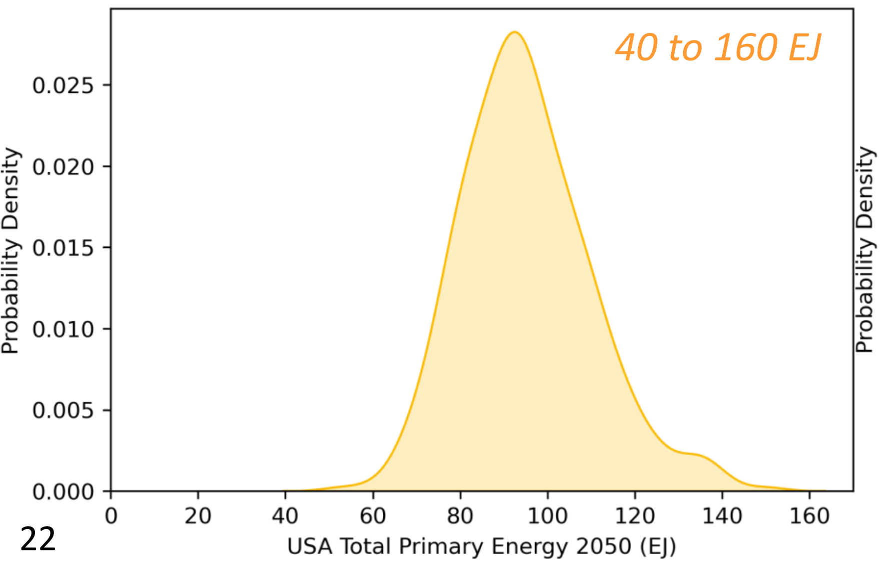
Fossil Energy CO_2 Emissions



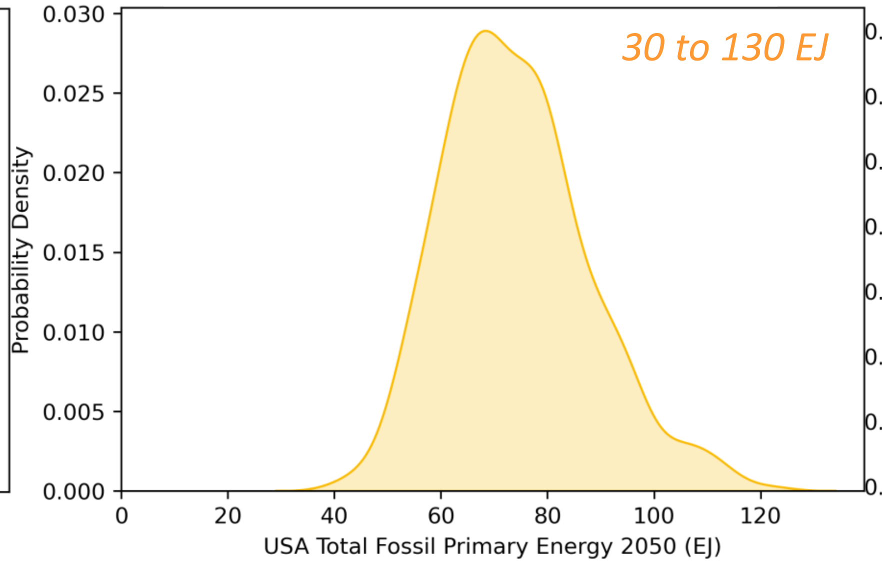
Non-CO_2 GHG Emissions



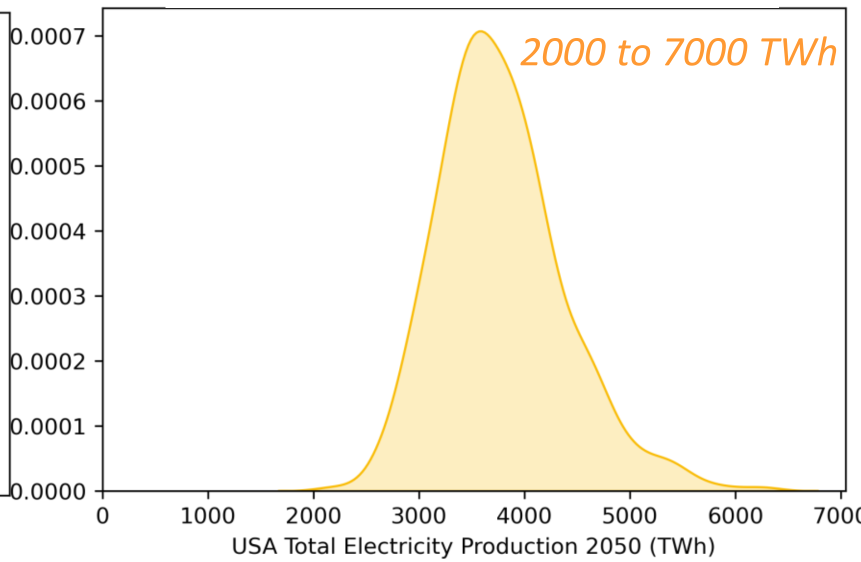
Total Primary Energy



Fossil Primary Energy



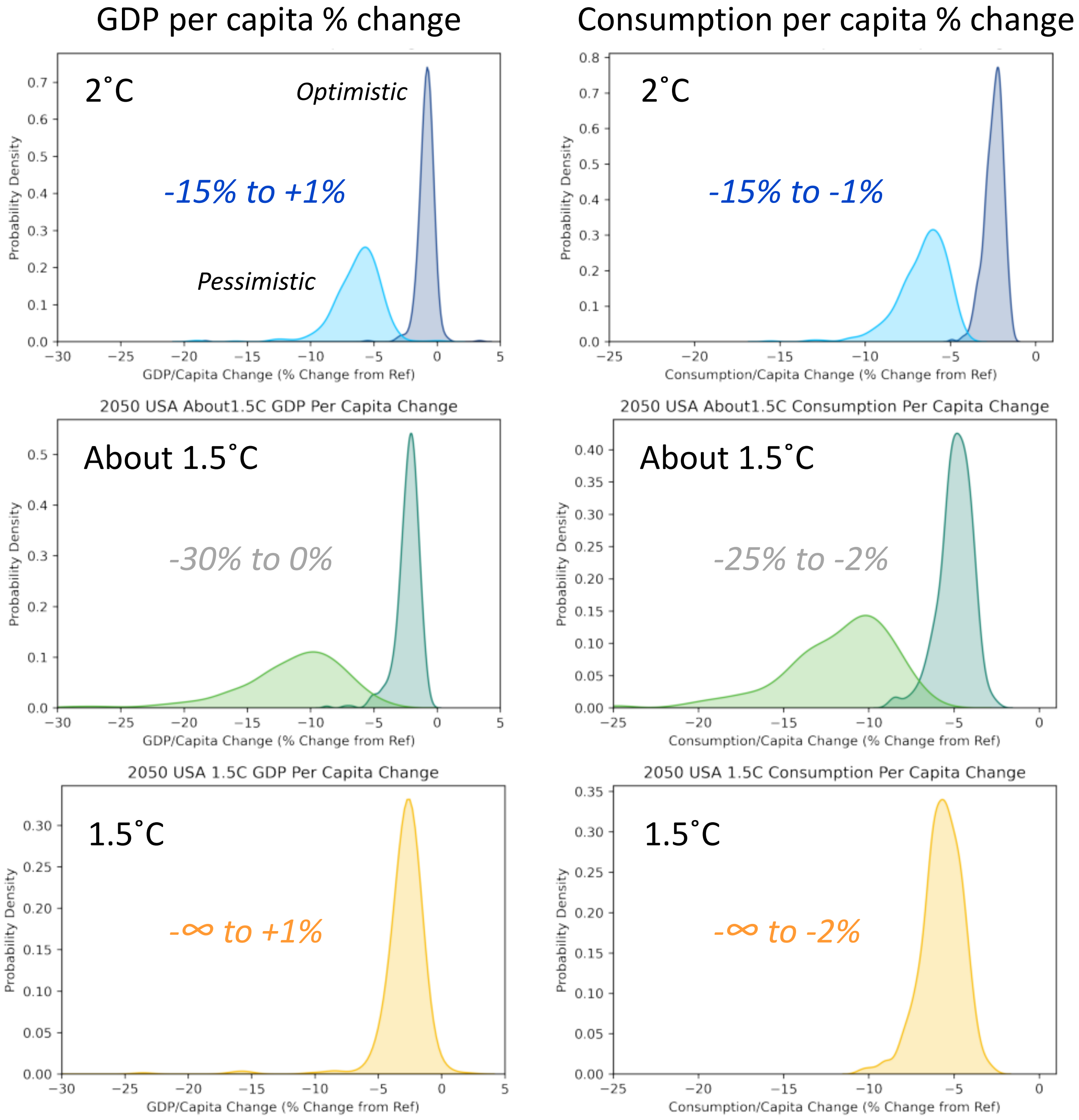
Electricity Generation



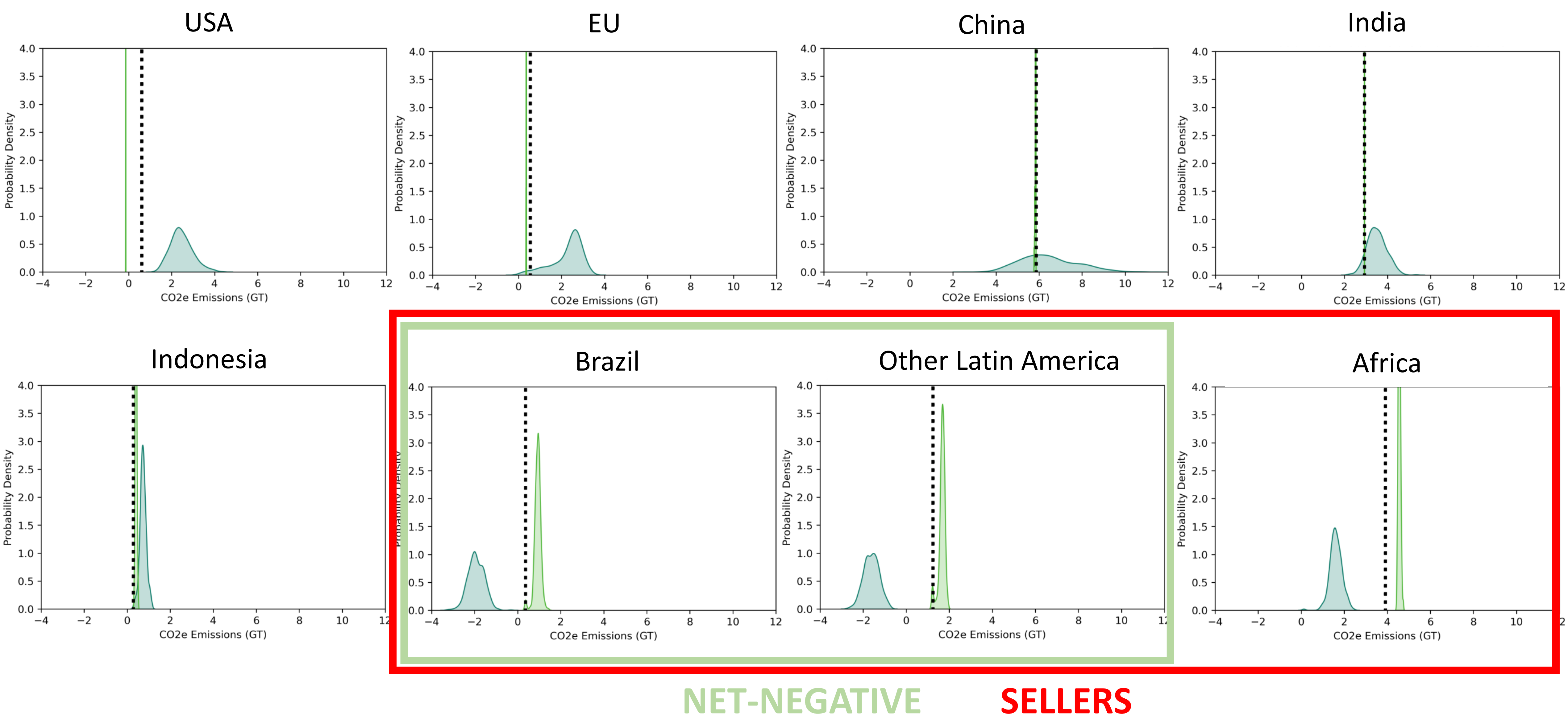
US 2050 cost uncertainty for different ˚C pathways

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

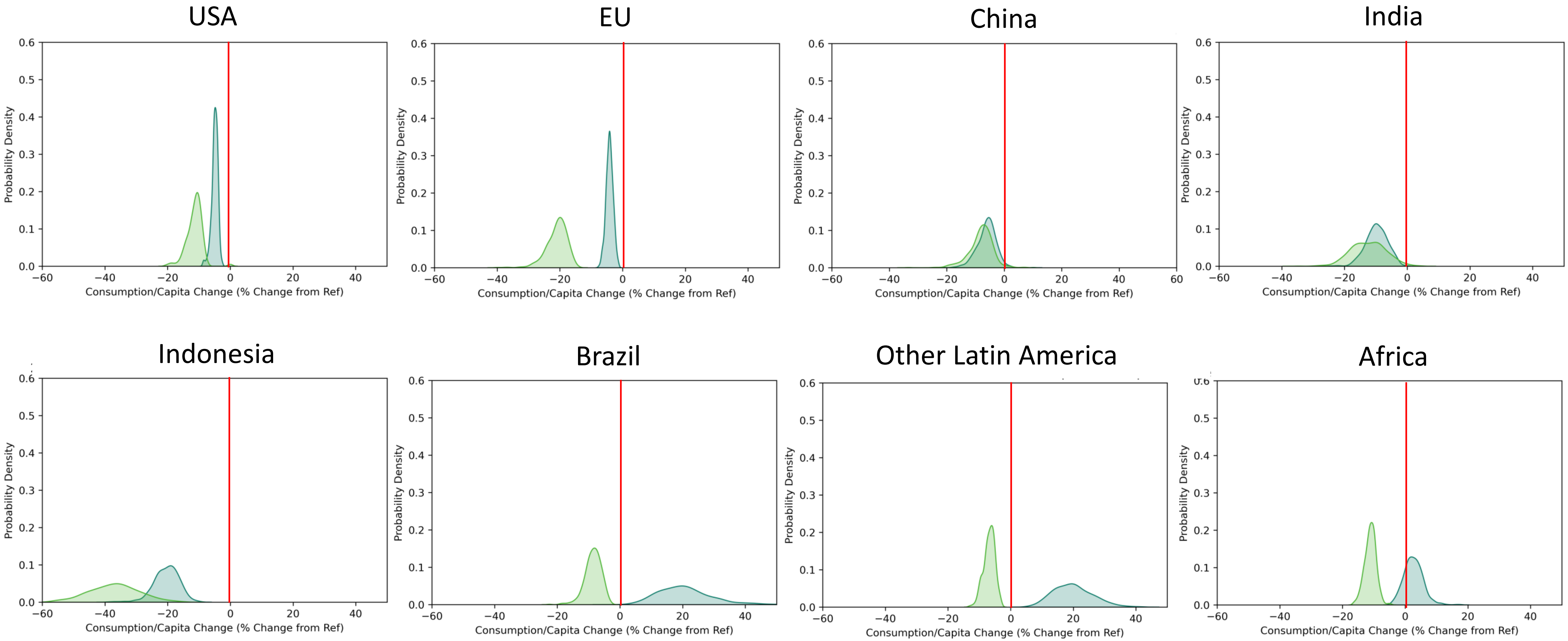
1.5˚C could not be solved with pessimistic assumptions



CO_2e emissions for selected regions under Almost 1.5˚C scenario



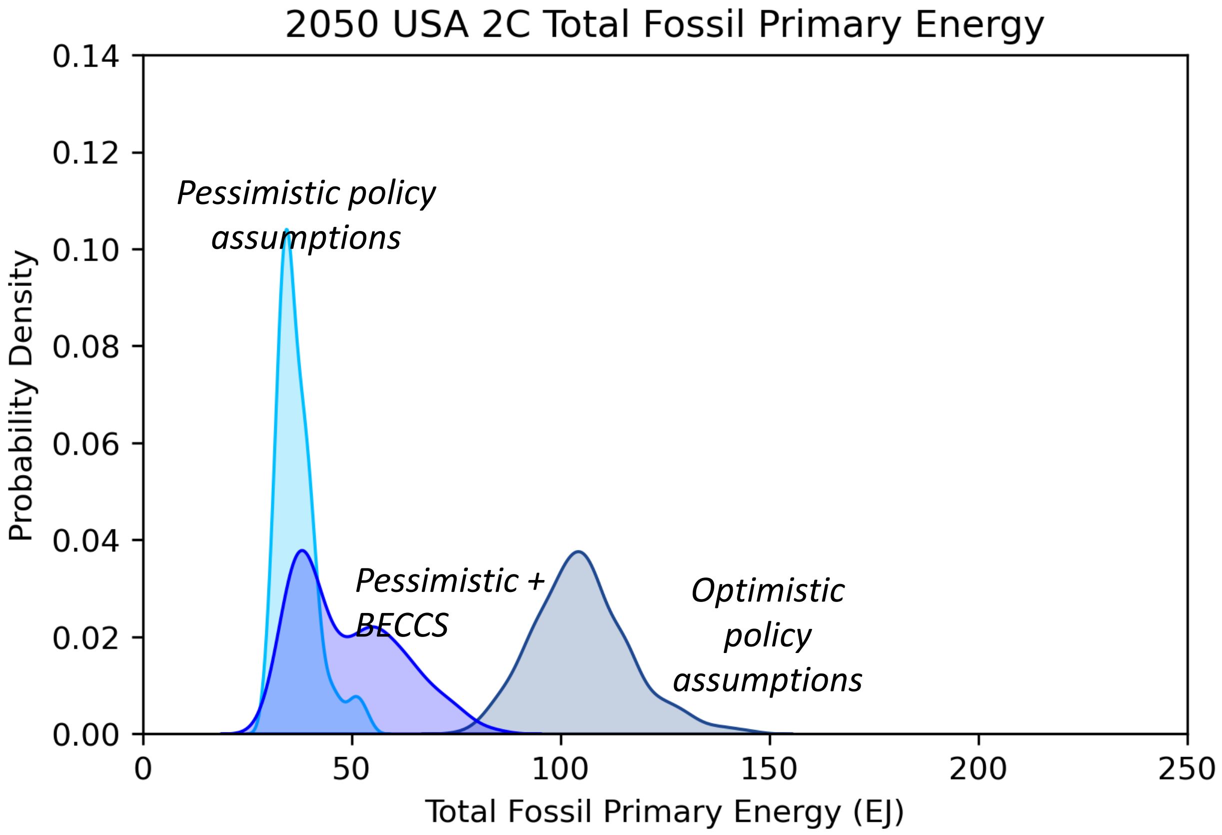
Consumption Impact for selected regions under Almost 1.5˚C scenario

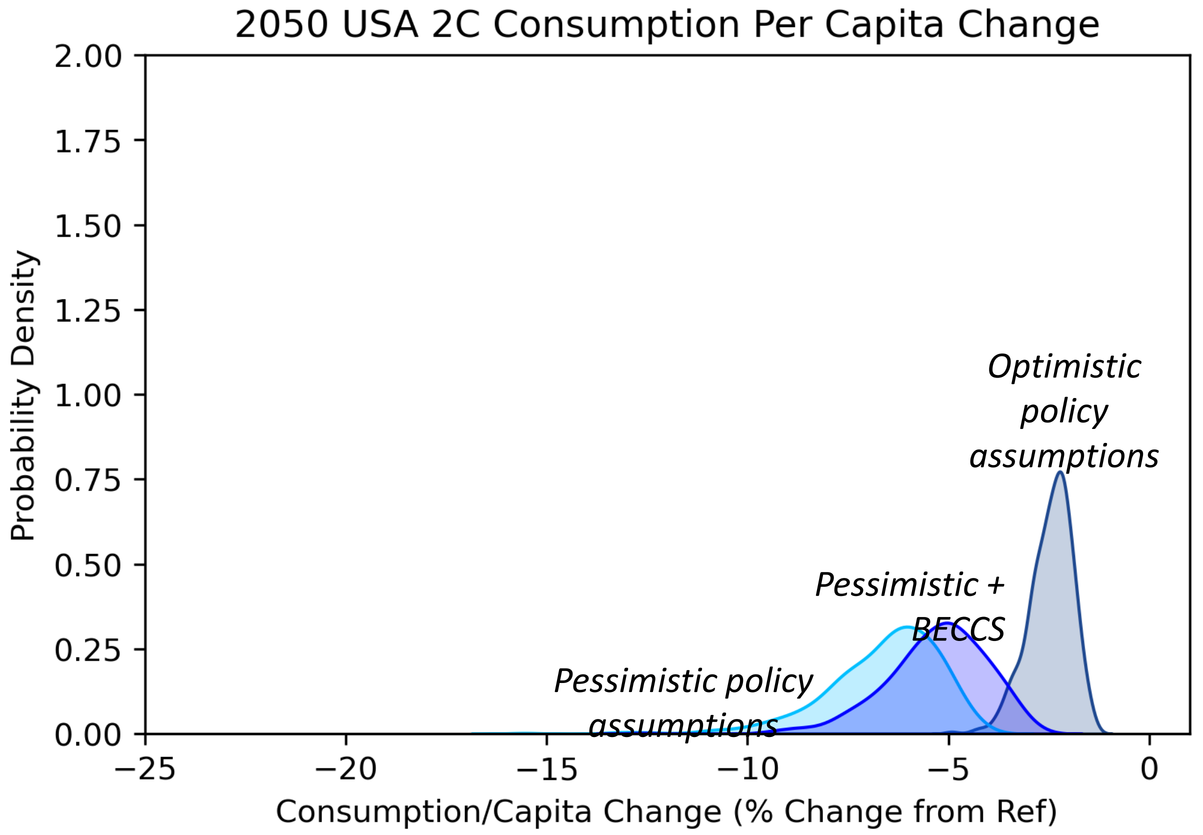


consumption/capita % change from Reference

What about an intermediate scenario? Pessimistic + BECCS

US 2050 uncertainty for 2˚C global emissions pathway





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Key insights

- **Future socioeconomic structural uncertainty is significant** – globally, nationally, at sector and household levels
- **Many societies** are consistent with a given global emissions 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), SC-GHG estimation, and GHG goal setting
  - Affecting climate impacts, damages, and risks (by affecting societal exposure, vulnerability, and adaptation opportunities)
  - Affecting potential country, sector, technology, and company transition roles and risks
  - Affecting country and company risk management strategies and practical GHG goals
  - Affecting discounting when discounting consistent with economic growth
- Results highlight that **climate policy and non-policy uncertainties** are risks companies need to manage (in addition to global pathway attainability uncertainty), and that planning for a single future (globally or sub-globally) is risky
- A **set of distributions** (optimistic & pessimistic, across policy stringency) is relevant to risk assessment & planning
  - Distribution overlap indicates that the same condition consistent with different global futures and climates – important for risk management
- Results could be used to **rule out or weight development pathways** in the literature
- Caveats: Sectoral policy uncertainty not considered – even greater range of relevant distributions, and even higher potential mitigation costs than the pessimistic. Also, land-related uncertainties not modeled.

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Thank you!

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