Scenario Discovery for Probabilistic Ensembles of a Coupled Human-Earth System Model

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and

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MultiSector Dynamics

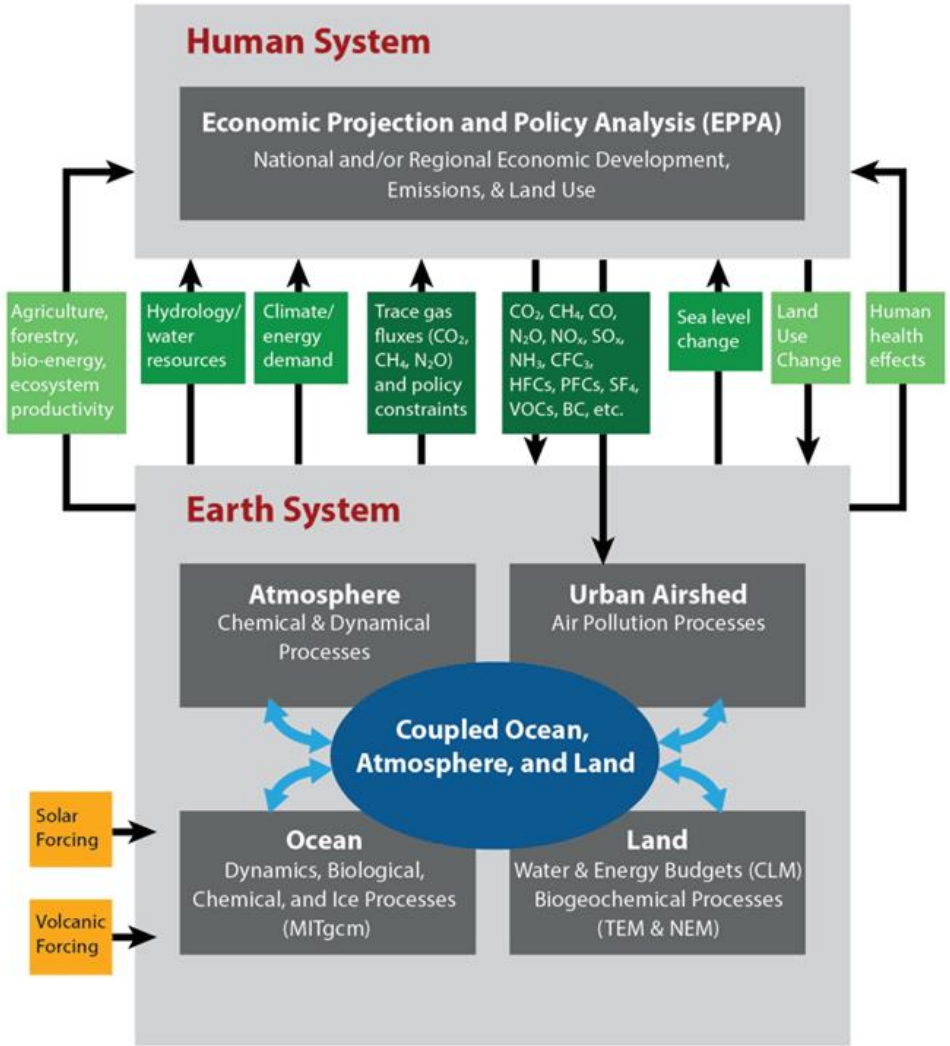
BIOLOGICAL AND ENVIRONMENTAL RESEARCH

Earth and Environmental System Modeling

Coupled Human-Earth System Models

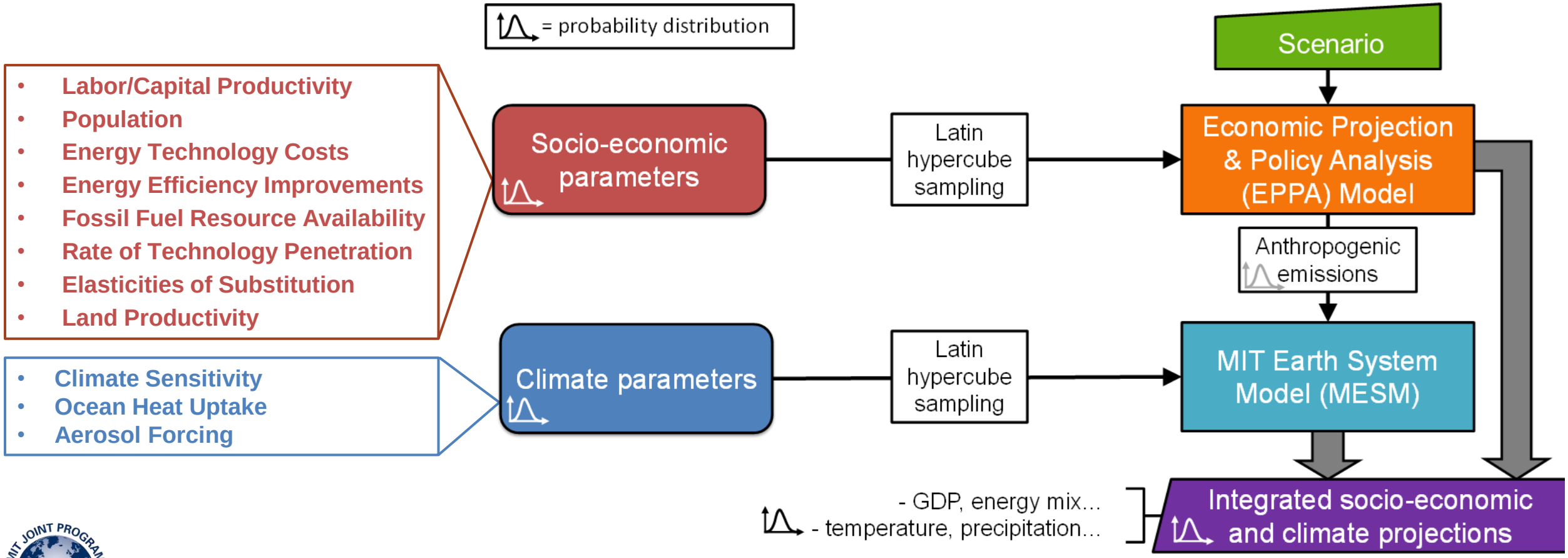
- Used to explore potential future outcomes for emissions, economics, energy, land, water, climate, etc.
- Uncertainty is often represented through sensitivity analysis, scenarios and model comparisons, which do not provide a probabilistic interpretation
- We take a probabilistic approach to uncertainty, creating probabilistic integrated socio-economic and climate projections

MIT Integrated Global System Modeling (IGSM) Framework



Uncertainty Quantification via Traditional Monte Carlo Approach

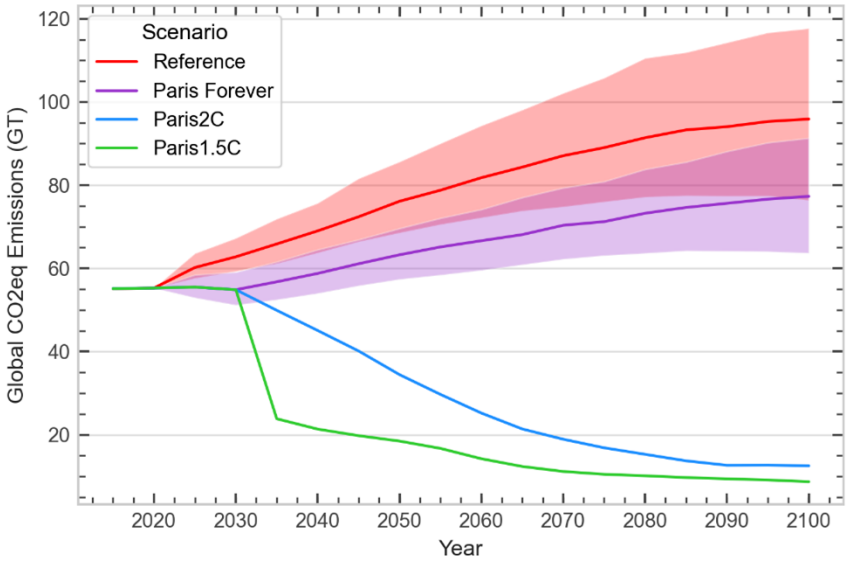
- Probability distributions for socio-economic & climate input parameters are developed & sampled
- Simulated through MIT integrated models to explore a range of possible future outcomes
- For a set of ensemble scenarios with different long-term temperature targets



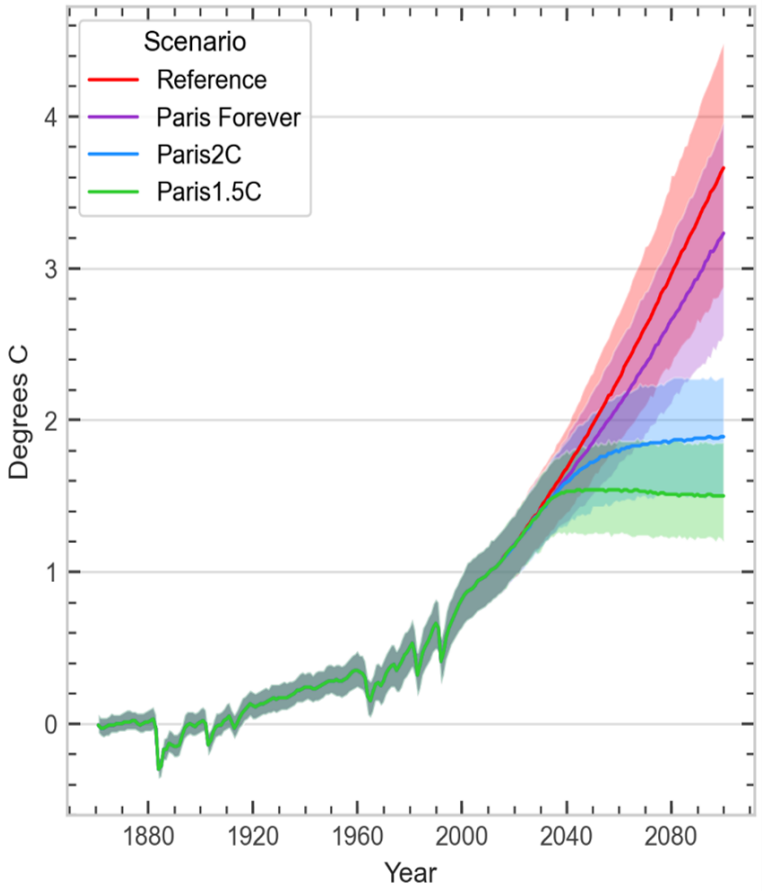
Distributions of Key Results

[Morris et al. (2022)]

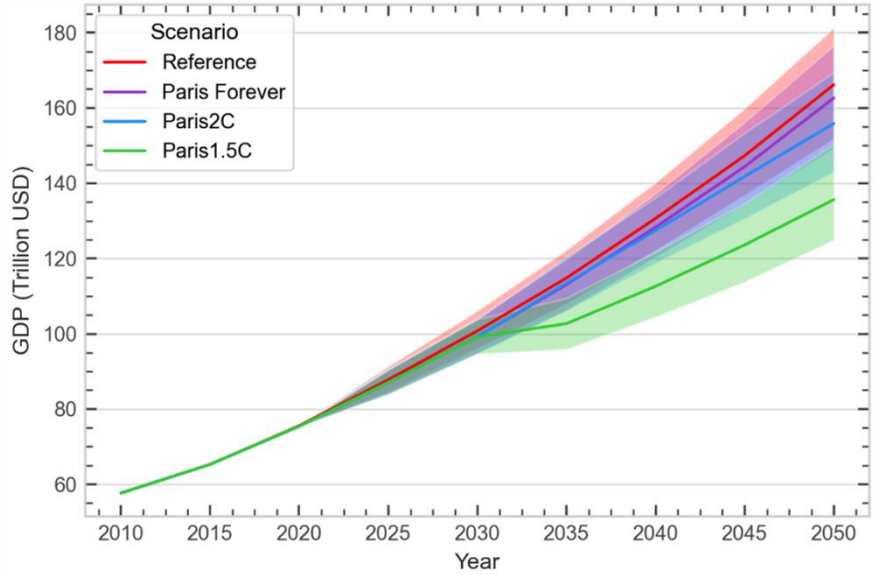
Emissions



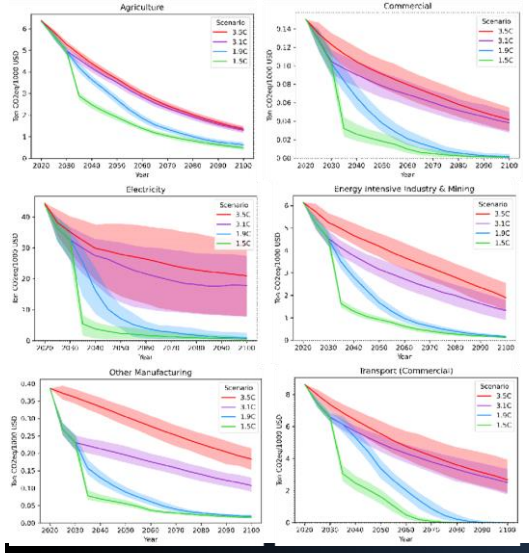
Temperature



GDP

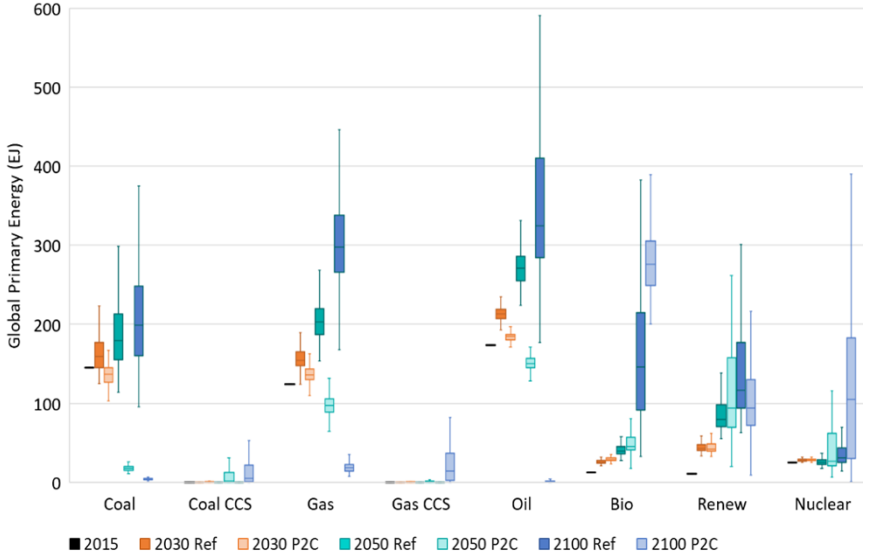


Sectoral Emissions Intensity



Precipitation; Sectoral Output; Air Pollutants; Land Use; Water Demand….

Energy Mix



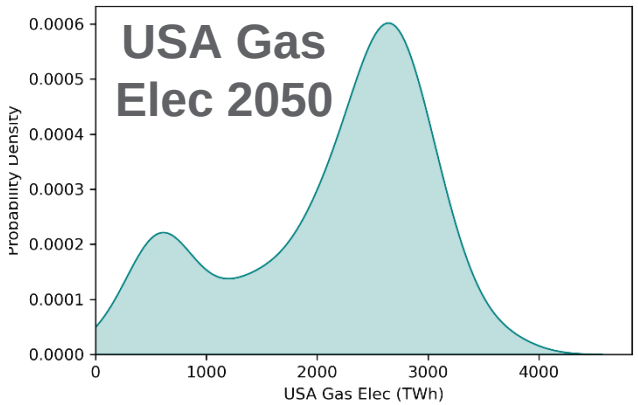
Probabilistic Ensembles

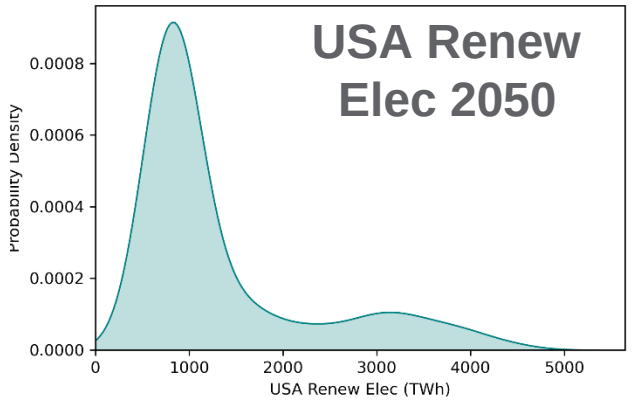
Approach more fully and systematically explores uncertainty space compared to limited number of scenarios and provides insight about likelihood of outcomes

BUT, some challenges:

1) Produces a lot of data- difficult to explore and extract insights

2) Distributions of each outcome are separately characterized and so relationships that may exist over time or among outcomes are lost

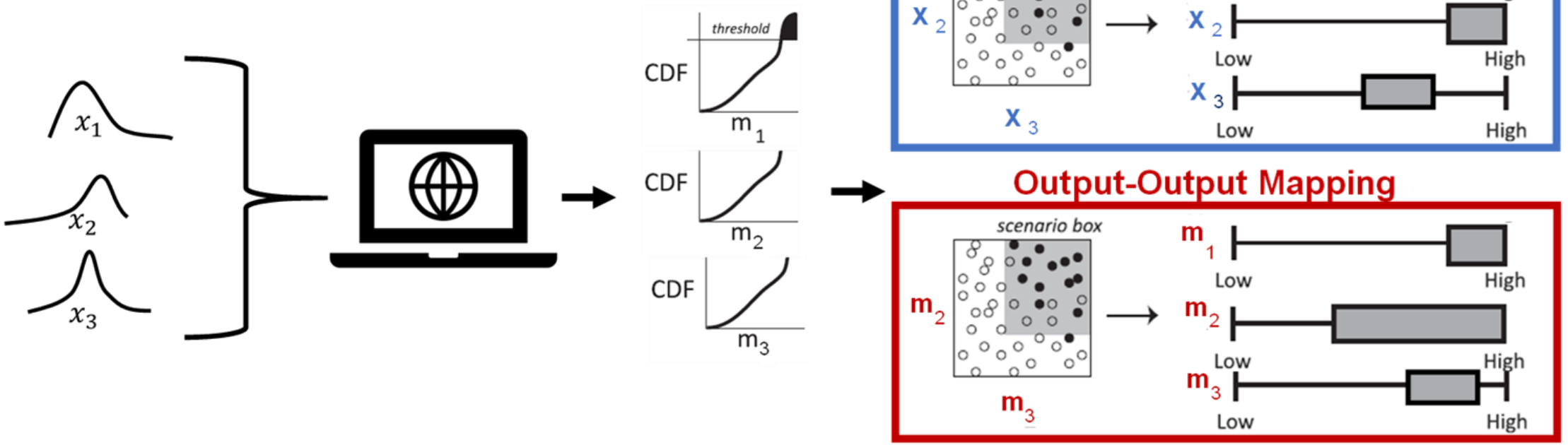




- **Scenario discovery** can address these issues

Scenario Discovery

- Tools for screening databases of model simulations to identify outcomes of interest and their conditions for occurring



Uncertain Inputs

Sampled from probability distributions

Computational Model→ Creates Simulation Ensemble

Outputs of Interest

Map Outputs of Interest Back to Ranges of Inputs or Other Outputs

Using machine learning classification methods

Exploratory Modeling / Scenarios Database

Scenario Discovery

(e.g. Classification and Regression Trees (CART), Random Forest Classifiers, etc.)

Scenario Discovery Visualization Tool

scenariodiscovery.mit.edu
(beta version: work in progress)

Interactive Web-Based Platform to:

- Visualize results of ensembles
- Elucidate how different outcomes and inputs are related
- Identify individual scenarios of interest for particular studies

Steps:

- Create database of large ensembles of model scenarios
- Create flexible web-based platform that calls from database and allows users to visualize results and relationships among selected variables

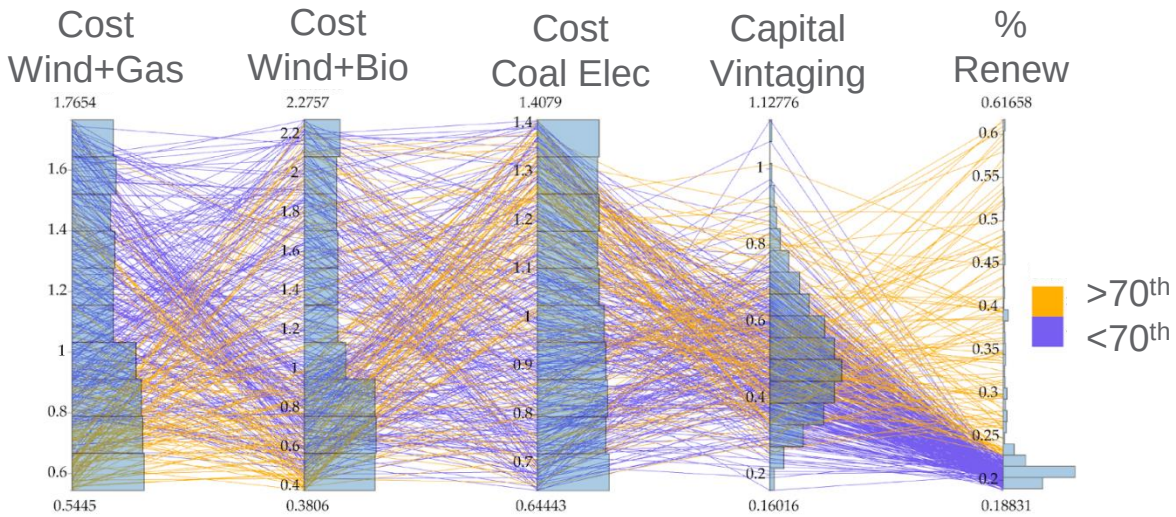
Tool enables quick exploration and analysis of:

- **distributions of model outputs**
- **input distributions driving ensembles**
- **relationships between inputs and outputs, and how they change over time, across regions and scenarios**
- **relationships between different outputs and potential tradeoffs**
- **output patterns over time and their drivers**
- **geographic maps of outputs**

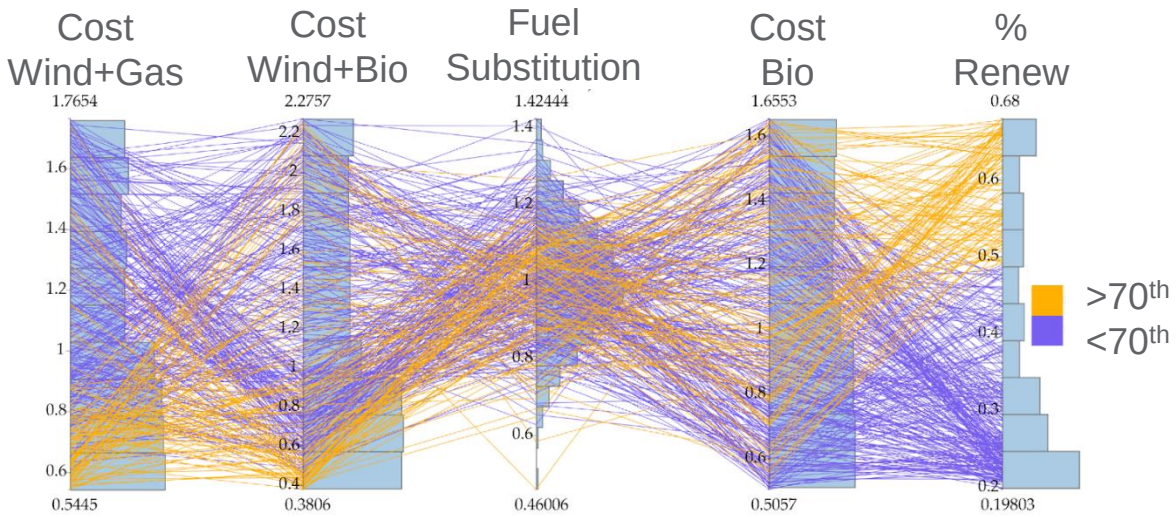
Application to Renewable Energy Penetration

Input-Output mapping: Identifies key drivers of outcome of interest

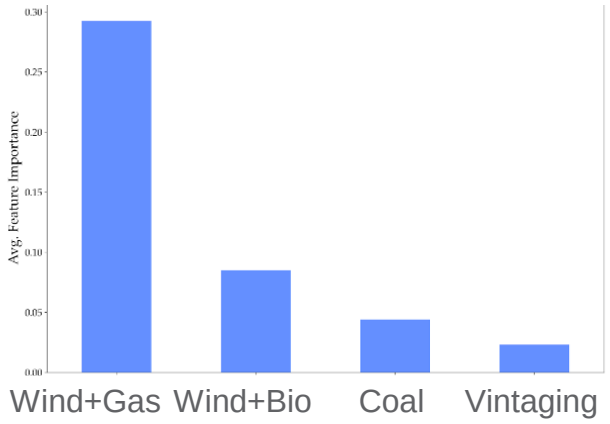
Reference Scenario in 2050



2C Scenario in 2050



Reference Feature Importance Scores



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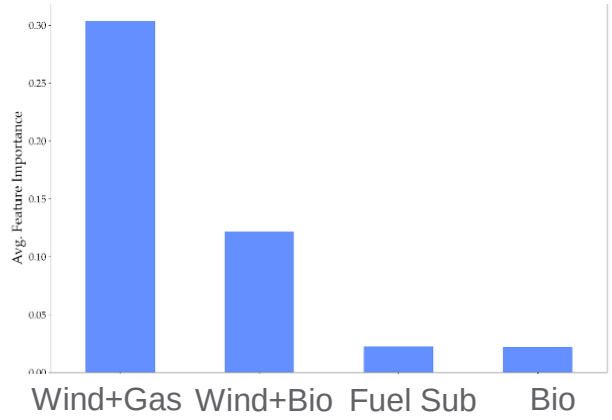
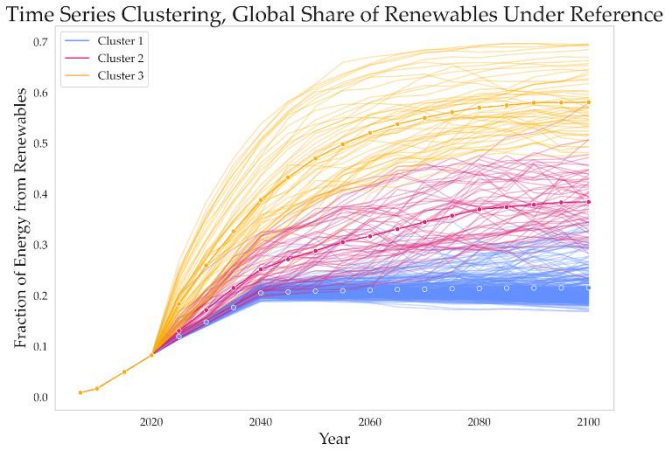


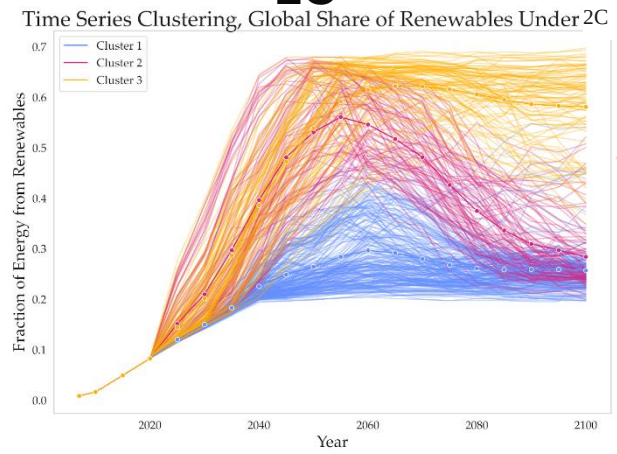
Application to Renewable Energy Penetration

Times series clustering: Identifies dynamics missed by looking at individual years, and main drivers of each cluster

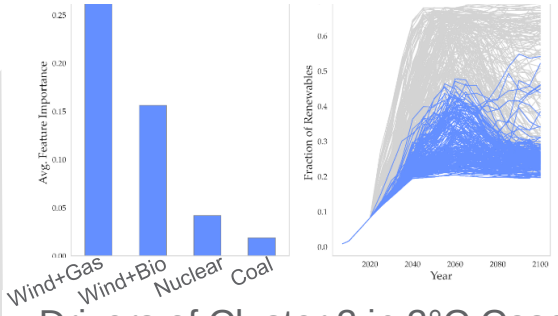
Reference



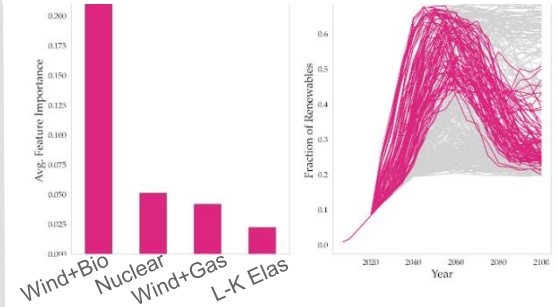
2C



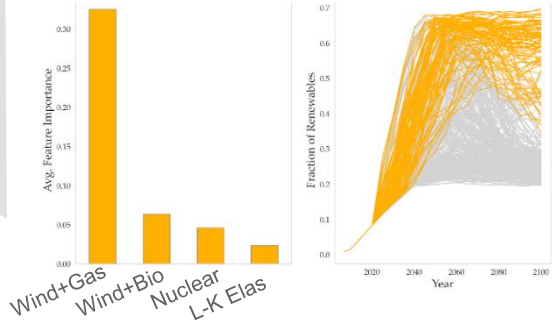
Drivers of Cluster 1 in 2°C Case



Drivers of Cluster 2 in 2°C Case

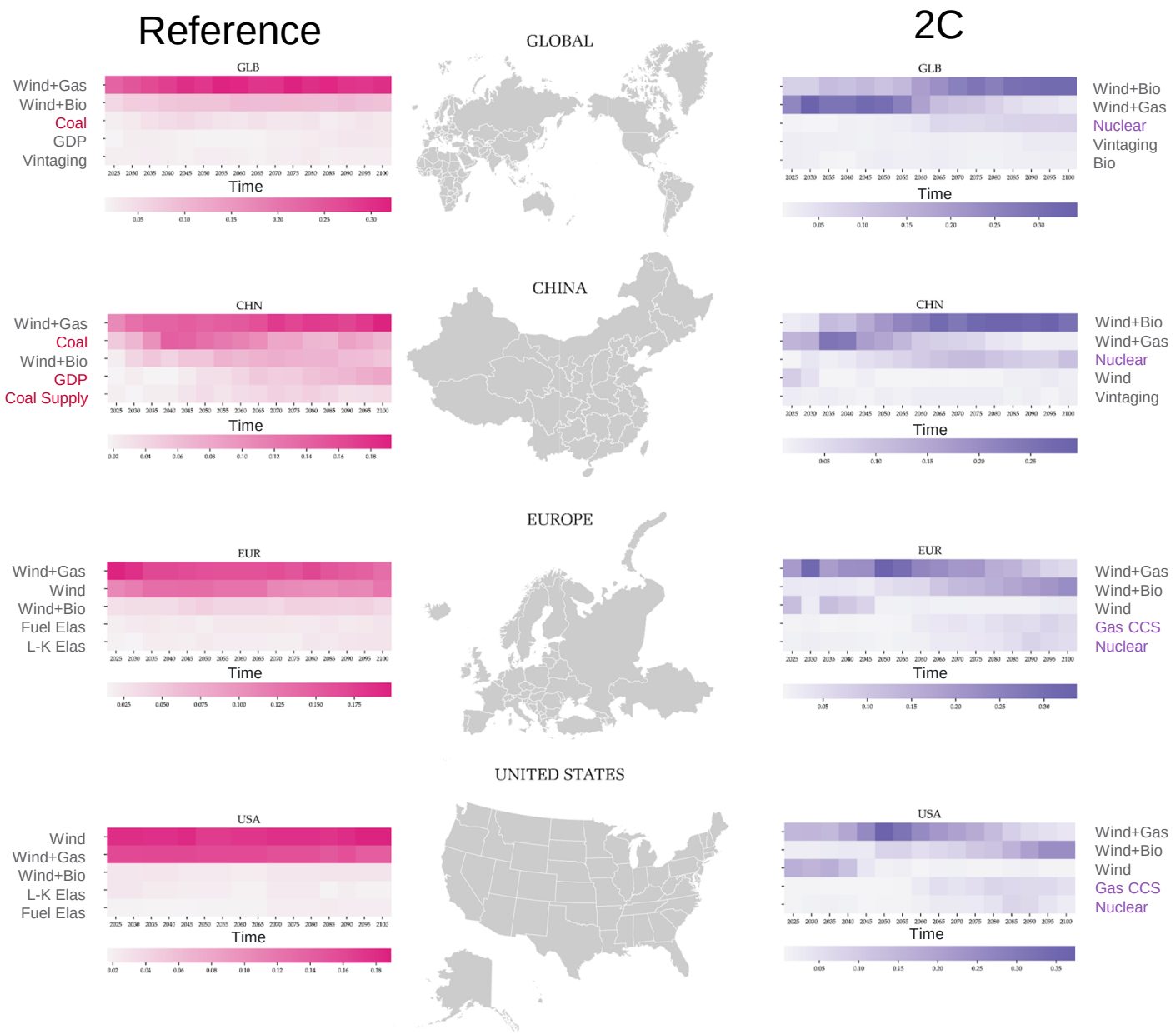


Drivers of Cluster 3 in 2°C Case



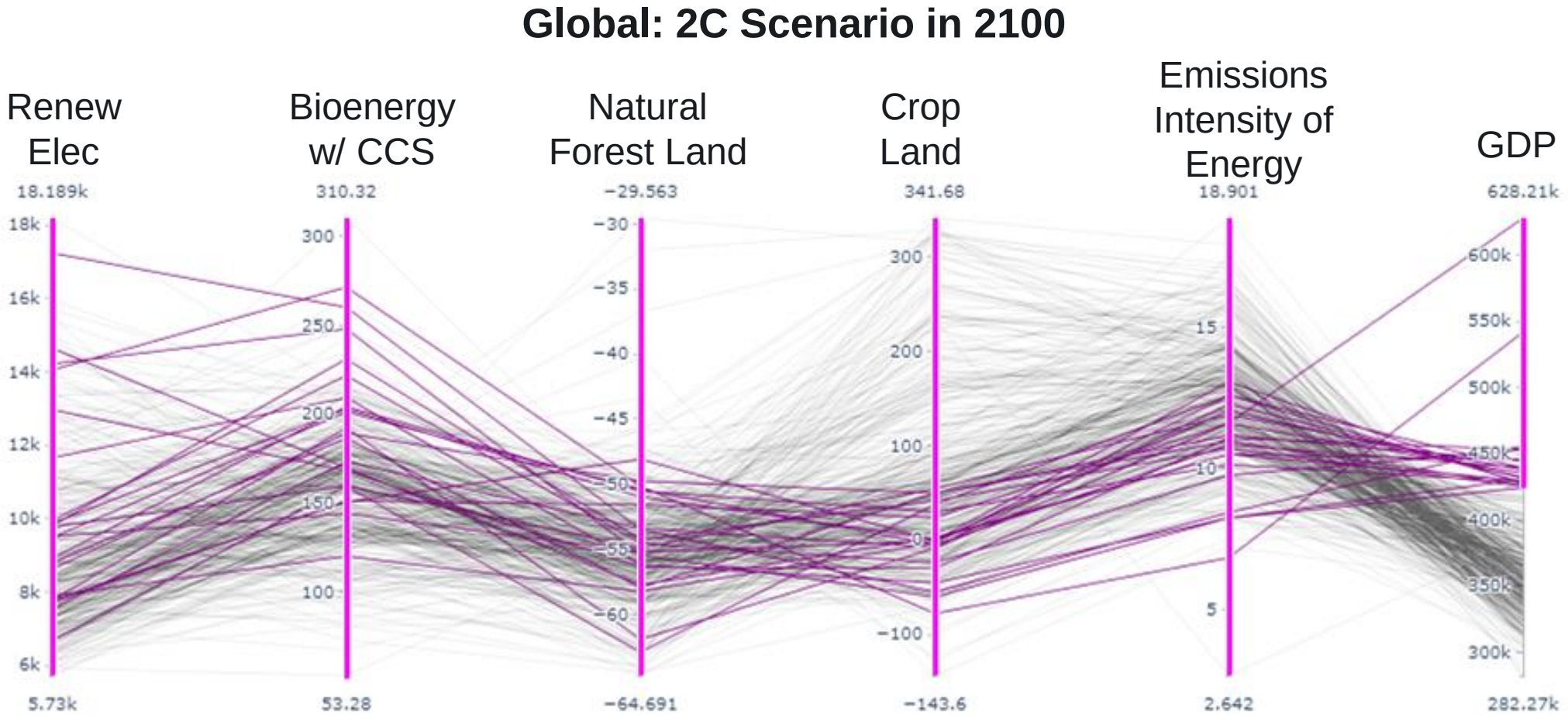
Application to Renewable Energy Penetration

Comprehensive assessment of how key drivers vary by region, time and scenario



Application to Renewable Energy Penetration

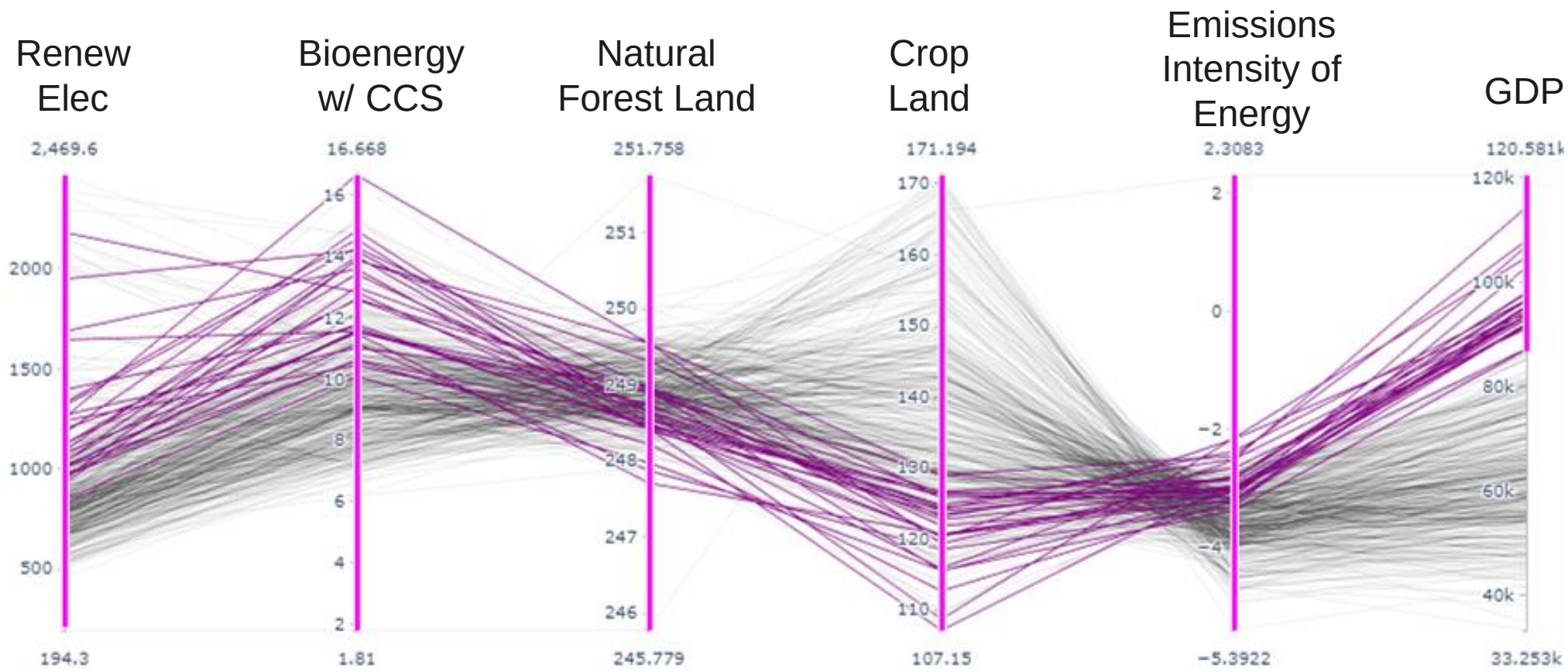
Output-Output mapping: Identifies relationships and tradeoffs across outputs



Application to Renewable Energy Penetration

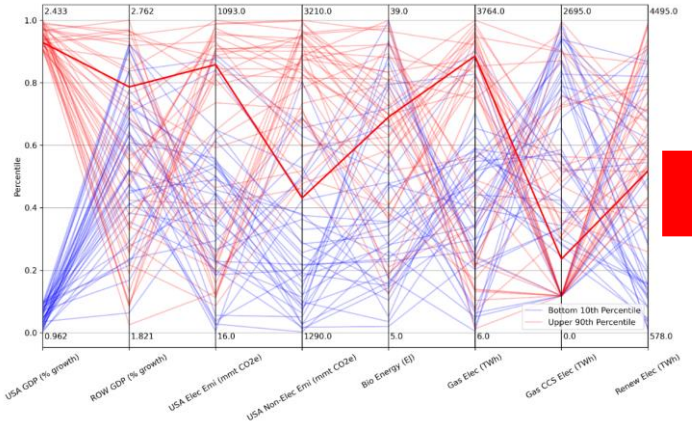
Output-Output mapping: Identifies relationships and tradeoffs across outputs

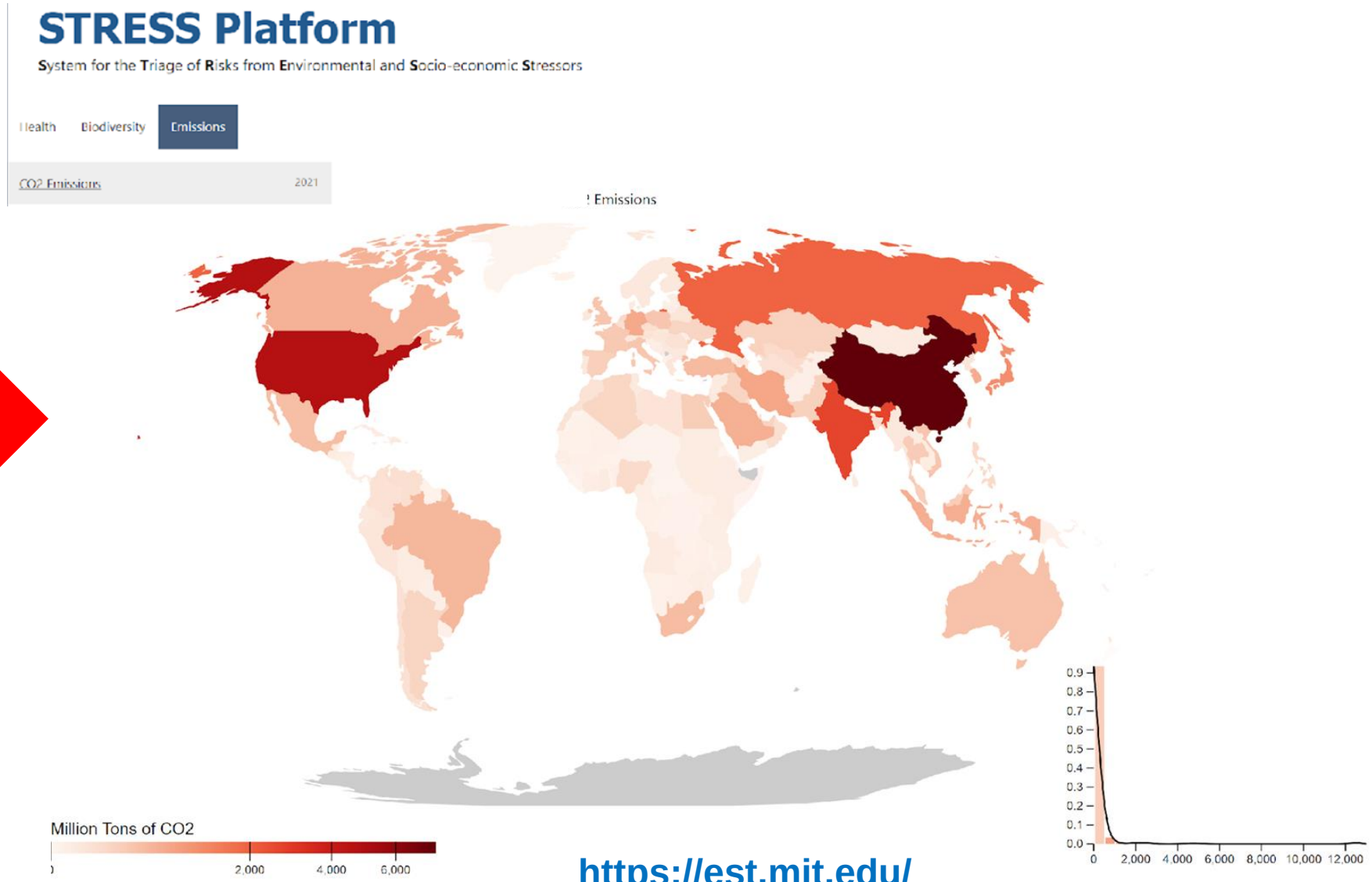
USA: 2C Scenario in 2100



Connecting to the STRESS Platform

Scenariodiscovery.mit.edu





https://est.mit.edu/

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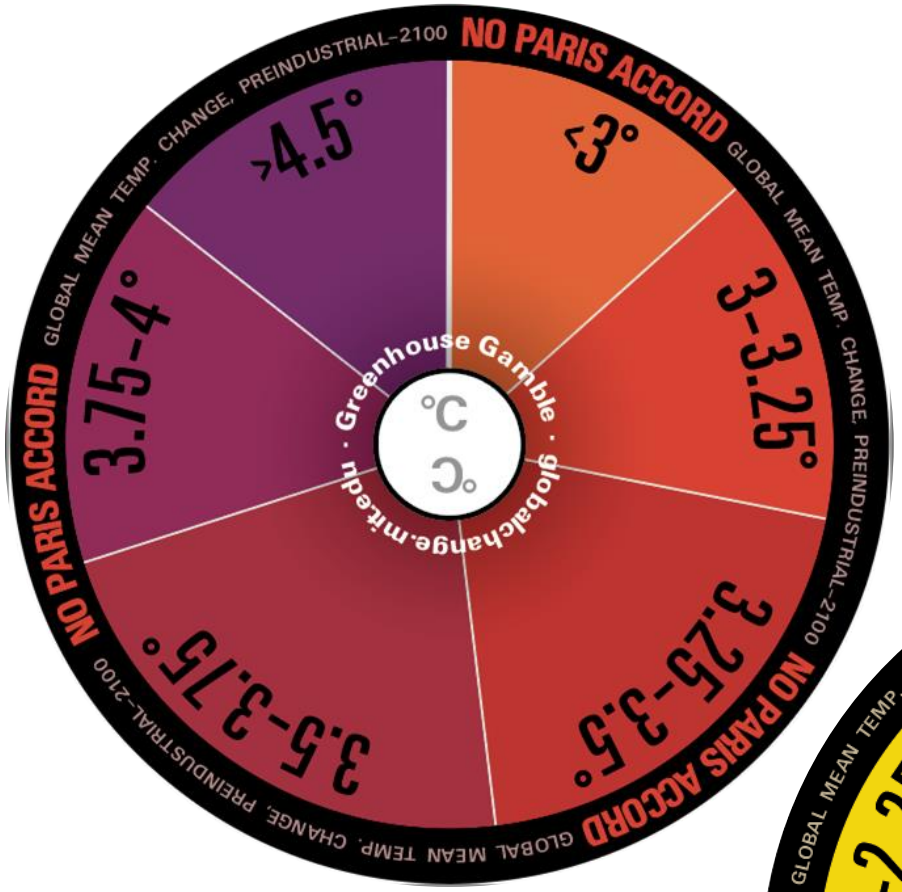
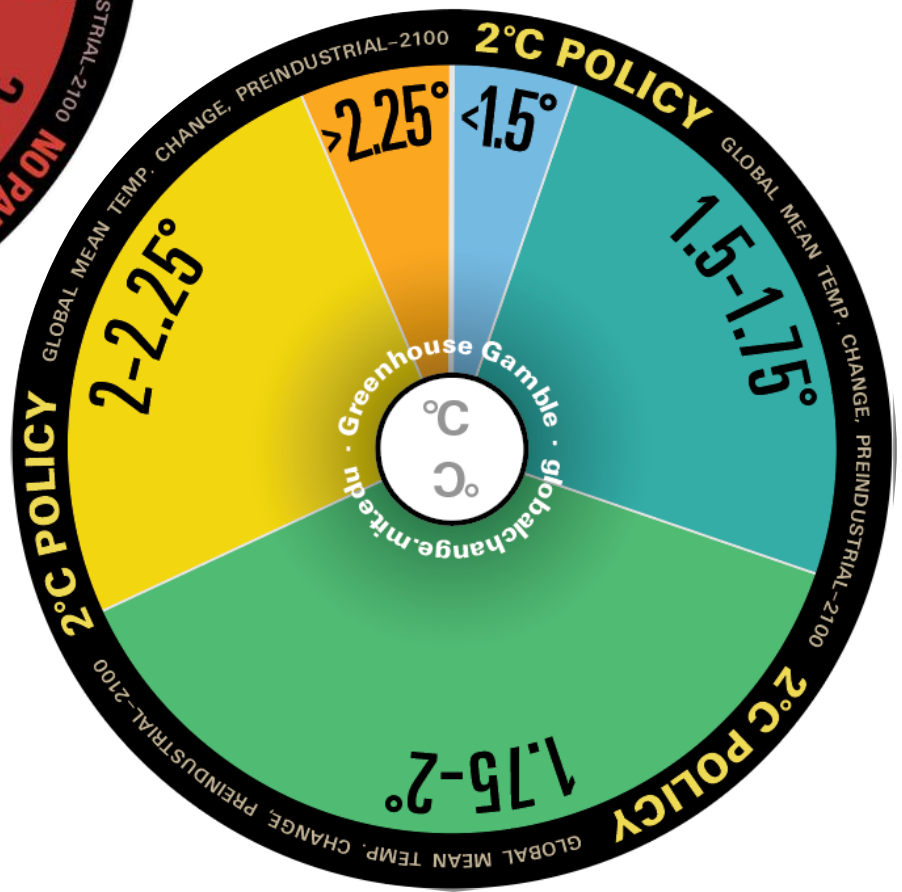
Benefits of Approach

- Ability to explore full range of outcomes with associated likelihoods while also maintaining intact individual scenarios
- Explore if there are prevailing storylines behind outcomes of interest
- Identify individual scenarios that are defined by specific combinations of outcomes to further explore… look at tradeoffs
- Develop smaller sets of scenarios that include a wide variety of possible futures and/or span a range of particular outcomes of interest… to use in finer scale models
- Help avoid potential biases in perceptions of what “needs” to happen to achieve certain outcomes

Challenges

- Scale!
- Model Connections & Feedbacks
- Dynamics and Metrics
- Deep Uncertainties





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

Thank you!

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