

Evaluating long-term reference scenarios for the energy system

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Motivation

- Energy-economic models are used to provide science-based decision support to governmental and private-sector entities about the long-term evolution of the energy system
- The dynamic systems being modeled could evolve along a number of distinct yet plausible pathways
- Not every question or application will lend itself to large ensemble analysis
- Evaluating scenarios for the energy system is important to ensuring the credibility of analyses they are used to support

Motivation (continued)

- Energy-economic modeling tools are often designed to conduct if-then analysis rather to produce forecasts
- Such analyses often employ a “reference” scenario which serves as a counterfactual against which alternative scenarios are compared
- Insights derived out of such if-then analyses depend critically on the characteristics of the reference scenario

Key questions

- *How can we understand the credibility of long-term reference scenarios from energy-economic models?*
- *What are the key elements of a framework for evaluating reference scenarios in a systematic way?*
- *What role can visual analytic tools play in facilitating this evaluation process, especially for models with high spatial resolution?*

Evaluation framework

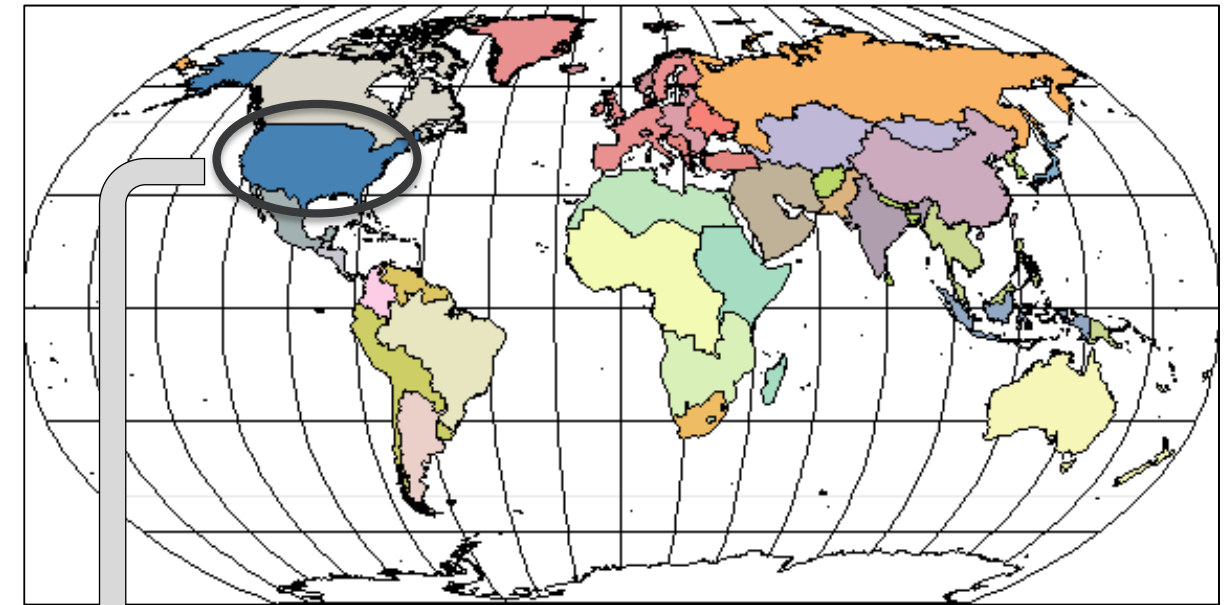
Our approach to evaluating scenarios consists of three elements:

- **Story-line:** Articulate a qualitative story-line for the long-term evolution of the modeled system
 - Every scenario has a story-line, whether it is explicit or implicit
- **Metrics:** Develop quantitative metrics to measure different characteristics of the modeled system
- **Evaluation Criteria:** Develop criteria that use these metrics to evaluate the alignment of model results with the qualitative story-line

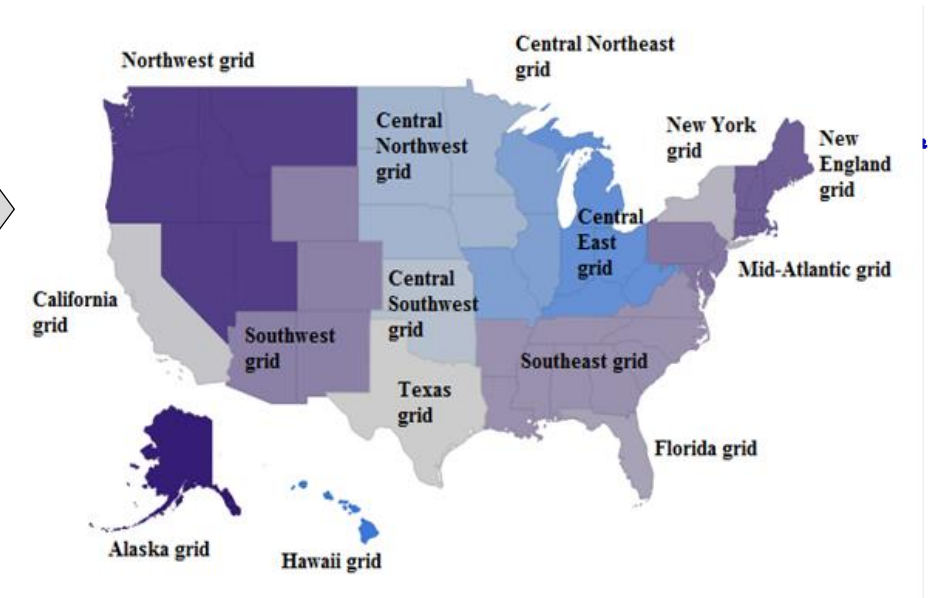
Test case: GCAM-USA electric power sector

- GCAM-USA is a version of GCAM with state-level detail in the United States
 - Conditions and markets in the U.S. are consistent with international conditions
- GCAM-USA includes sub-national representation of electricity supply, demand, and trade
- States are grouped into electricity “grid regions” (generally consistent with the North American Electric Reliability Corporation regions).

GCAM: 32 geopolitical regions



GCAM-USA: 50 states + D.C. in the U.S.



Key characteristics of the electricity system

- Electricity Demand
 - Total Electricity Consumption
 - End-Use Electrification (Buildings, Industry, Transportation)
- Electricity Supply
 - Fossil Fuels: share of generation, relative shares of coal & gas generation
 - Renewables: new installations, share of generation
 - Nuclear: new installations
- Electricity Transmission
 - State-Level (Intra-Grid)
 - USA-Level (Inter-Grid)
- Definitions
 - Near Future: ≤ 10 years
 - Long-Term: beyond 10 years

GCAM-USA's story-line

- Overarching story-line for the energy system in general
 - Historical trends continue in the near-term due to inertia in the system and continuation of current policies
 - In the long-term, outcomes are largely driven by economic forces, and technological / economic / social / policy developments that run counter to prevailing historical trends may develop



<https://me.me/i/in-object-at-rest-will-remain-at-rest-unless-acted-17335051>

GCAM-USA's story-line

- Electric Power Sector

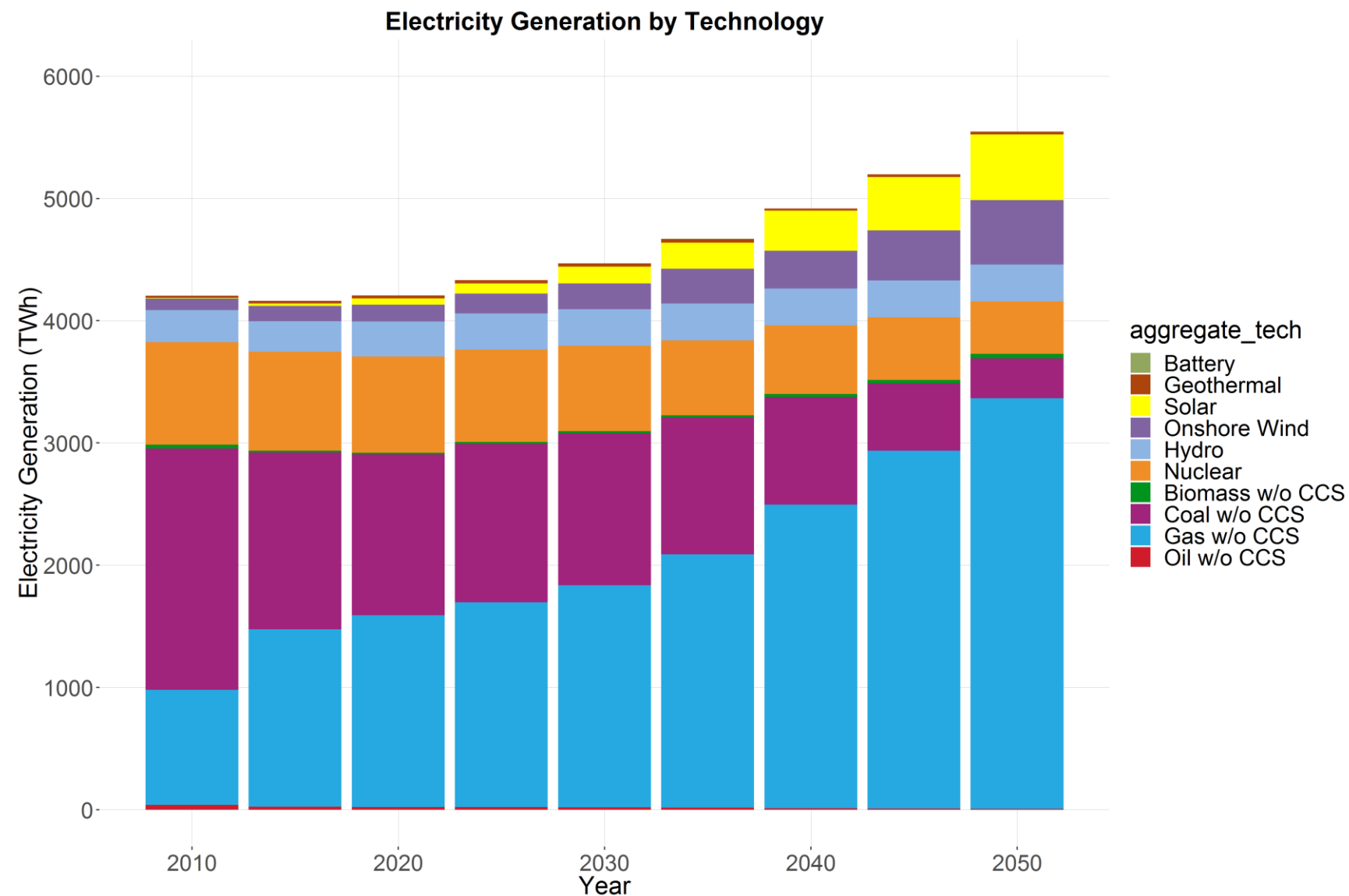
- Electricity Demand: Electricity demand will grow over the coming century, including modest growth over the next decade due to increased electrification in industrial, buildings and transportation sectors.
 - ✓ This departs from recently observed flat electricity demands.
- Electricity Supply: Increasing shares of natural gas and renewables will be deployed to meet the growing demand for electricity.
 - ✓ No new deployment of coal-fired power plants without CCS throughout the U.S.
 - ✓ Limited deployment of nuclear technologies
- Electricity Trade:
 - ✓ Electricity is freely traded among states within “grid regions”.
 - ✓ Grid regions do not change between being a net importer or exporter over time, but the magnitude of inter-regional trade across grid regions can change from historical levels as relative regional electricity prices change.

Metrics

Dimensions of Electricity Future			Metric	Point of Comparison
Category	Subcategory	Aspect		
	Total Consumption	Total Consumption	Electricity Consumption per unit of GDP	recent historical average
Electricity Demand	Buildings	Electrification	Electricity Share of Final Energy Mix	recent historical average
	Industry	Electrification	Electricity Share of Final Energy Mix	recent historical average
	Transport	Electrification	Electricity Share of Final Energy Mix	recent historical average
	Fossil Fuels	Share of Generation	Fossil Fuels Share of Electricity Mix	recent historical average
Electricity Supply		Relative shares of coal and gas generation	Ratio of Coal to Gas in Electricity Mix	recent historical average
	Renewables	New Installations	Growth Rate of New Installations	recent historical average
		Share of Generation	Intermittent Renewables Share of Electricity Mix	threshold as defined by academic literature
	Nuclear	New Installations	Growth Rate of New Installations	recent historical average
Electricity Transmission	Electricity Trade	State-Level (Intra-Grid)	Ratio of Electricity Generation to Electricity Consumption	recent historical average
		USA-Level (Inter-Grid)	Ratio of Traded Electricity to Total Generation	recent historical average

Electricity Generation in GCAM-USA

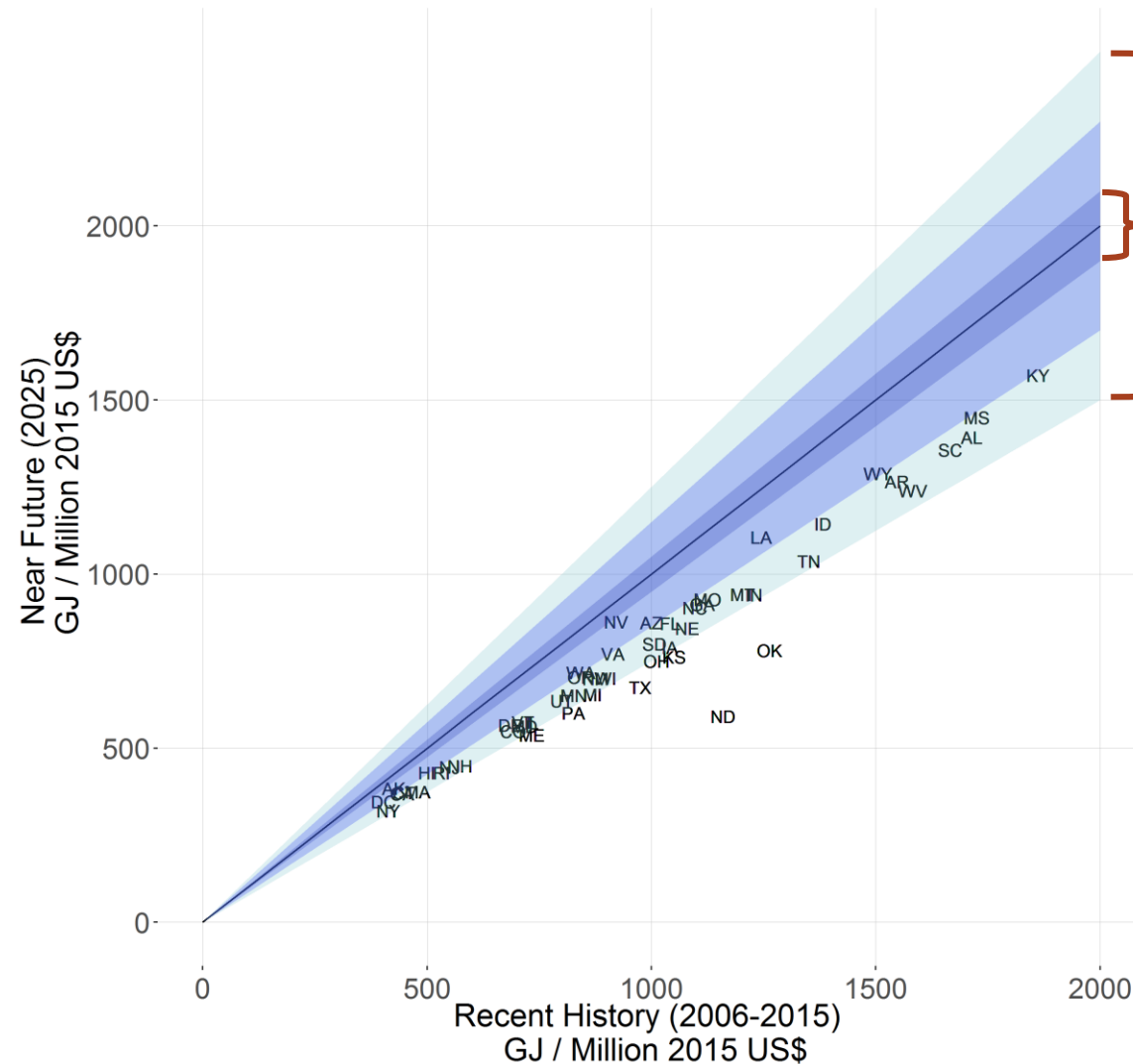
- Story-line: Electricity demand will increase modestly in the long-term due to economic growth and end-use electrification.



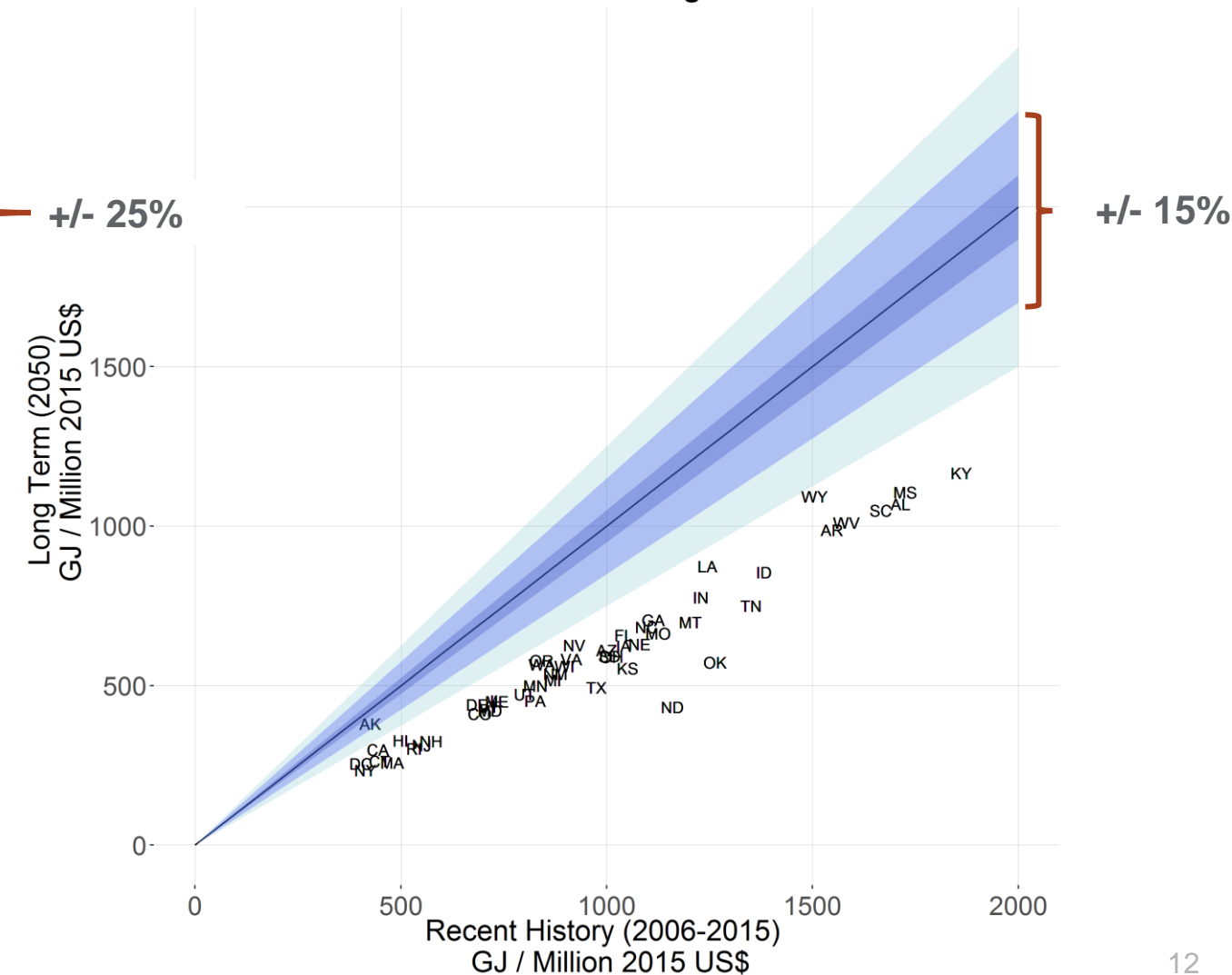
Electricity Consumption per GDP – 2025, 2050

- Story-line: The recent trend of economic growth slowly decoupling from electricity consumption will continue.

Electricity Consumption per GDP
Historical vs. Near Future



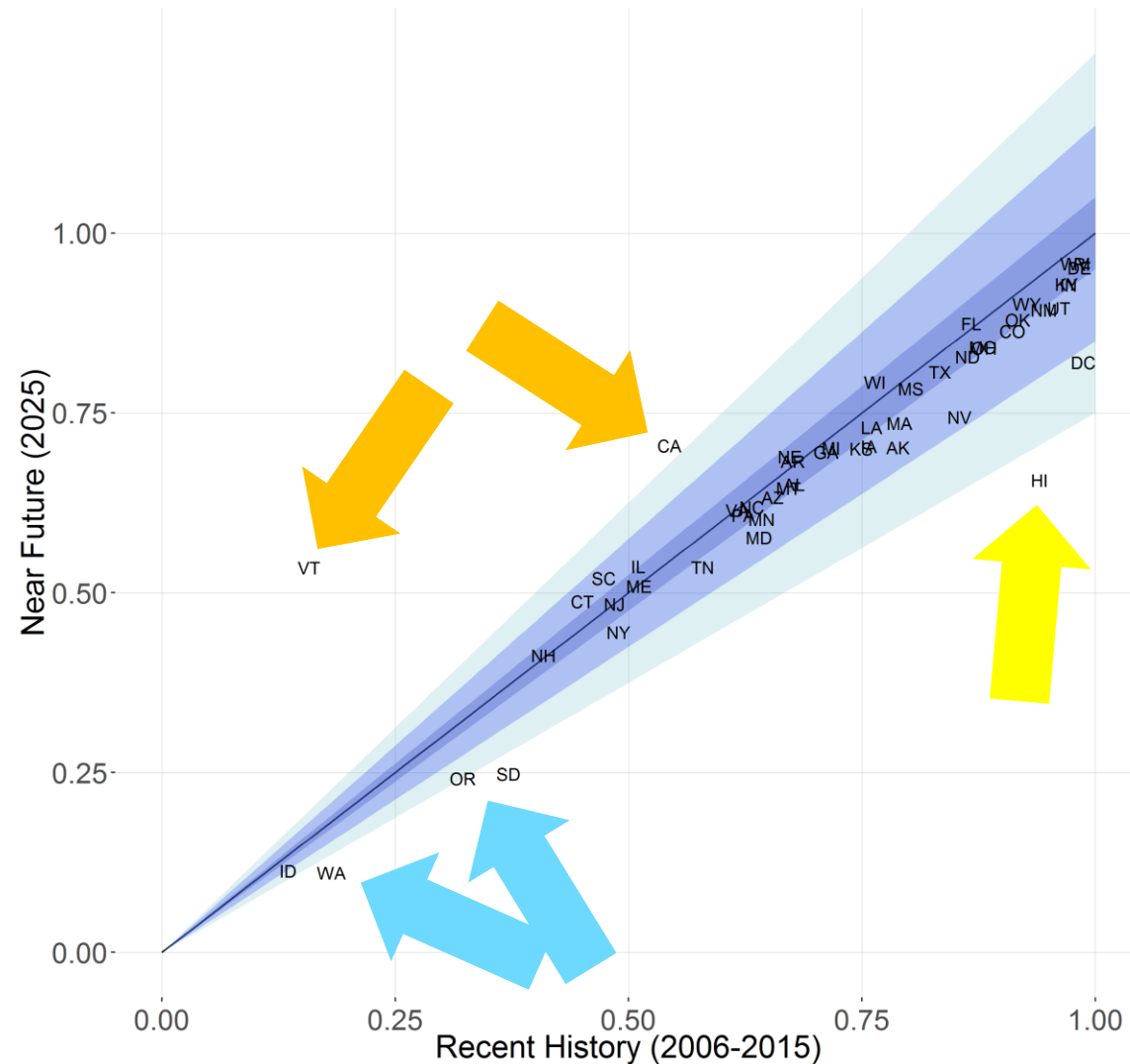
Electricity Consumption per GDP
Historical vs. Long Term



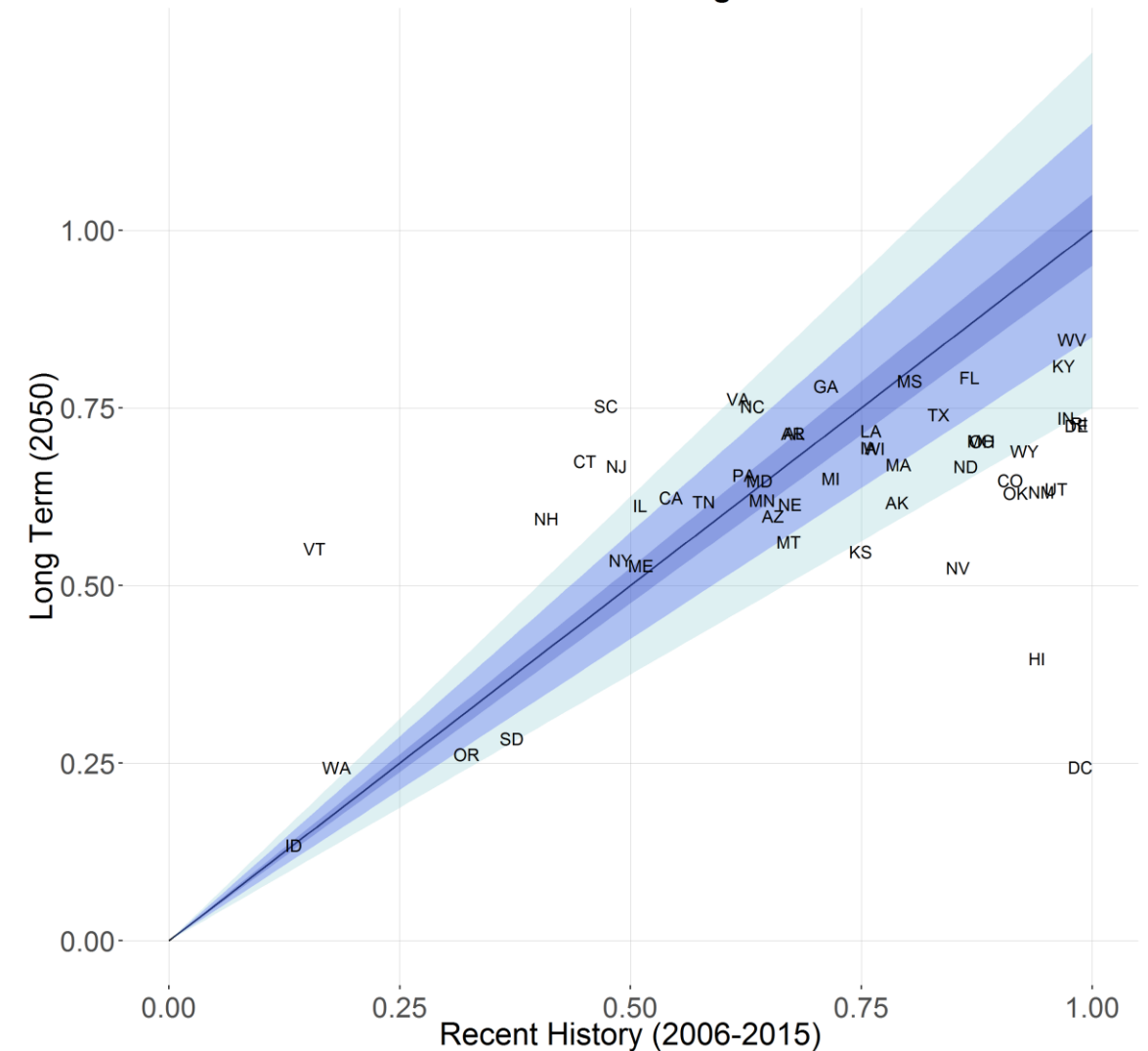
Fossil Fuels Share of Generation – 2025, 2050

- Story-line: Low-cost renewables will continue to slowly reduce fossil fuel's share of electricity generation.

Fossil Fuel Share of Electricity Generation
Historical vs. Near Future



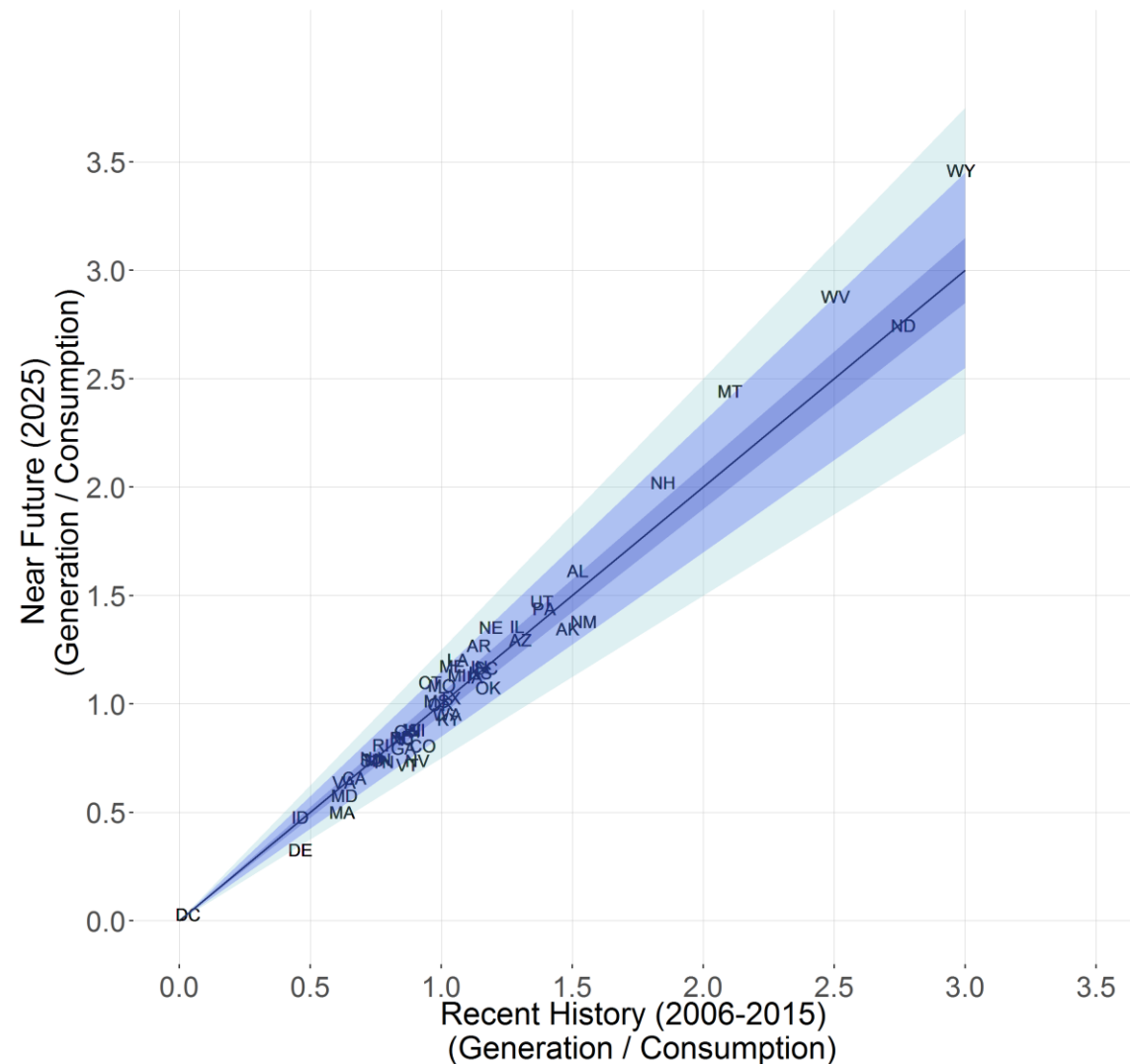
Fossil Fuel Share of Electricity Generation
Historical vs. Long Term



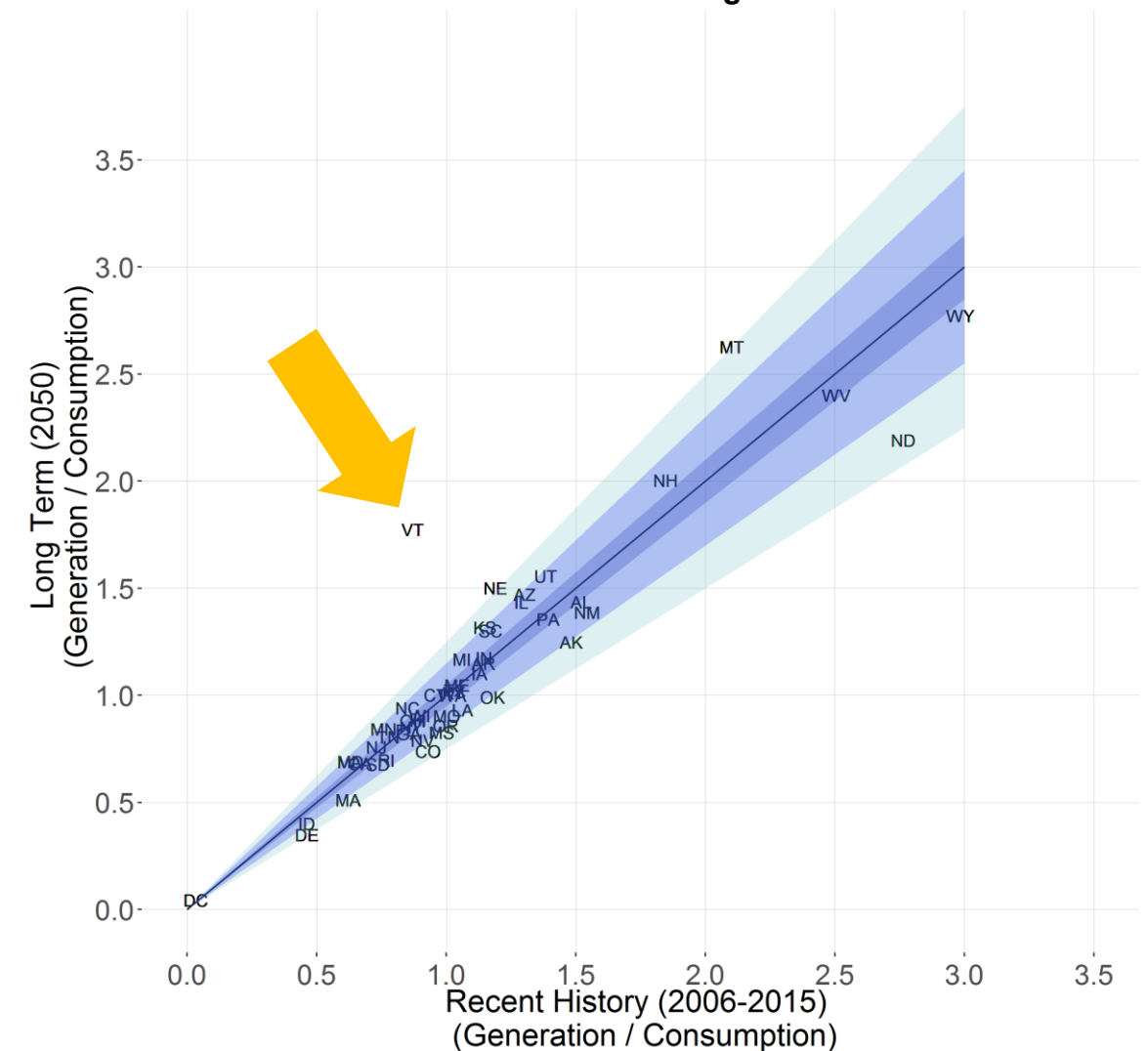
Ratio of Electricity Generation to Consumption – 2025, 2050

- Story-line: Electricity is freely traded within grid regions, but there is some inertia in the balance of trade among states within a grid region.

Electricity Trade Balance
Historical vs. Near Future



Electricity Trade Balance
Historical vs. Long Term



Closing thoughts

- Evaluating scenarios is important to ensuring the credibility of modelers' analysis
- Articulating a scenario's qualitative storyline is key to this process
 - Models provide a quantitative realization of that storyline
- Metrics can be used to assess the fidelity of a scenario's qualitative description of the future and its quantitative representation of that future, or to characterize a scenario's storyline if it is not explicit
- Visual analytic tools can facilitate the evaluation of scenarios with higher spatial resolution

Thank you