SCEP
STATE & COMMUNITY ENERGY PROGRAMS

Long-Term Electricity Projections for Kentucky

State Energy Technical Assistance Program

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National Renewable Energy Laboratory

October 18, 2024

Introduction

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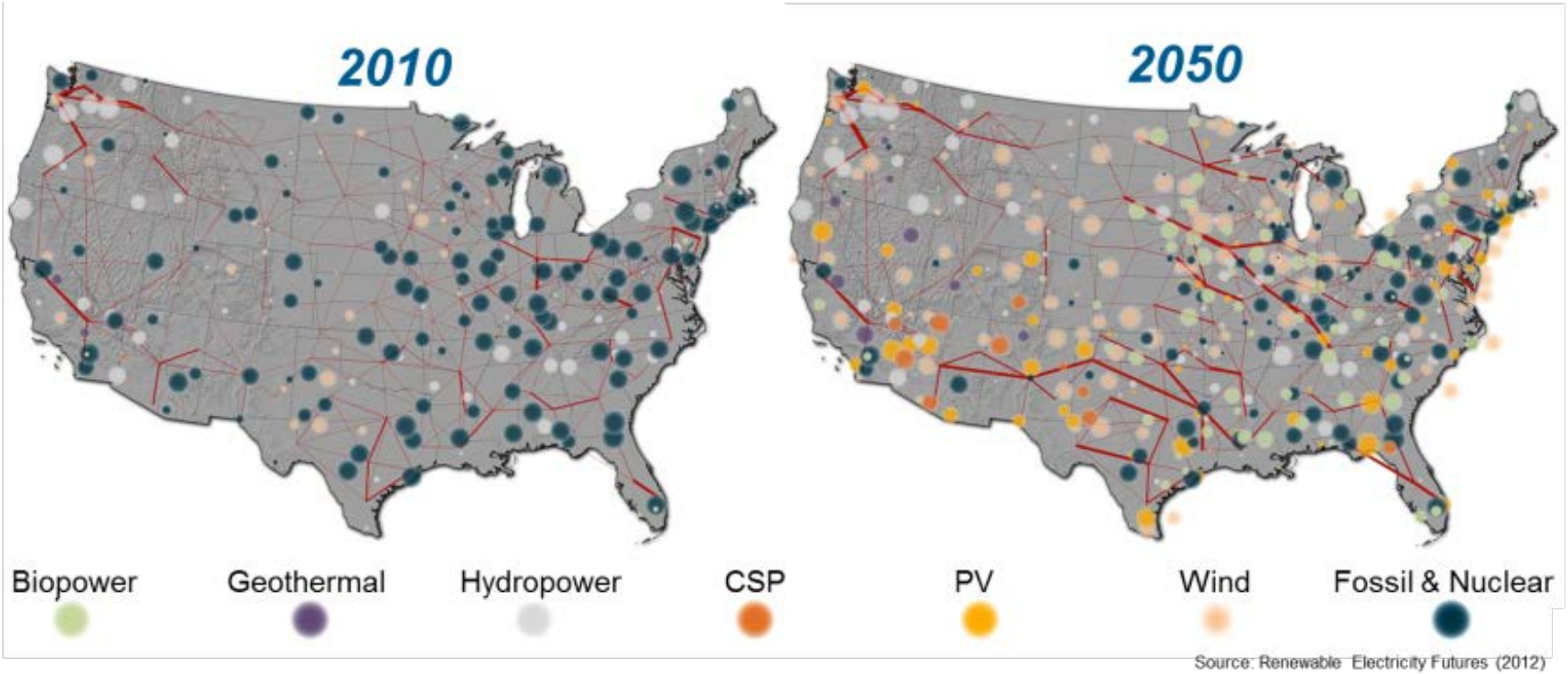
NREL

NATIONAL RENEWABLE ENERGY LABORATORY

SCEP provided funding in summer 2024 for Kentucky and NREL to work together to investigate long-term projections of the Kentucky power system.

What Does ReEDS Do?



Given a set of input assumptions, the Renewable Energy Deployment System model (ReEDS™) simulates the evolution and operation of U.S. generation, storage, and transmission technologies.

How Does ReEDS Work?

ReEDS uses optimization to identify the least-cost investment and operation of grid assets that simultaneously meets load; all other electricity service requirements; and other physical, environmental, or policy constraints.

Fossil

Nuclear

Storage

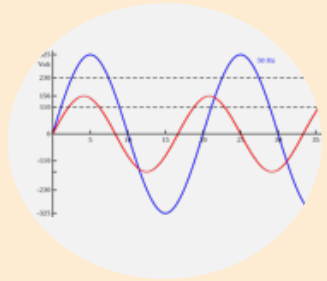
Transmission

Renewables

Regulations

Load

(DC) Power Flow



Ancillary Services

How Does ReEDS Work?

Objective: Minimize total **capital + operational** cost of electricity system **subject to…**

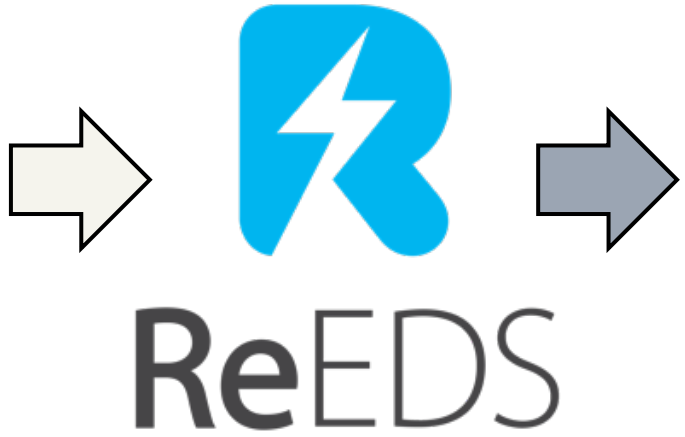
Price-forming constraints: Energy balance; planning/operating reserves; renewable portfolio standards/carbon policies

Additional constraints: Resource availability (spatial and temporal); energy/reserve trading; generation/storage operations; fuel supply; planned builds and retirements; etc.

Inputs

- **Existing and planned** capacity
- **Variable renewable energy** temporal (hourly) and spatial (11.5 km × 11.5 km) availability
- State and federal **policies** (current and/or hypothetical)
- **Load** (hourly) projections for 134 zones across contiguous U.S.
- Capital, operations and maintenance, and fuel **cost** projections
- **Technology** availability and performance projections.

Regional Energy Deployment System

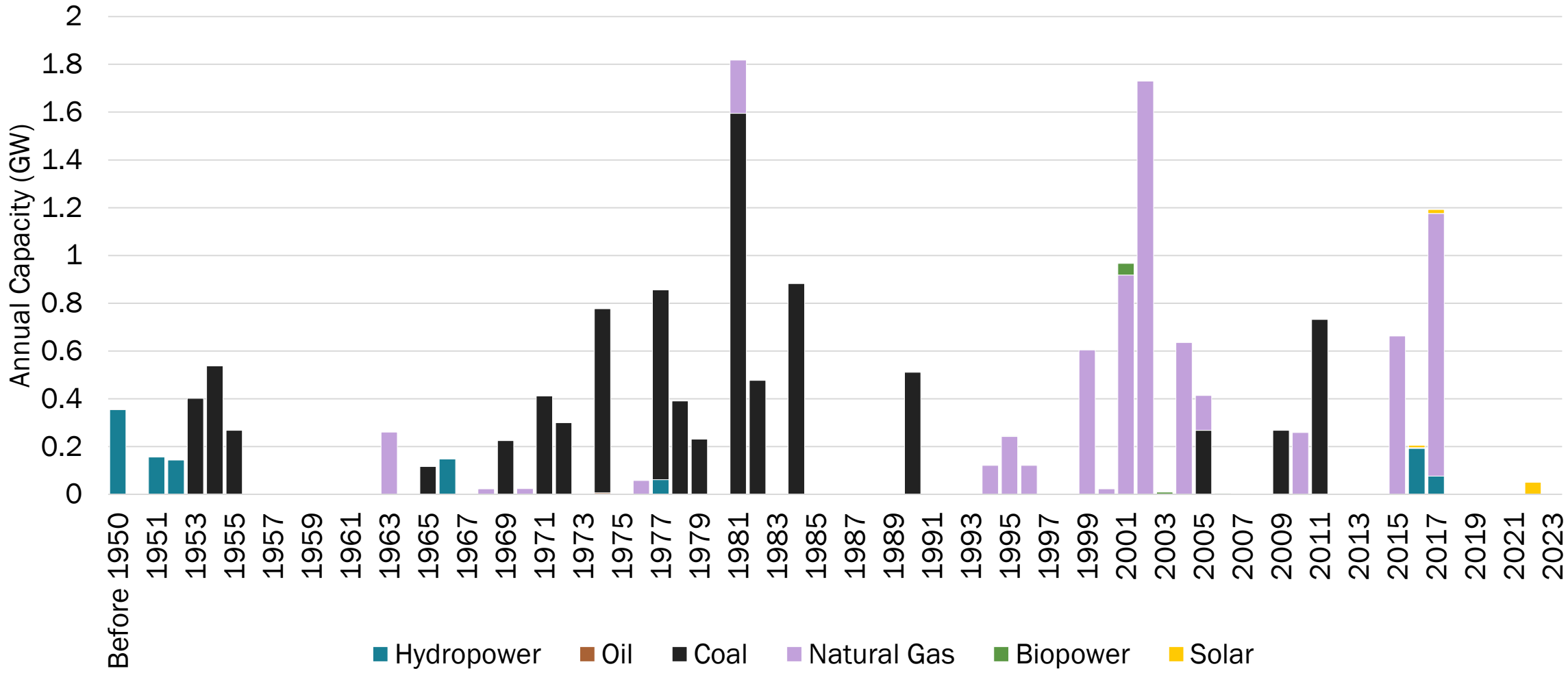


https://www.nrel.gov/analysis/reeds/

Outputs

- Generation and storage **capacity** additions and retirements in each solve year
- **Transmission** capacity additions
- **Operations**: Energy generation, firm capacity, and operating reserves by tech
- CO_2, NO_x, SO_2, CH_4 **emissions**
- System **cost** [$ billion], electricity **price** [$/MWh], retail **rates** [¢/kWh].

Kentucky Power System Additions



Scenario Definitions

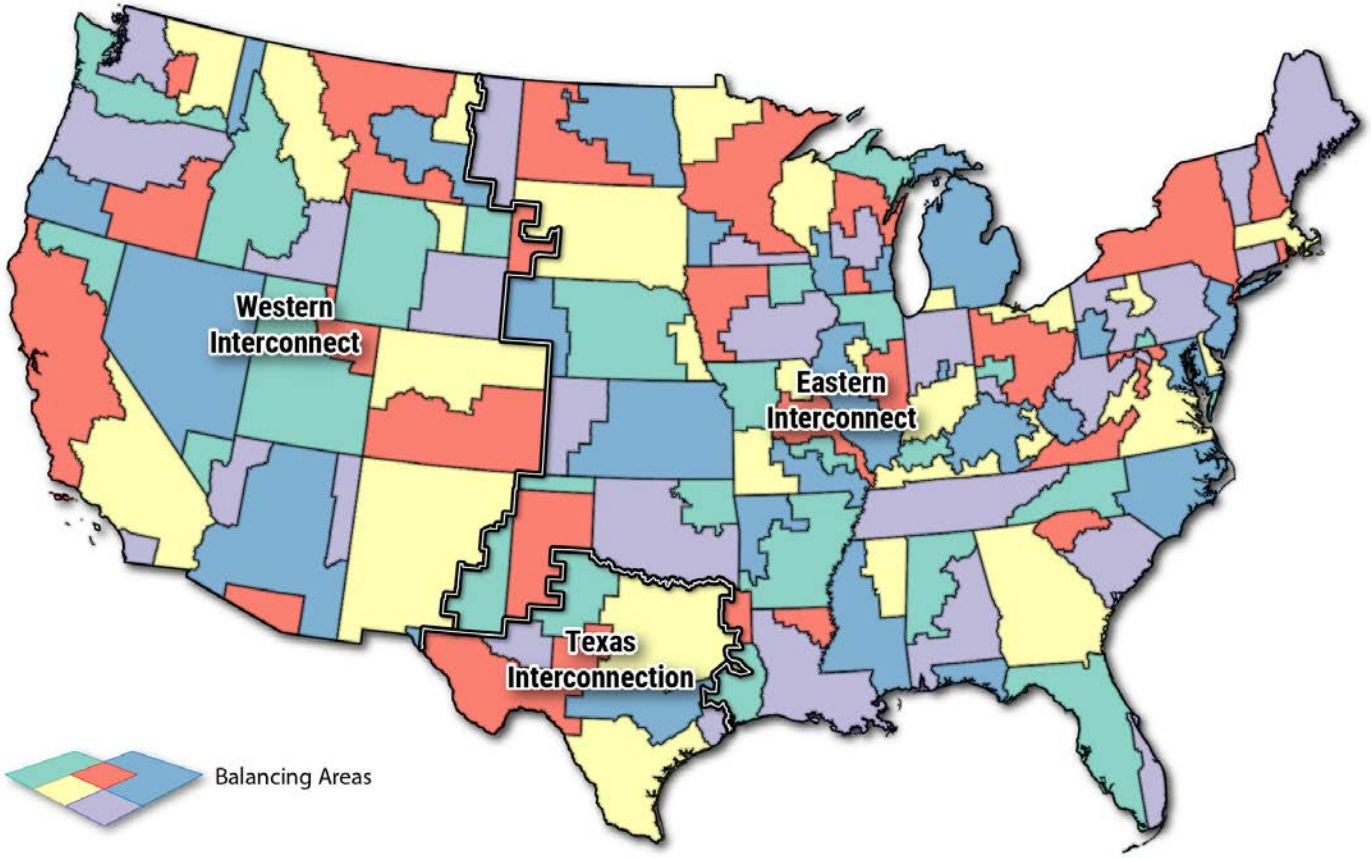
Case Title	Wind/Solar Resource	Load	Gas Prices	Nuclear Costs	EPA 111 (on unless noted)
Reference					
Limited Renewables	Limited solar siting, limited onshore wind siting				
Limited Renewables, Low Nuclear	Limited solar siting, limited onshore wind siting			Advanced nuclear costs	
High Gas, Low Nuclear			High gas prices	Advanced nuclear costs	
High Load		High load growth			
High Gas, Low Nuclear, High Load		High load growth	High gas prices	Advanced nuclear costs	
No EPA 111					No EPA 111

The scenarios were run under two different conditions (described more on the next slide):

- Kentucky at a county resolution and no electricity interchange
- Entire Eastern Interconnection (EI) at ReEDS default model resolution.

Scenario Sets (used for each scenario on Slide 7)*

- Kentucky county:
  - Kentucky is an electricity island (no interstate electricity exchange).
  - County resolution.
- EI/Kentucky:
  - Full EI is modeled.
  - Coordination and electricity trading occurs across the full interconnection.
  - Model resolution is at the ReEDS balancing area level.

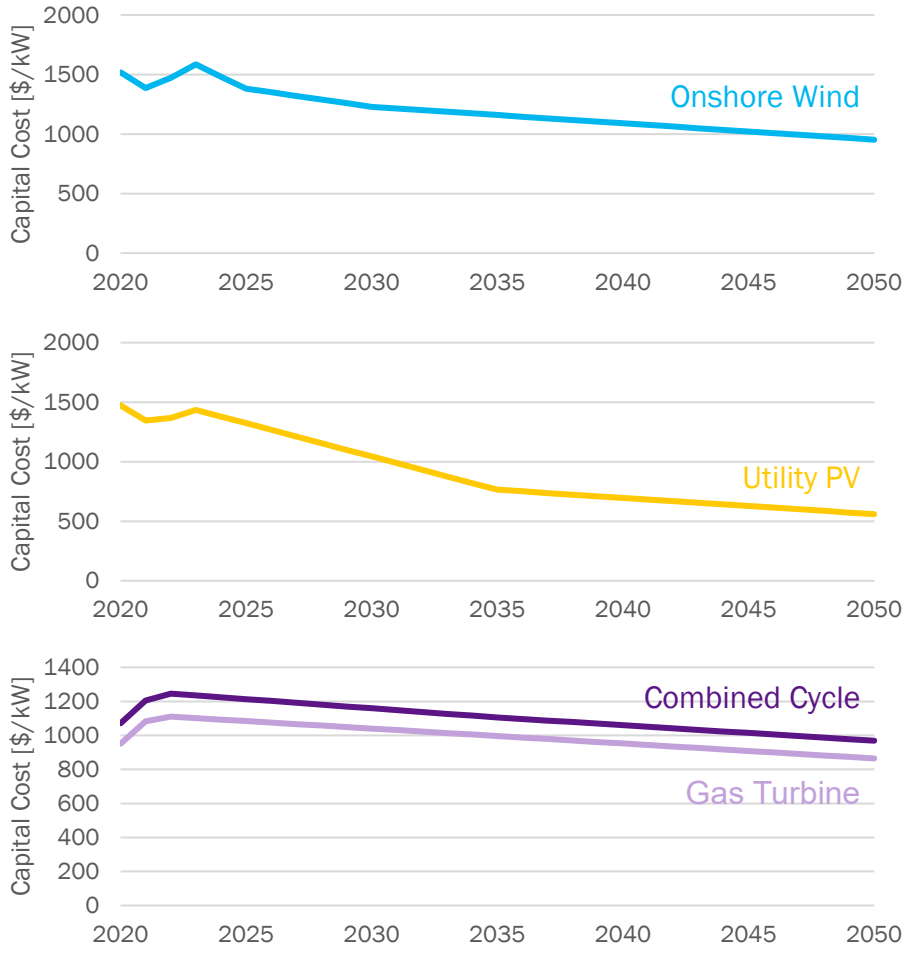


*Each scenario from Slide 7 was run twice, once as an islanded system at county resolution, and once with the full EI using the resolution shown in the map above. In both cases, we present the results only for resources located within Kentucky.

Reference Case Parameters

- Renewable siting is limited by physical obstacles, existing ordinances and regulations, protected areas, etc.
  - For a full list, see Table 4 at https://www.nrel.gov/docs/fy24osti/87843.pdf.
- Annual load and growth are provided by Evolved Energy Research (EER) and include electrification impacts of the Inflation Reduction Act (IRA).
- Generator costs are from the 2024 NREL ATB.
- Transmission expansion allowed starting in 2032.
- Apply state, regional, and federal policy as of summer 2024.

NREL Annual Technology Baseline (ATB) capital costs, 2024



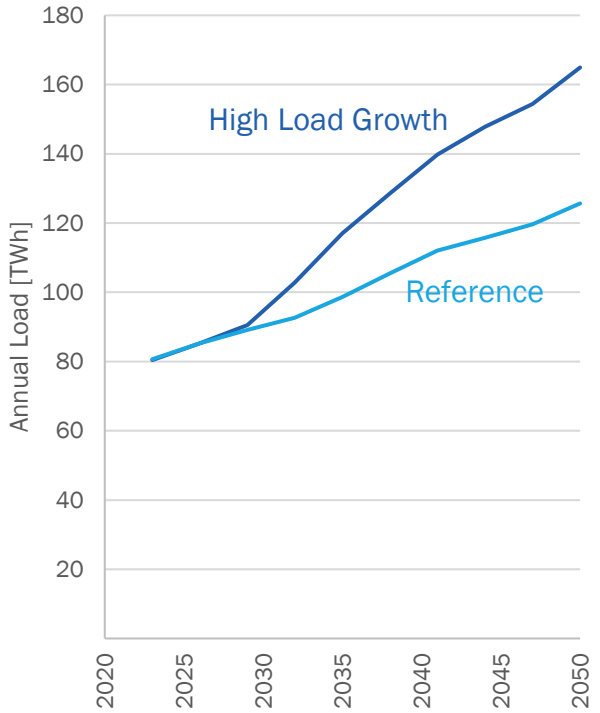
Modeled EPA 111 Representation

- Existing coal plants:
  - If the plant will permanently cease operations before Jan. 1, 2032: they are not subject to EPA 111.
  - If the plant is operating on or after Jan. 1, 2032, and demonstrate that they plan to permanently cease operations before Jan. 1, 2039: they must cofire with 40% natural gas from 2030 through 2039 **[not modeled].***
  - If the plant plans to operate on or after Jan. 1, 2039: they must upgrade with carbon capture and storage (CCS) with 90% capture by Jan. 1, 2032 **[included].**
- Existing gas combined cycles and gas combustion turbines:
  - No regulations.
- New gas combined cycles and gas combustion turbines:
  - If the plant is operating at <= 40% capacity factor: they are unregulated **[included].**
  - If a plant is operating above 40% capacity factor: they must upgrade with CCS by 2032 **[included].**
- Emissions rate-based mechanism: the emissions rate of the coal fleet within a state must be < = a 90% coal CCS plant **[included].**
- There are other potential compliance mechanisms for this regulation, and those are not modeled.

*In several ReEDS test scenarios, we found that the model almost never chose this compliance pathway, so we opted to exclude it from the main version of the model.

Scenario Input Assumptions

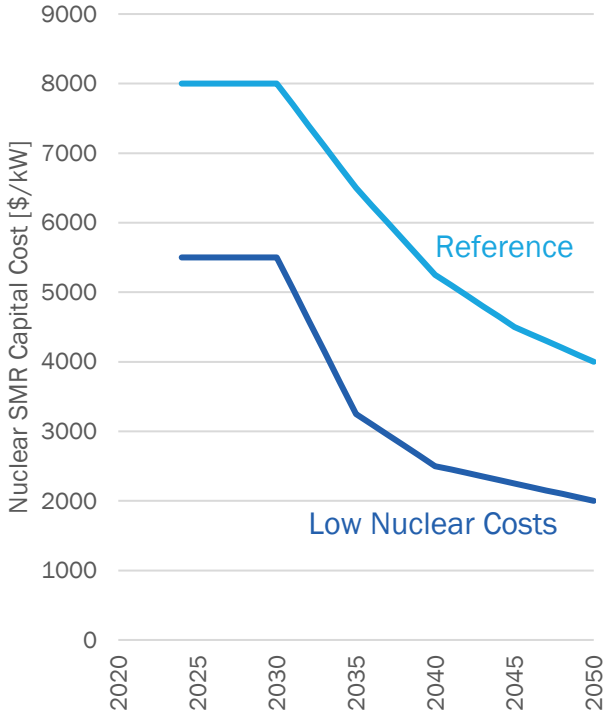
Load Scenarios



<u>Reference</u>: NREL Standard Scenarios Ref. Load (EER IRA Low)

<u>High Load</u>: EER IRA 100 by 2050

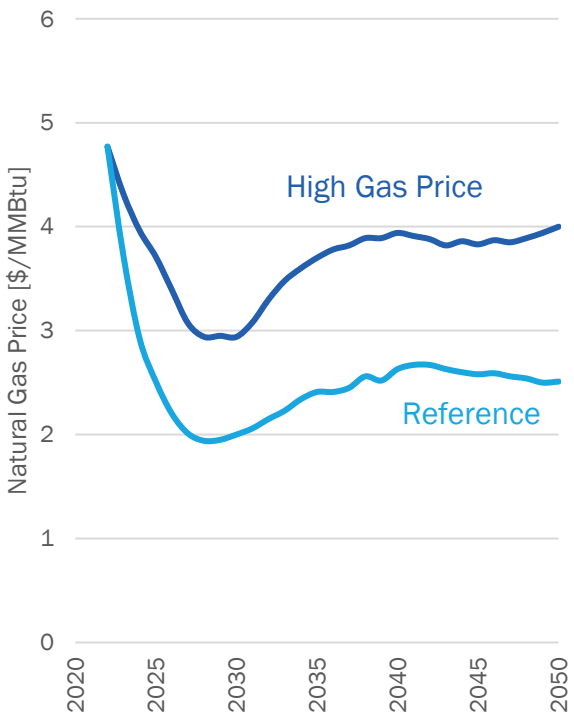
Nuclear Costs



<u>Reference</u>: 2024 NREL ATB

<u>Low Nuclear</u>: 2024 NREL ATB-advanced nuclear

Fuel Costs



<u>Reference</u>: AEO 2023 Reference

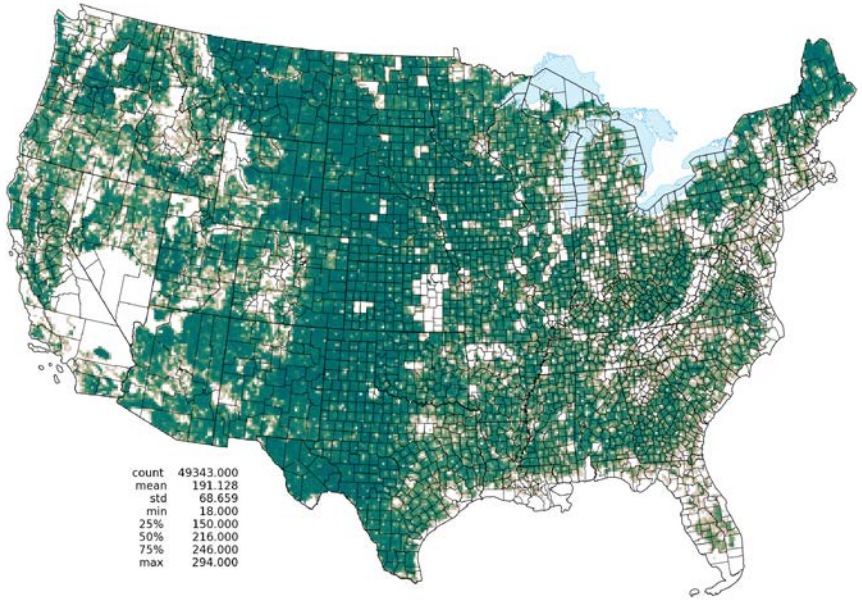
<u>High Gas</u>: AEO 2023 Low Oil and Gas Resource and Technology

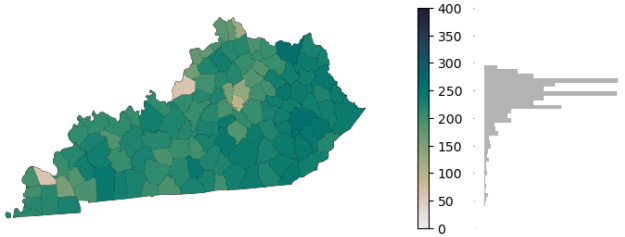
AEO = Annual Energy Outlook

Land-Based Wind Siting Assumptions

Limited renewable energy scenarios: Onshore wind (NREL Wind Supply Curve, 2024)

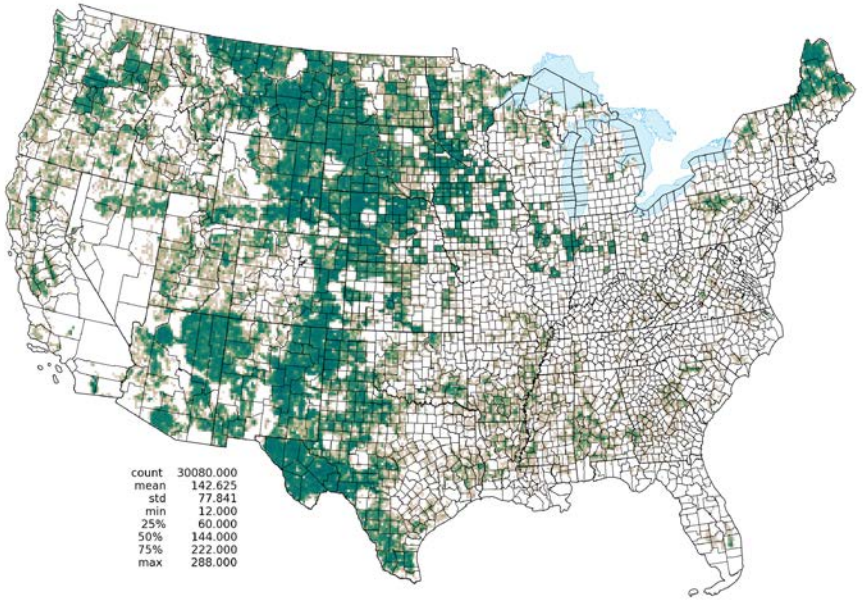
Reference

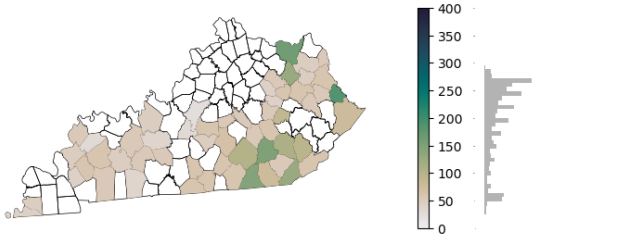




Total Potential: 124 GW

Limited



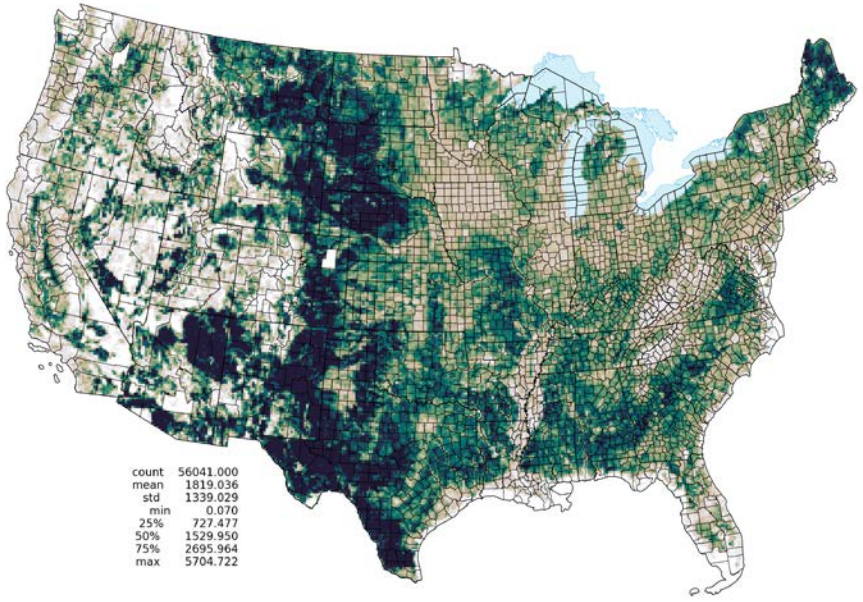


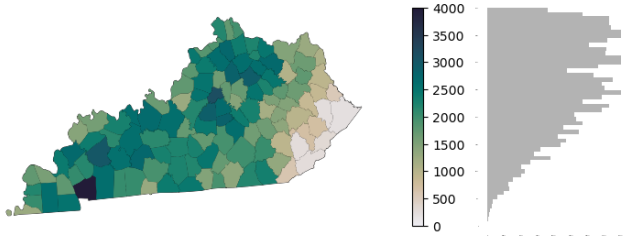
Total Potential: 8.0 GW

Utility-Scale Solar Siting Assumptions

Limited renewable energy scenarios: Utility-scale photovoltaics (PV) (NREL Solar Supply Curve, 2024)

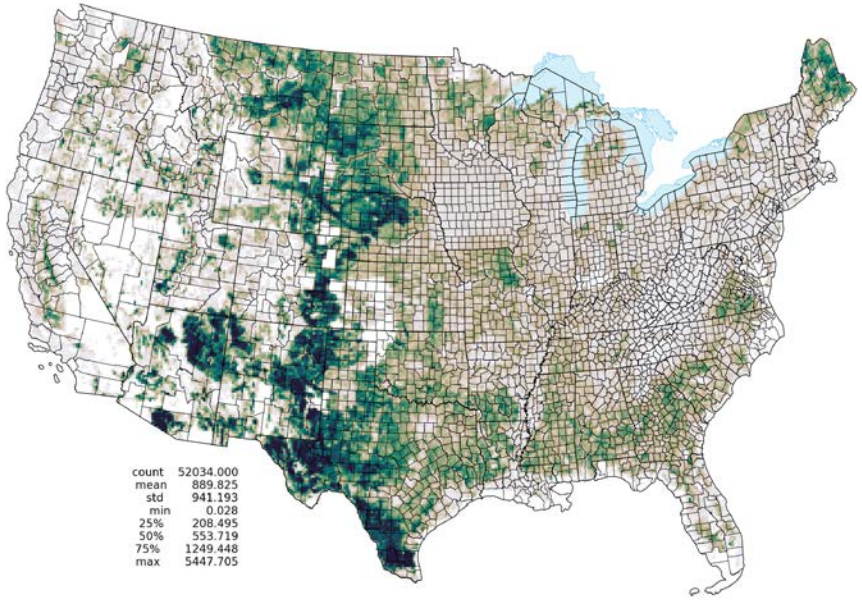
Reference

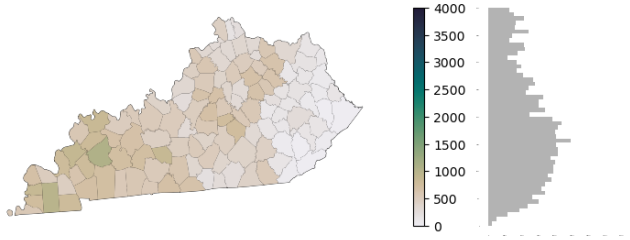




Total Potential: 1,076 GW

Limited

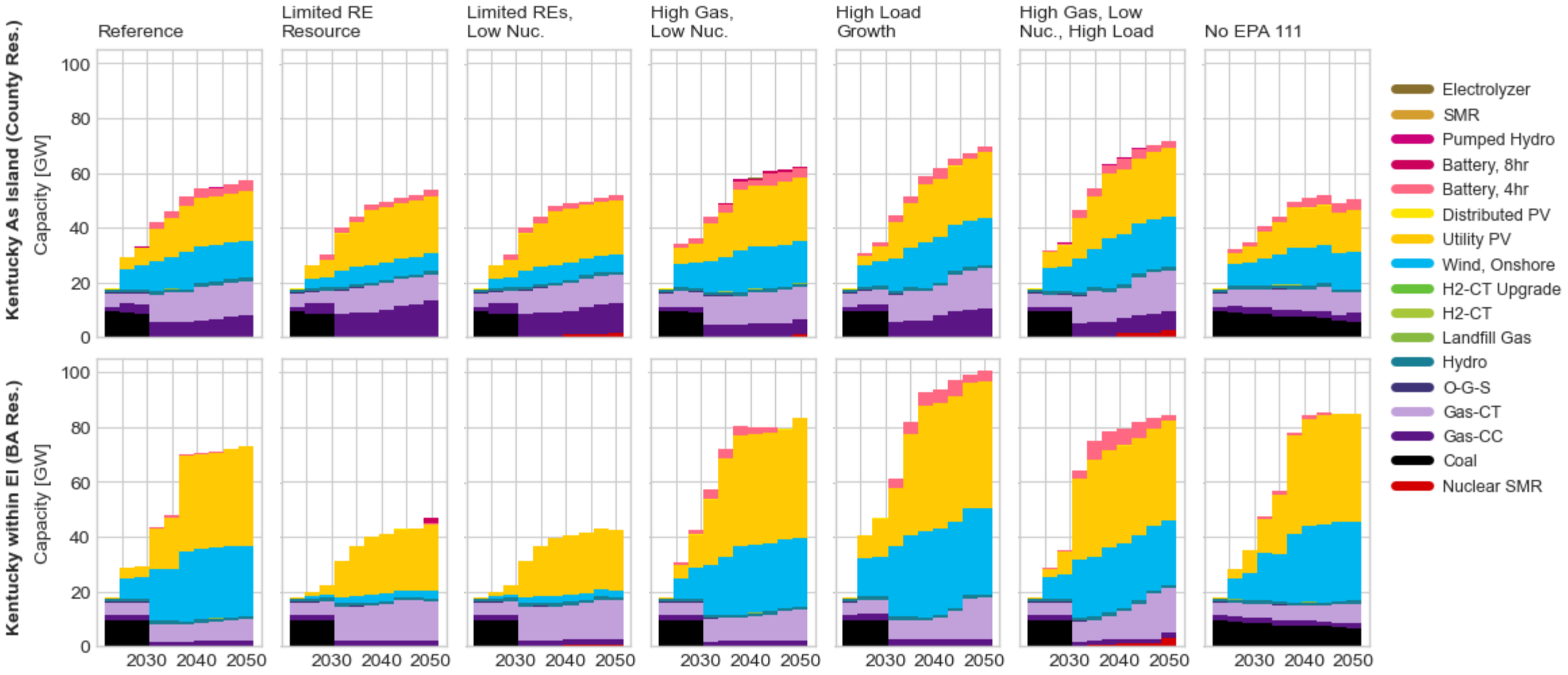




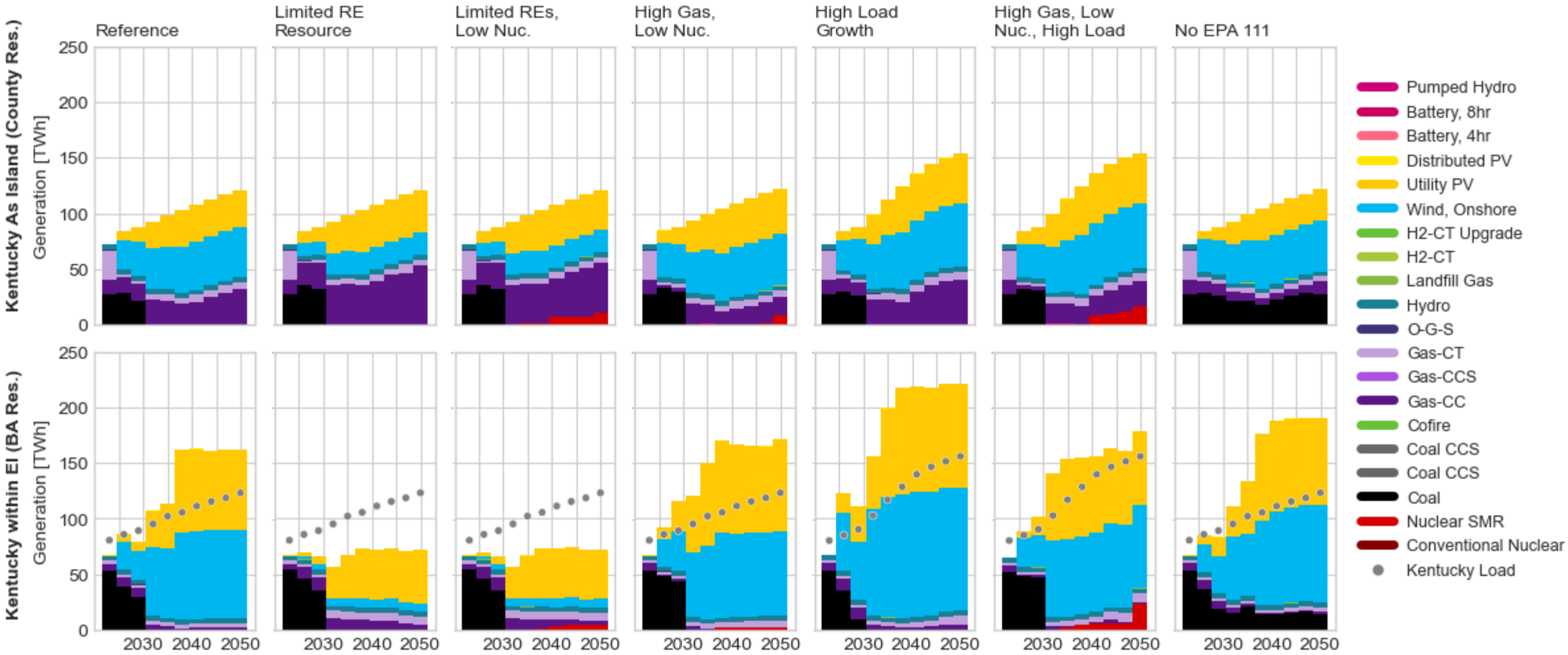
Total Potential: 228 GW

Scenario Results

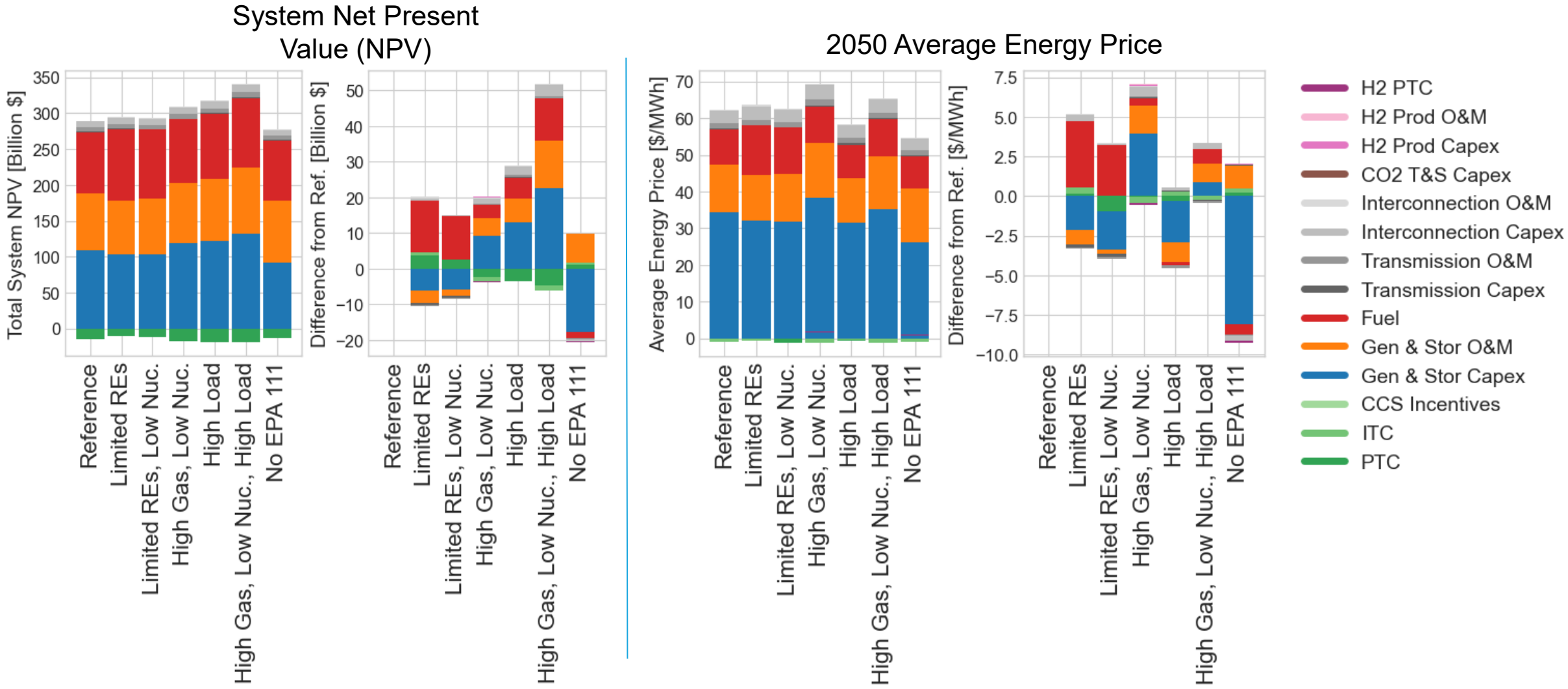
Interconnection Cases Are More Sensitive to System Conditions



Islanded Kentucky Cases Rely More Heavily on Fossil Assets for Generation



High Gas Prices Can Have a Significant Impact on System Costs

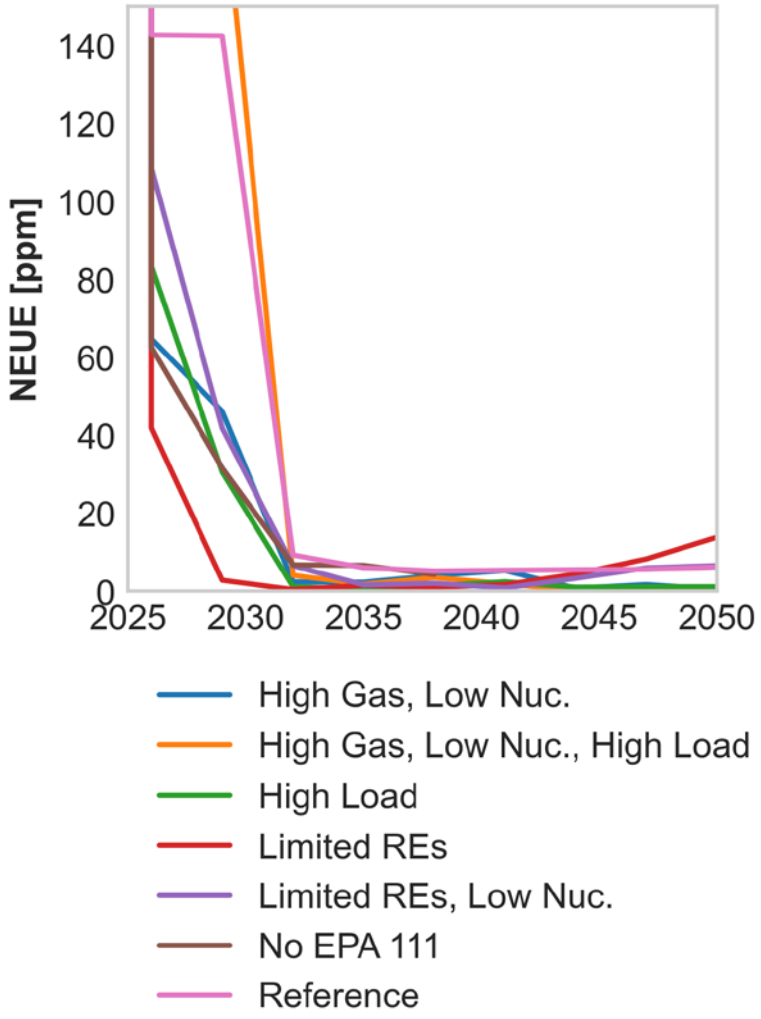


Scenario Set: Kentucky Islanded at County Resolution

All Scenarios Provide Comparable System Reliability

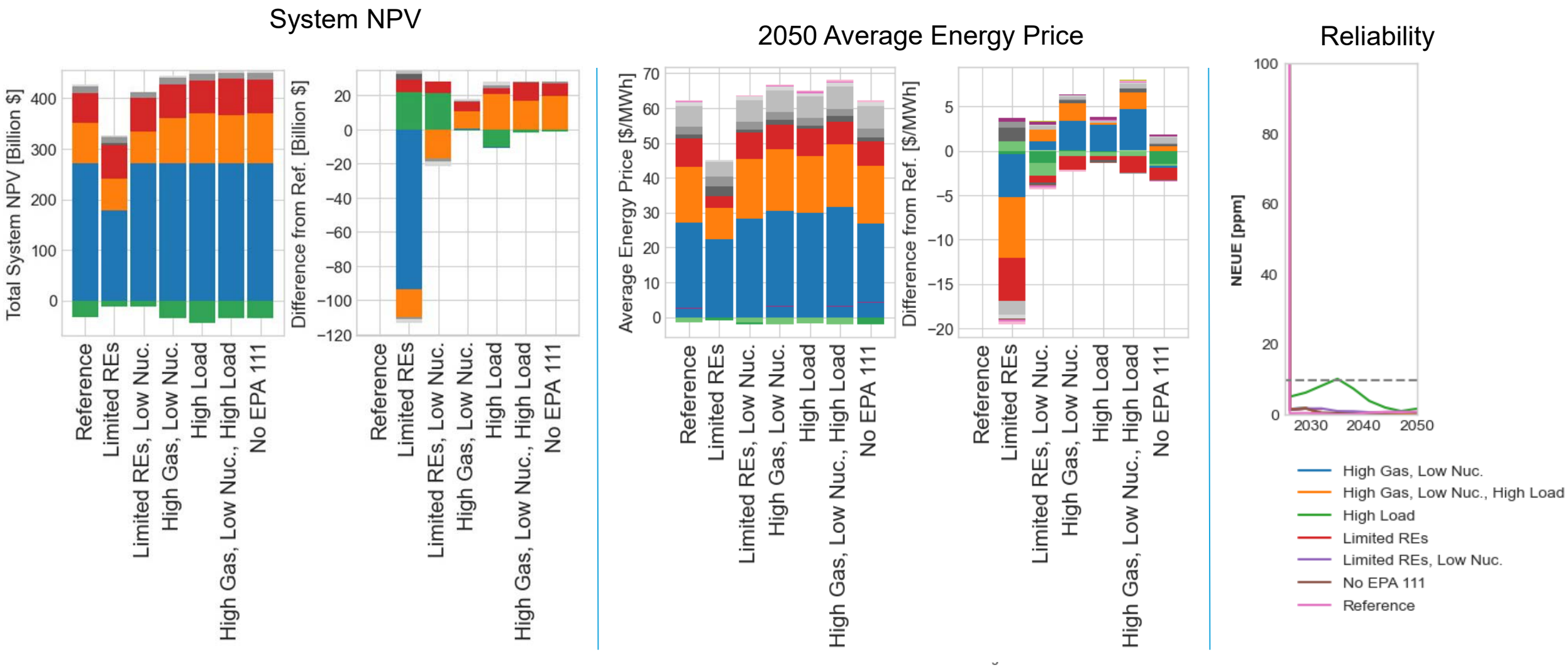
NEUE: Normalized expected unserved energy

- NEUE is the ratio of unserved energy to the total energy. In our results, we measure this in parts per million (ppm).
- NERC considers 0 to be low risk, ≤0.002% (20 ppm) medium risk, and above to be high risk.
- Our model uses a threshold of 10 ppm.



Scenario Set: Kentucky Islanded at County Resolution

System Costs Do Not Account for Imports/Exports

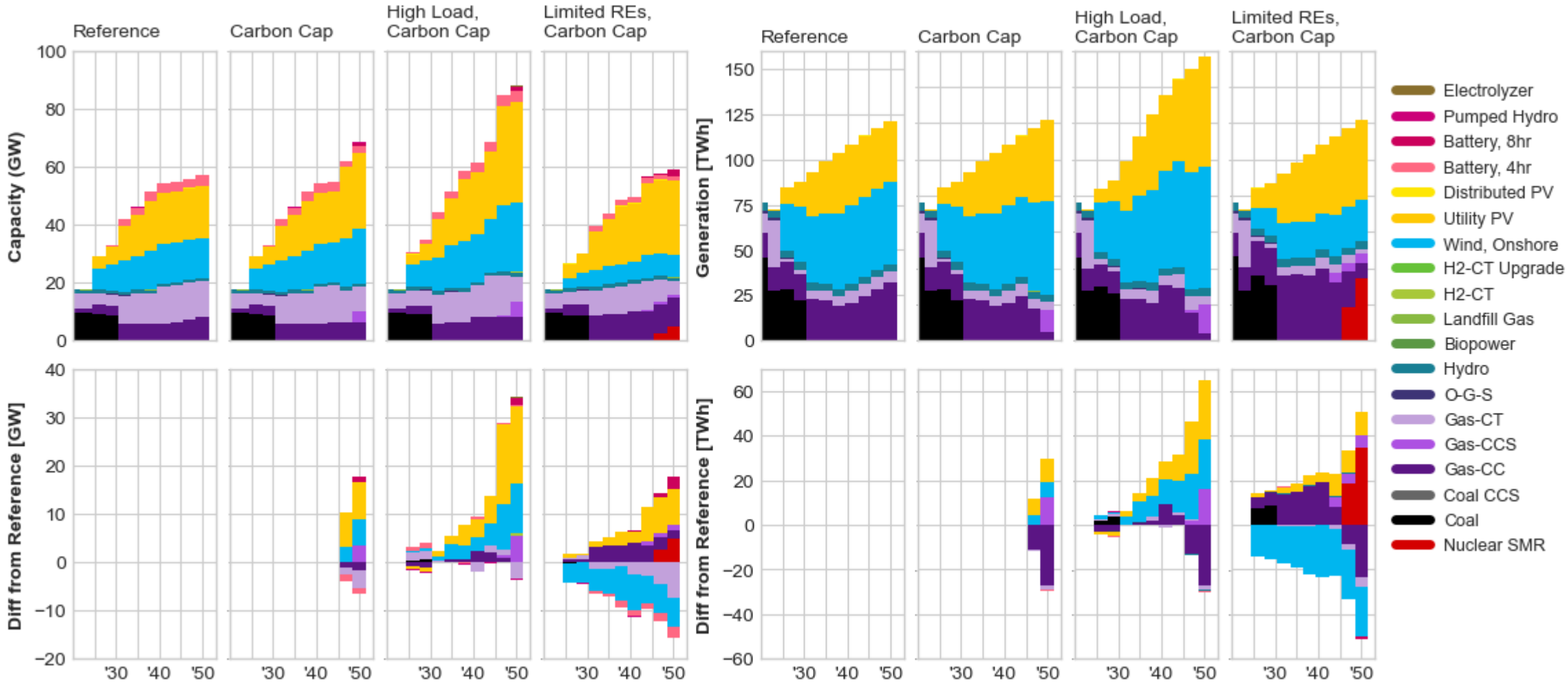


Scenario Set: EI

Carbon Limits Incentivize CCS and Nuclear Small Modular Reactor Generation

We imposed a maximum annual CO_2 emissions limit to evaluate the potential of CCS and other low-carbon firm generation.

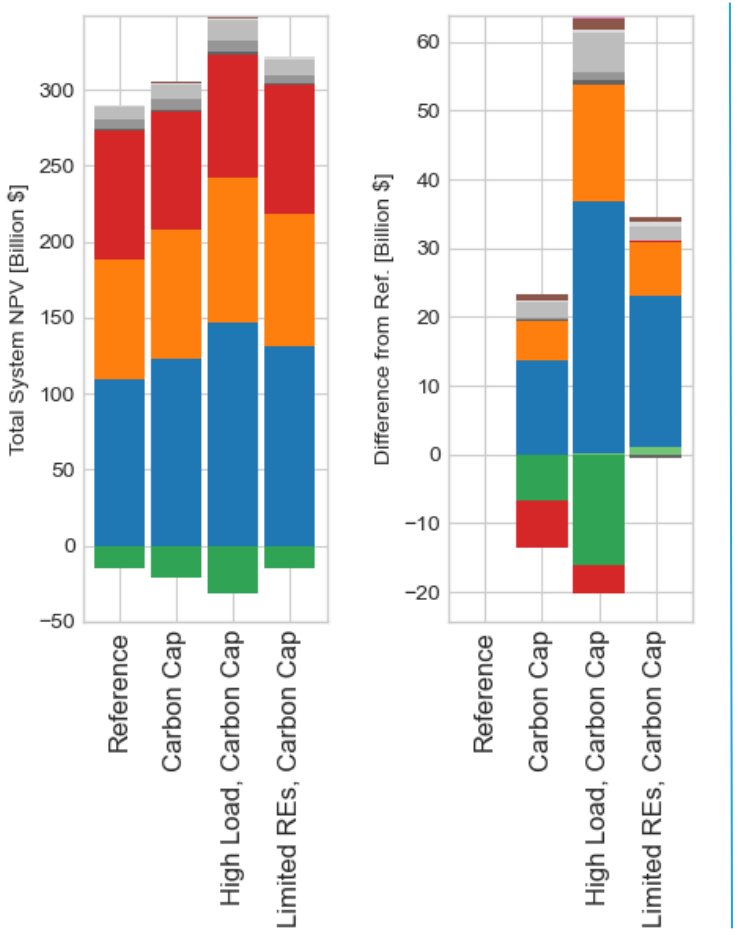
- Our carbon cap starts in 2023 and reduces total CO_2 by 95% in 2050.



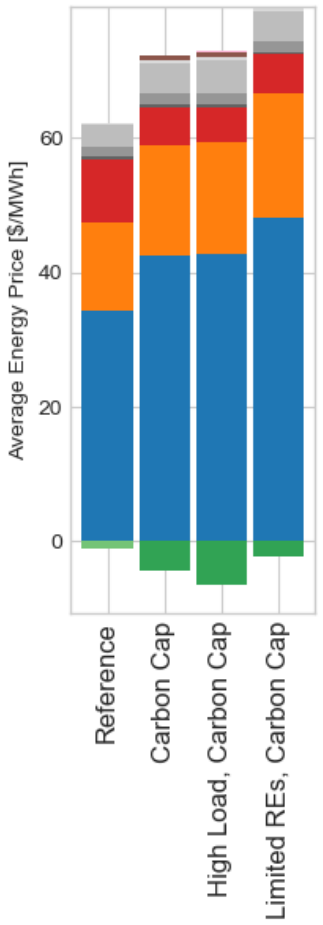
Scenario Set: Kentucky Islanded at County Resolution

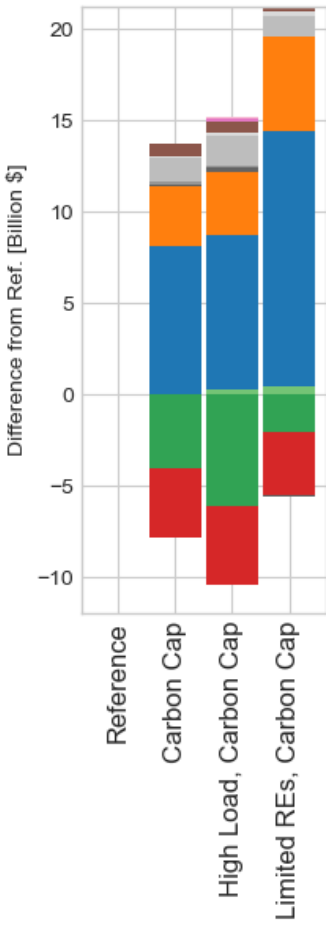
Carbon Cap Scenarios Increase NPV by 1% to 10% and Energy Price by 9% to 25%

System NPV

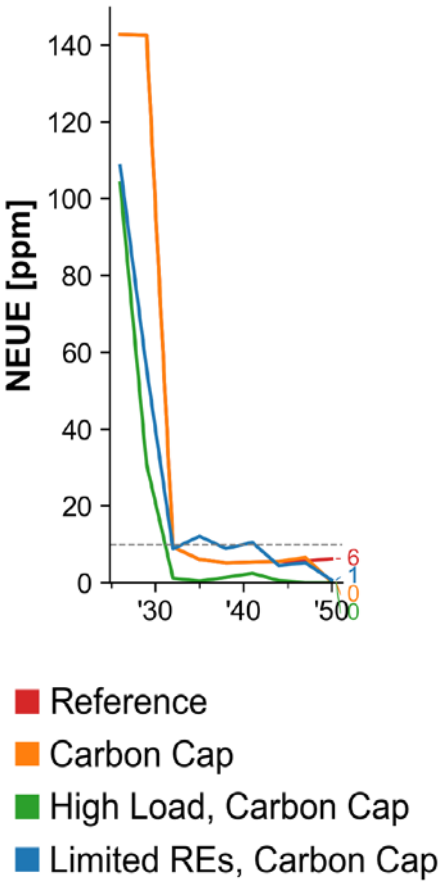


2050 Average Energy Price





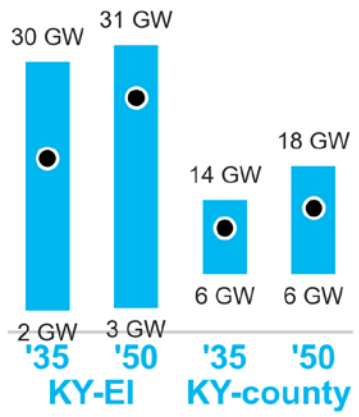
Reliability



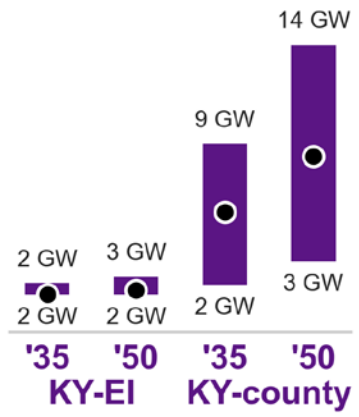
Scenario Set: Kentucky Islanded at County Resolution

Potential Capacities for the Future Kentucky Power System

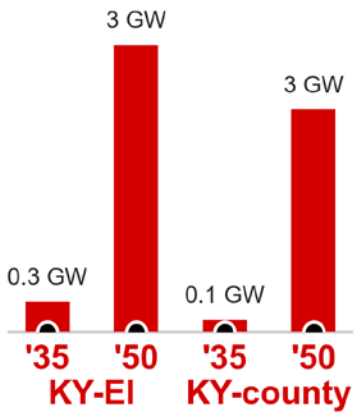
Wind



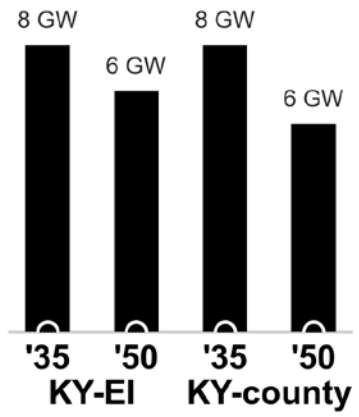
Gas Combined Cycle



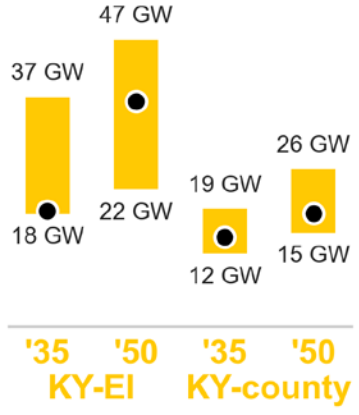
Nuclear SMR



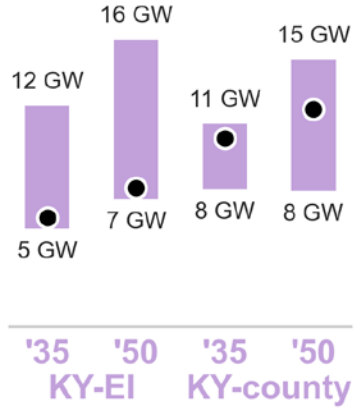
Coal



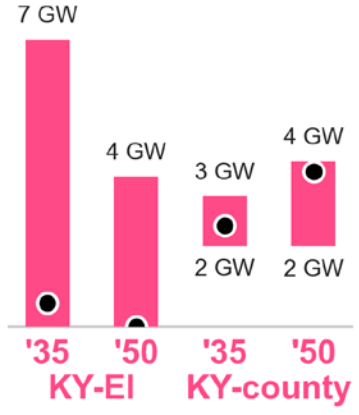
Solar



Gas Combustion Turbine



Battery Storage



KY-EI: Kentucky within the EI.

KY-county: Kentucky islanded at county resolution.

Points denote *Reference* case result.

Coal is only online in 2035 and 2050 without modeled EPA 111 rules.

Summary of Key Observations

- Wind generators appears to be cost-competitive in Kentucky, but if it is challenging to find locations for the wind generators, then the overall potential for wind deployment is limited.
- The ability to coordinate and the extent of coordination with the broader interconnection shapes the trajectory of the least-cost mix.
  - Some scenarios showed Kentucky as a net exporter, particularly of renewable energy.
  - Limited renewable energy siting scenarios showed Kentucky as a net importer.
  - Scenarios with no coordination relied much more heavily on in-state fossil resources.
- New nuclear can be part of the optimal mix if nuclear costs are successfully reduced.
- Carbon capture and storage was not observed except in scenarios that included a carbon cap.
- The modeled EPA 111 representation indicates that coal will drop out of the resource mix once the rule is active.

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