SCEP
STATE & COMMUNITY ENERGY PROGRAMS

Long-term Electricity Projections for Kentucky

State Energy Technical Assistance Program

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National Renewable Energy Laboratory

September 24, 2024

Introduction

SCEP
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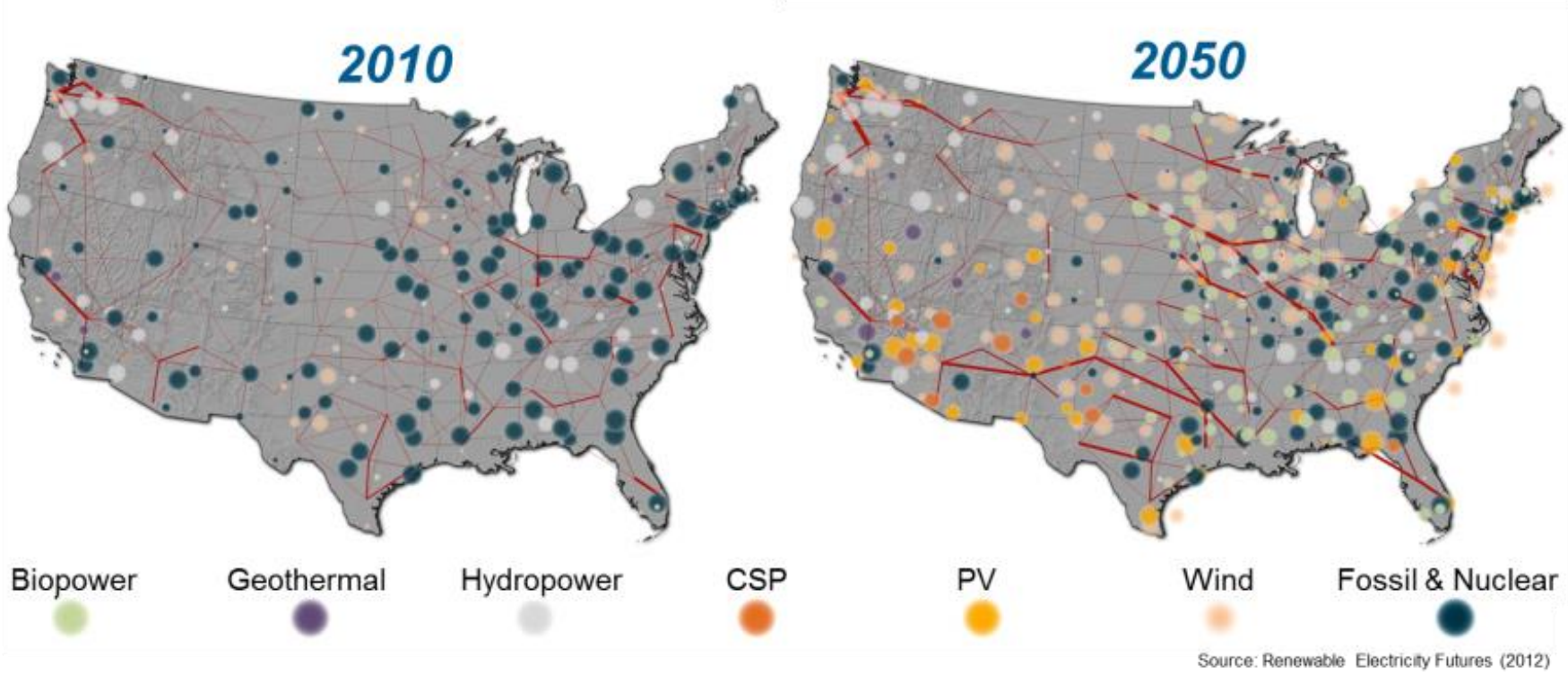
TEAM KENTUCKY®
ENERGY AND ENVIRONMENT CABINET

+

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

SCEP provided funding in summer of 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, ReEDS simulates the evolution and operation of US 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

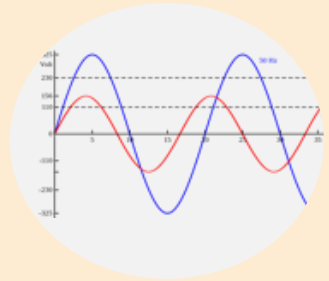
Transmission

Renewables

Regulations

Load

(DC) Power-flow



Ancillary Services

How does ReEDS work?

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

subject to…

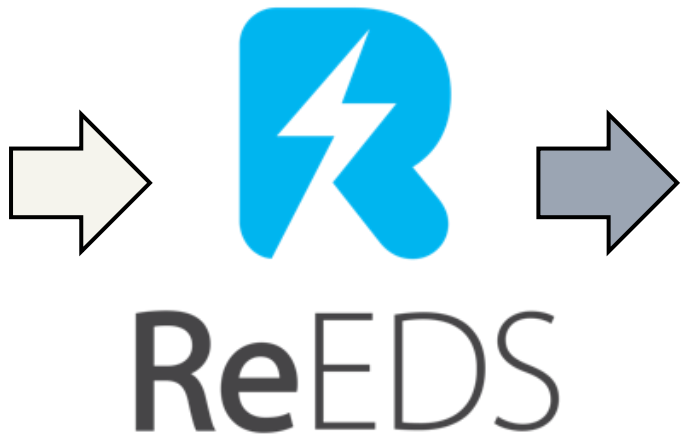
Price-forming constraints: Energy balance; planning/operating reserves; RPS/carbon policies

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

Inputs

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

Regional **E**nergy **D**eployment **S**ystem

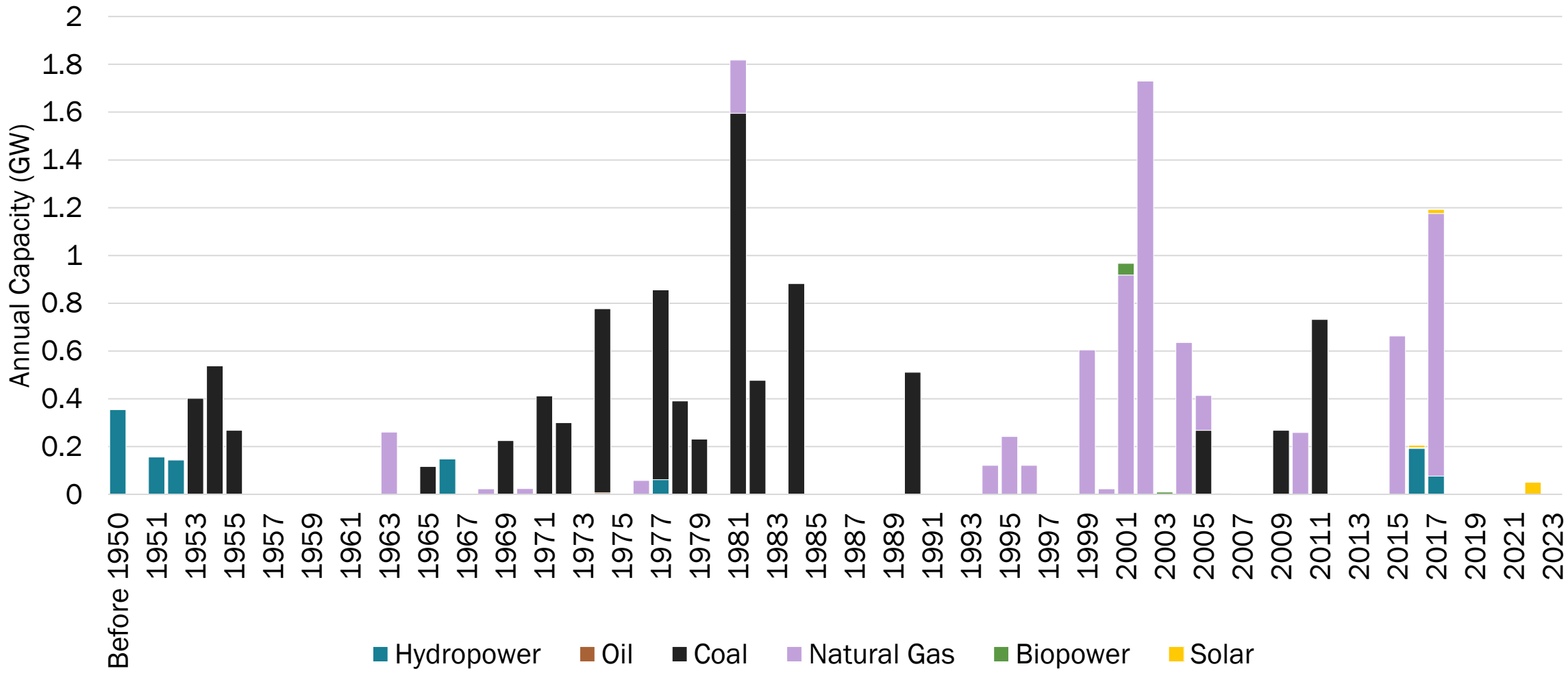


https://www.nrel.gov/analysis/reeds/

Outputs

- Generation and storage **capacity** additions & retirements in each solve year
- **Transmission** capacity additions
- **Operations**: Energy generation, firm capacity, & 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

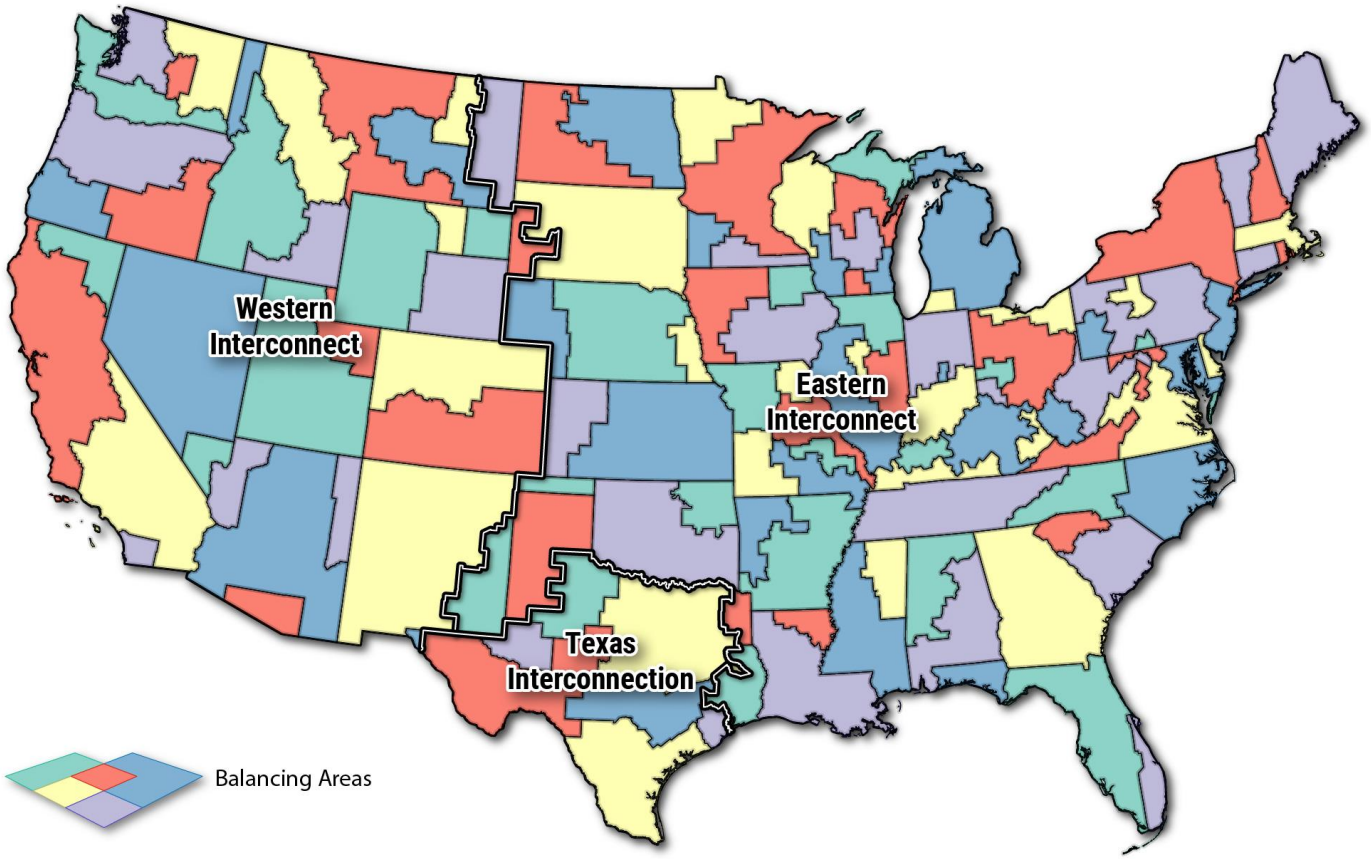
Case Title	Wind/Solar Resource	Load	Gas Prices	Nuclear Costs	EPA 111 (on unless noted)
Reference					
Limited REs	Limited UPV siting, limited onshore wind siting				
Limited REs, Low Nuclear	Limited UPV siting, limited onshore wind siting			Advanced Nuclear Costs	
High gas, Low. Nuclear			High Gas Prices	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 within the context of:

- Kentucky at a county resolution
- Entire Eastern interconnect with KY isolated

Scenario Sets

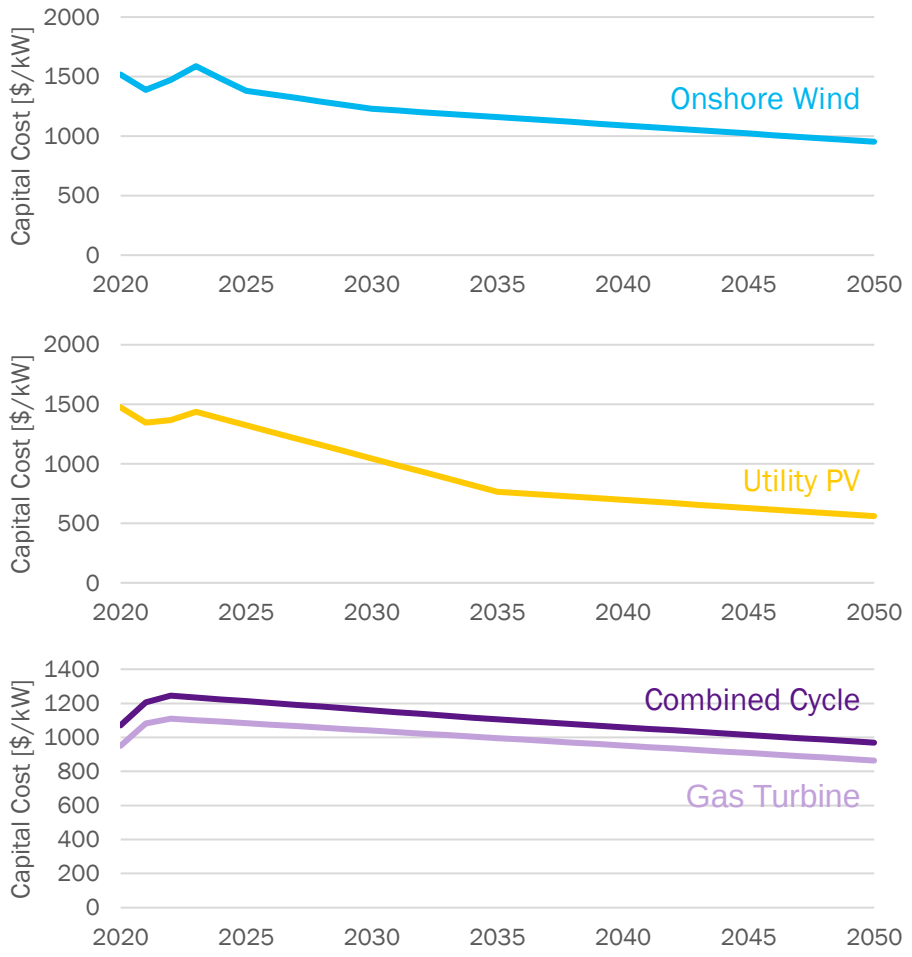
- Kentucky County:
  - Kentucky is an electricity island (no interstate electricity exchange)
  - County resolution
- EI/Kentucky:
  - Full eastern interconnection is modeled
  - Coordination and electricity trading occurs across the full interconnection
  - Model resolution is at the ReEDS balancing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



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, is provided by Evolved Energy Research (EER) and includes 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



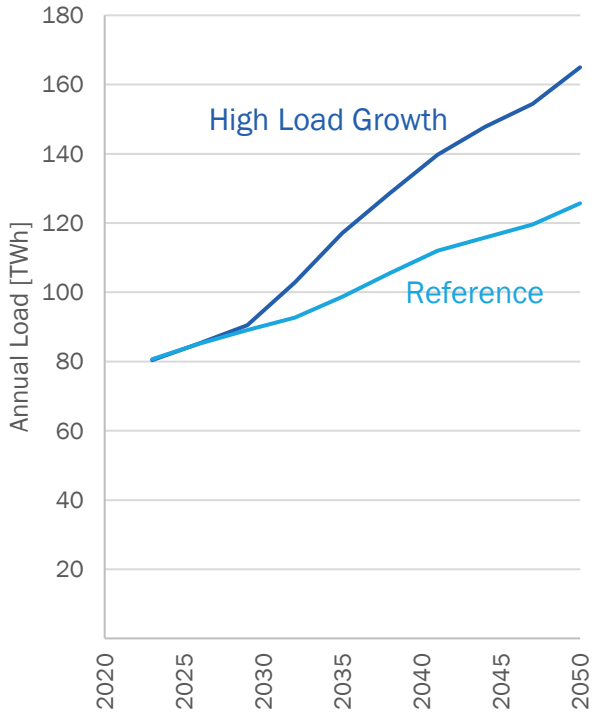
Modeled EPA 111 Representation

- 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 operation 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 CCS with 90% capture by Jan. 1, 2032 **[included]**
- Existing gas-CCs and gas-CTs:
  - No regulations
- New gas-CCs and gas-CTs:
  - If the plant is operating at <= 40% capacity factor: they are unregulated **[included]**
  - If a plant is operating above 40% CF: 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

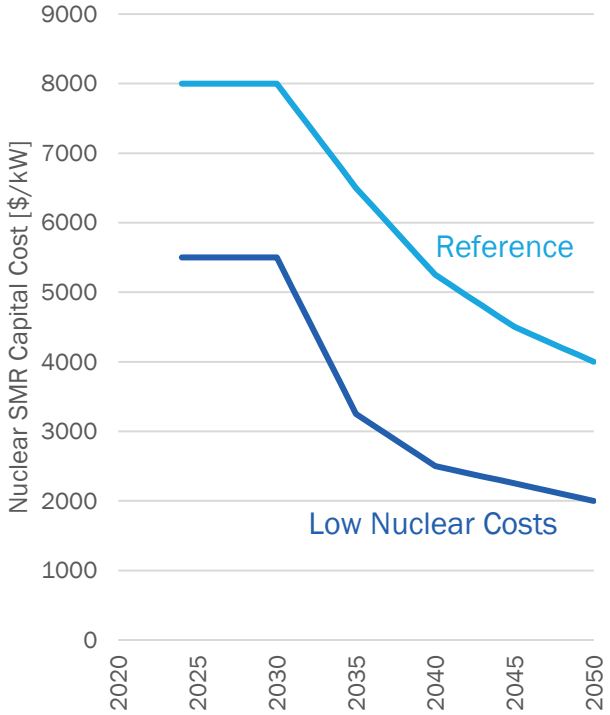
Load scenarios



Reference: NREL Standard Scenarios Ref. Load (EER IRA Low)

High Load: EER IRA 100 by 2050

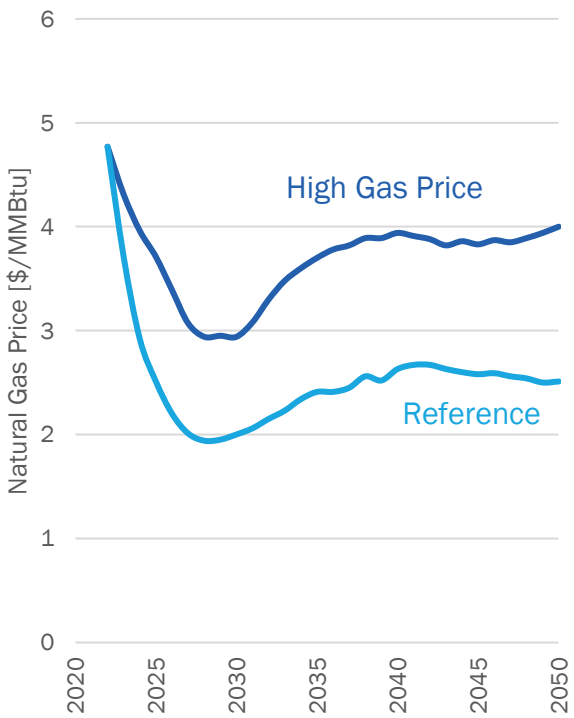
Nuclear Costs



Reference: 2024 NREL ATB

Low Nuclear: 2024 NREL ATB-advanced nuclear

Fuel costs



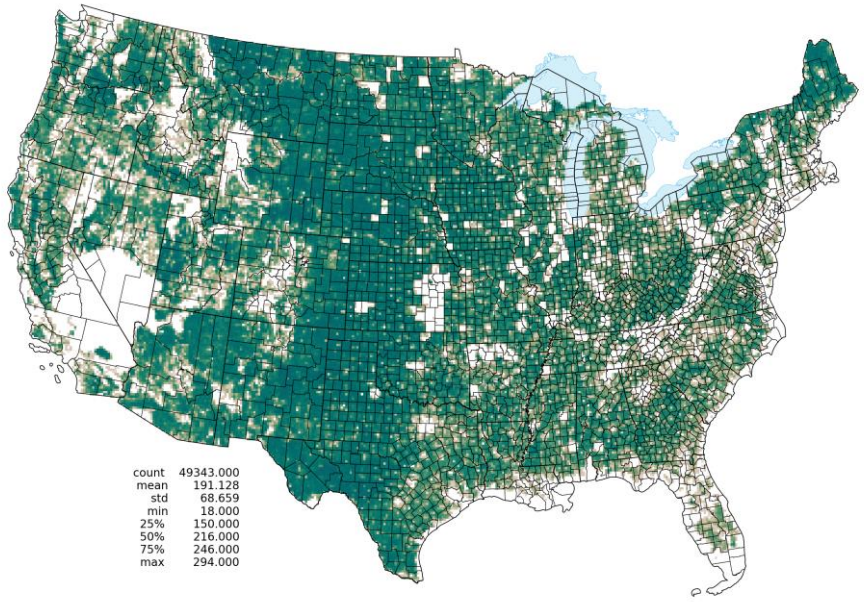
Reference: AEO 2023 reference

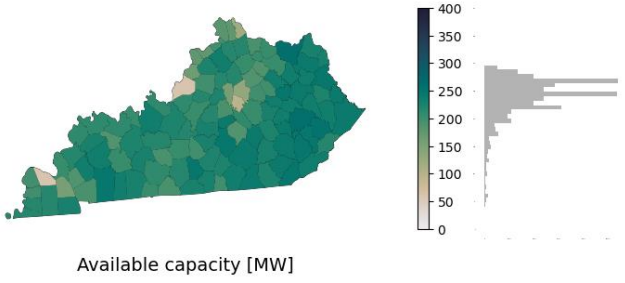
High Gas: AEO 2023 LOG

Land-based Wind Siting Assumptions

Limited RE scenarios: Onshore Wind (NREL Wind Supply Curve, 2024)

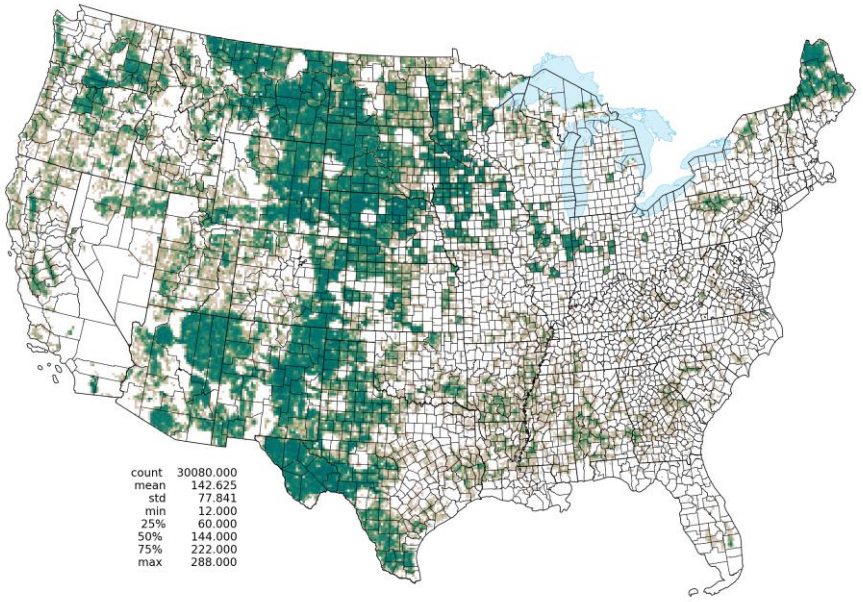
reference

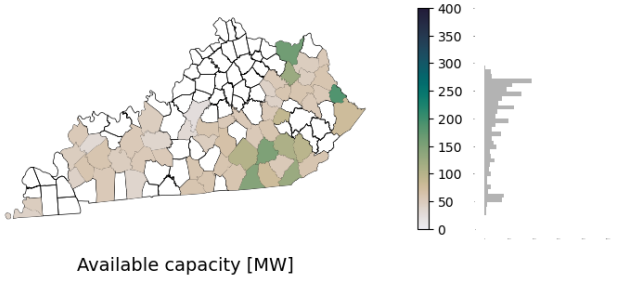




Total Potential: 124 GW

limited



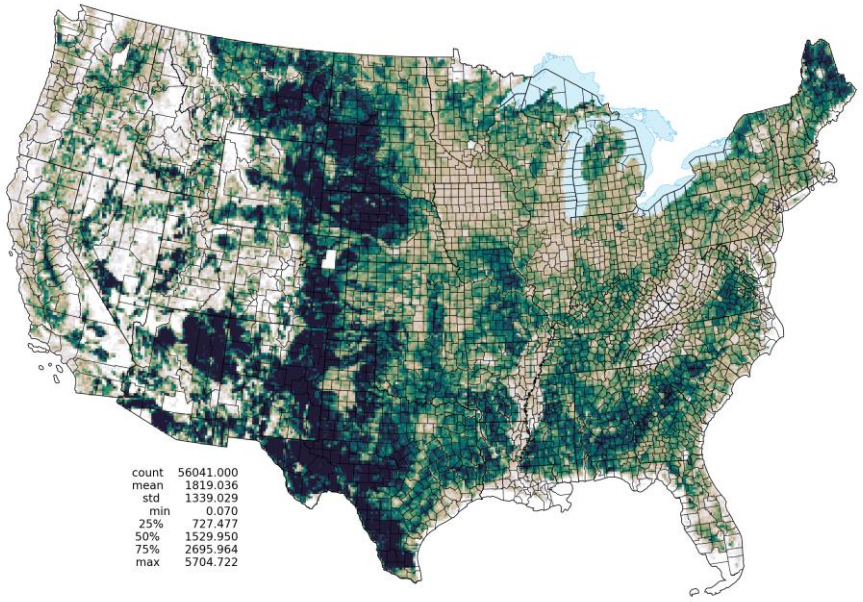


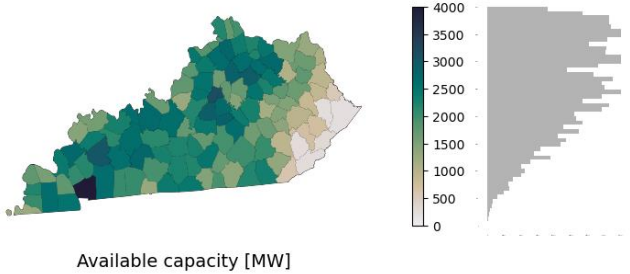
Total Potential: 8.0 GW

Utility-scale Solar Siting Assumptions

Limited RE scenarios: Utility Scale PV (NREL Solar Supply Curve, 2024)

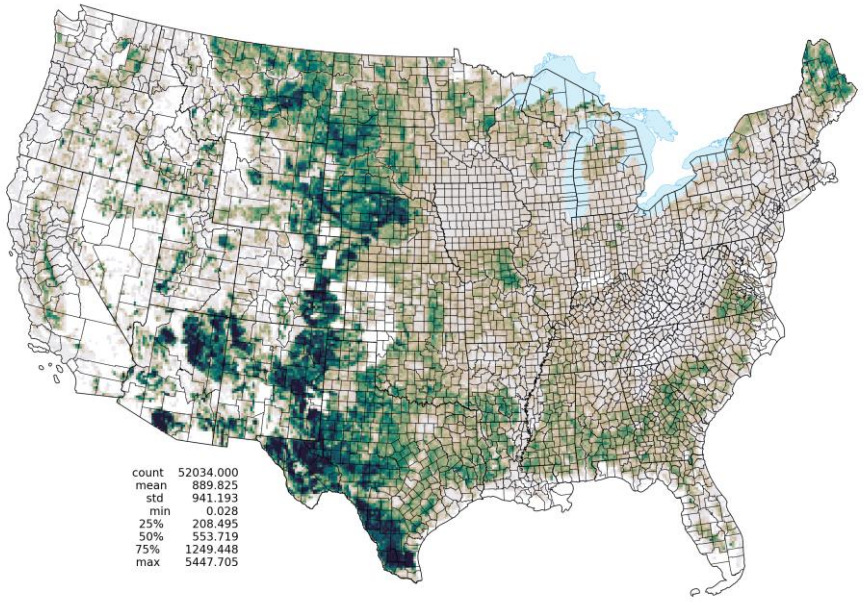
reference

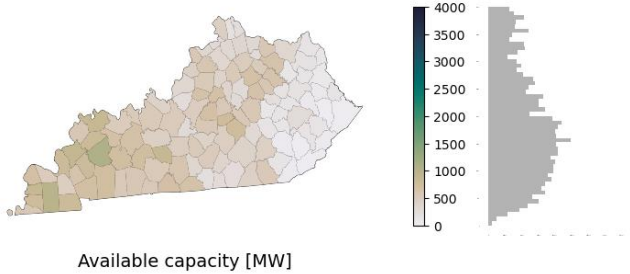




Total Potential: 1,076 GW

limited





Total Potential: 228 GW

Scenario Results

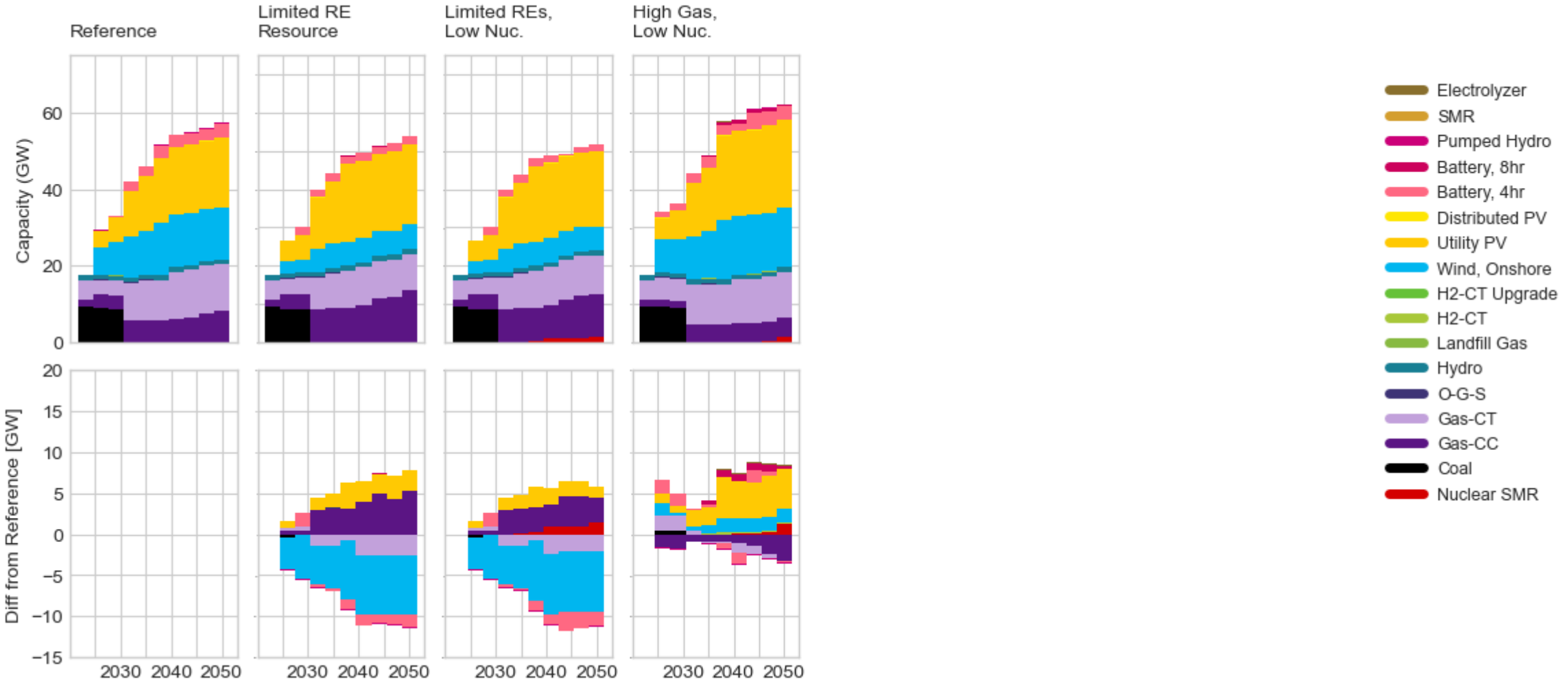
The Reference case shows growth across many technologies

Scenario Set: Kentucky Islanded at County Resolution

Limiting renewable siting significantly reduces wind capacity.

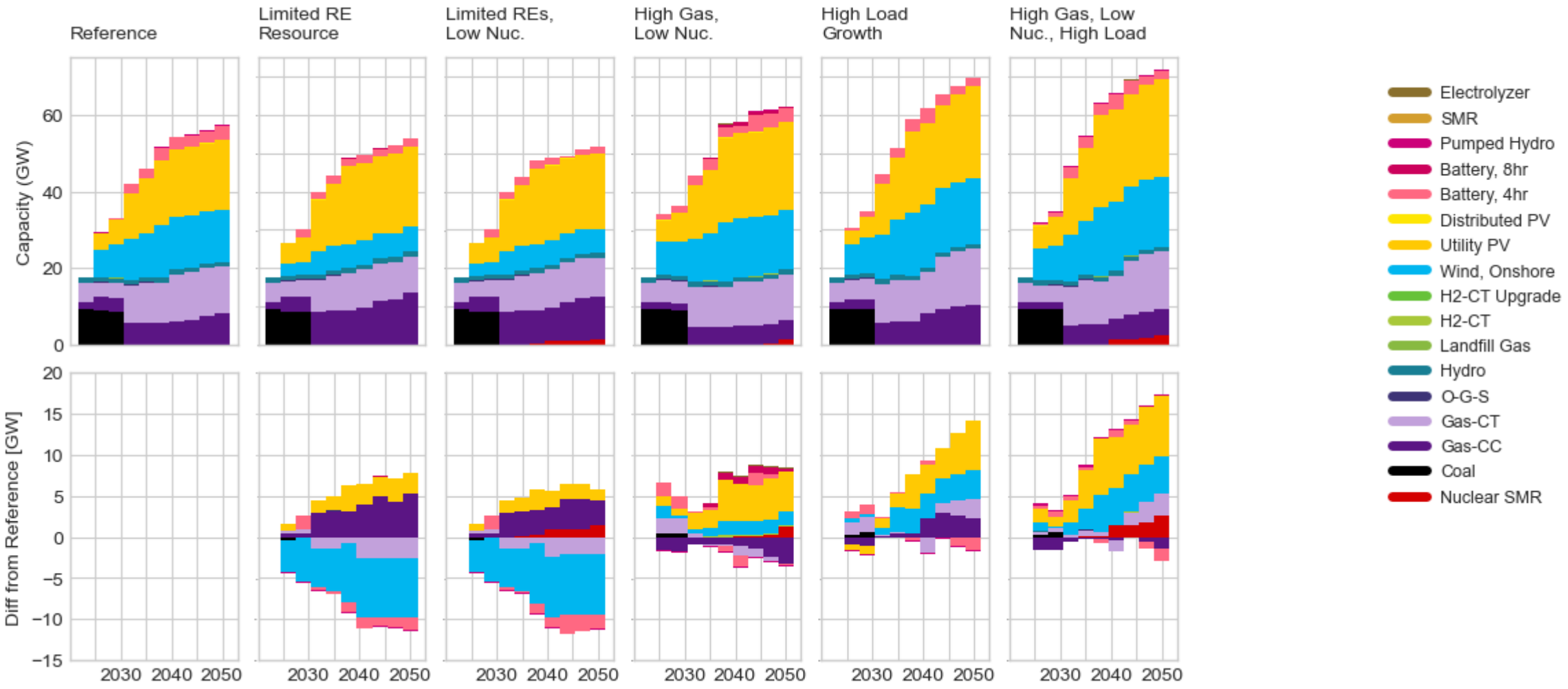
Scenario Set: Kentucky Islanded at County Resolution

With low costs, small amounts of nuclear capacity are deployed.



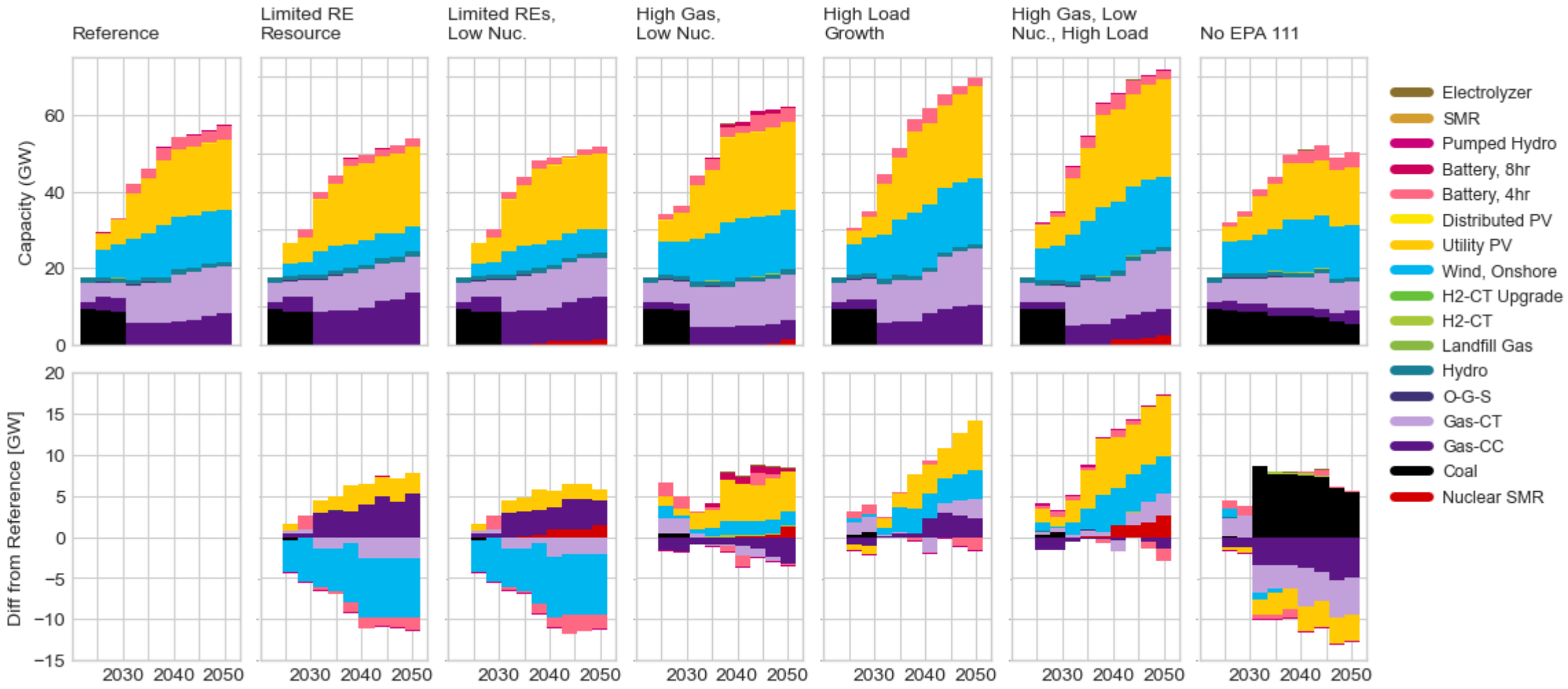
Scenario Set: Kentucky Islanded at County Resolution

High load growth yields increases to many technology types.



Scenario Set: Kentucky Islanded at County Resolution

Without EPA 111 modeled rules, coal capacity remains online.

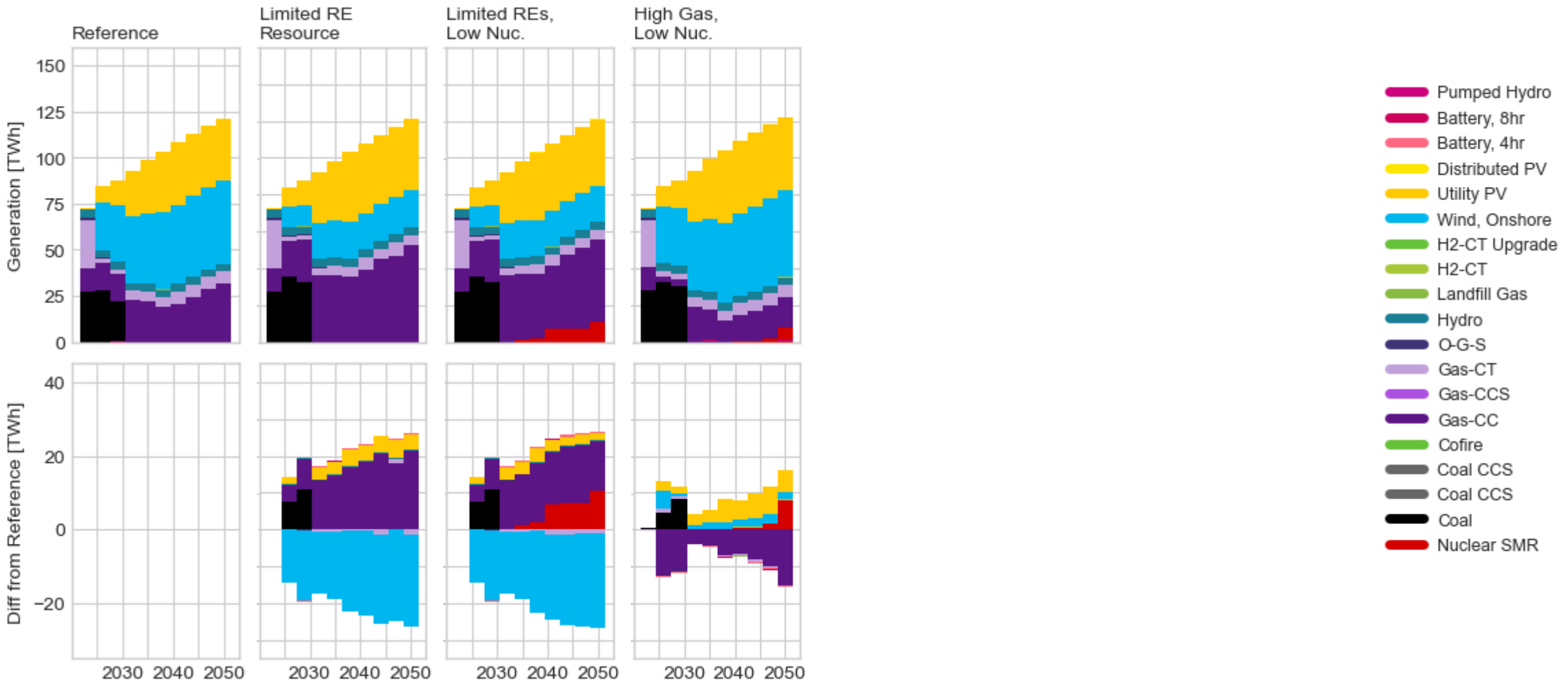


Scenario Set: Kentucky Islanded at County Resolution

Limited renewable siting shifts generation to gas and solar.

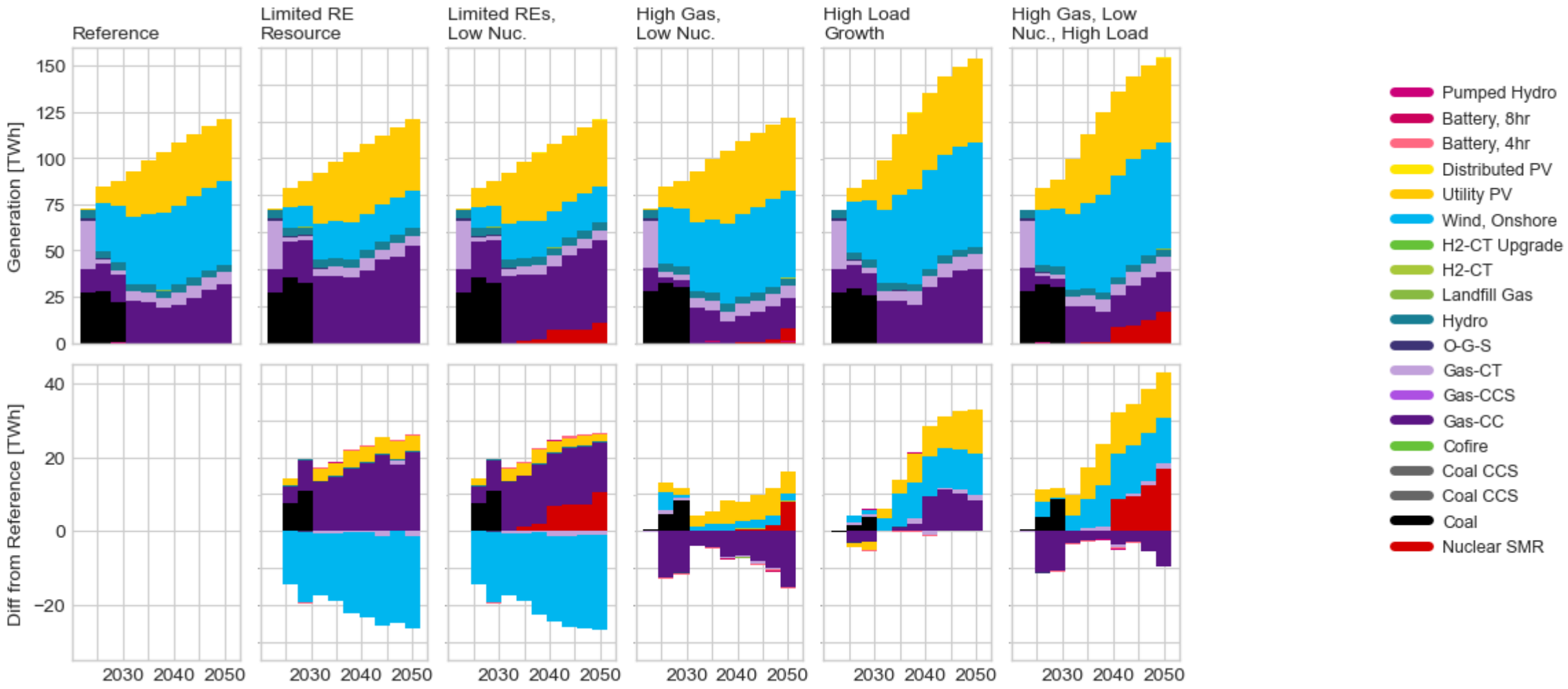
Scenario Set: Kentucky Islanded at County Resolution

Nuclear operates at high capacity factor when installed.



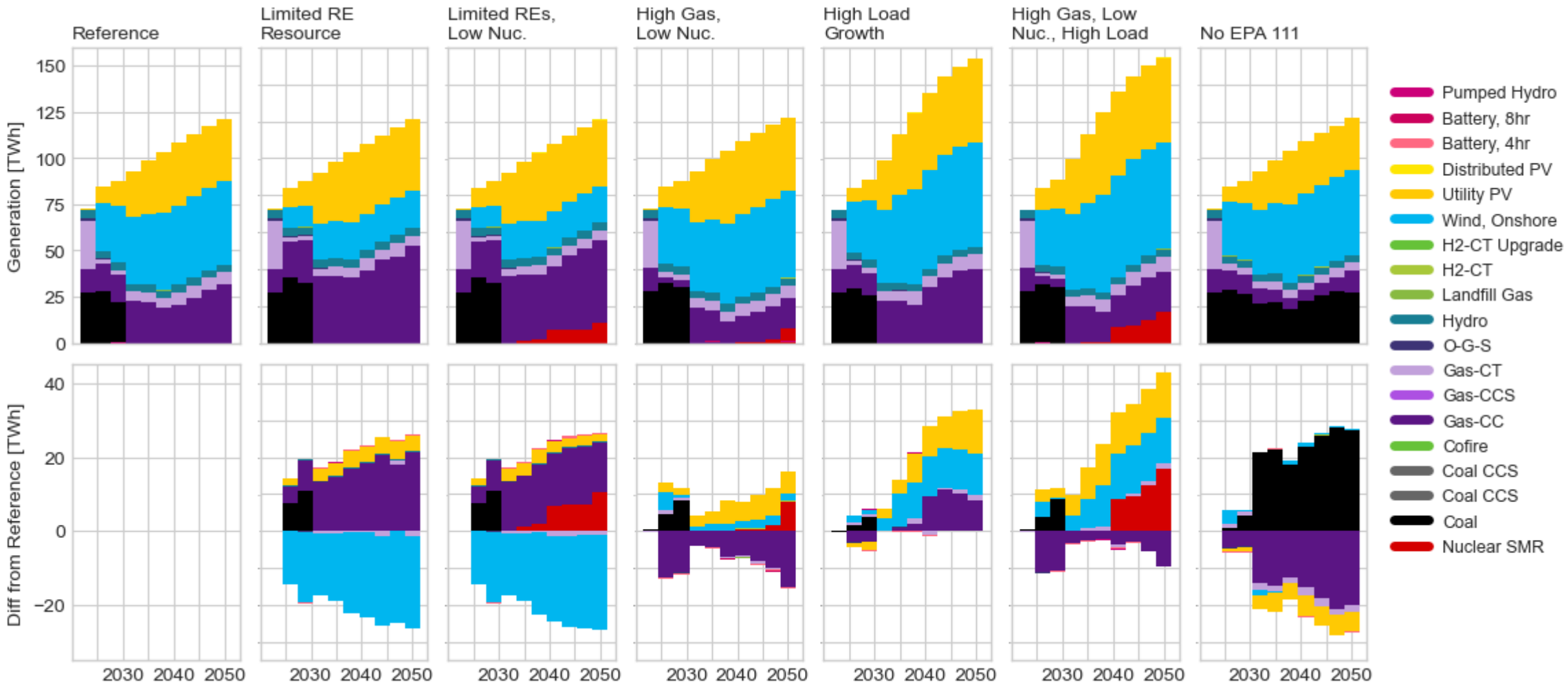
Scenario Set: Kentucky Islanded at County Resolution

Higher load is distributed among assets.



Scenario Set: Kentucky Islanded at County Resolution

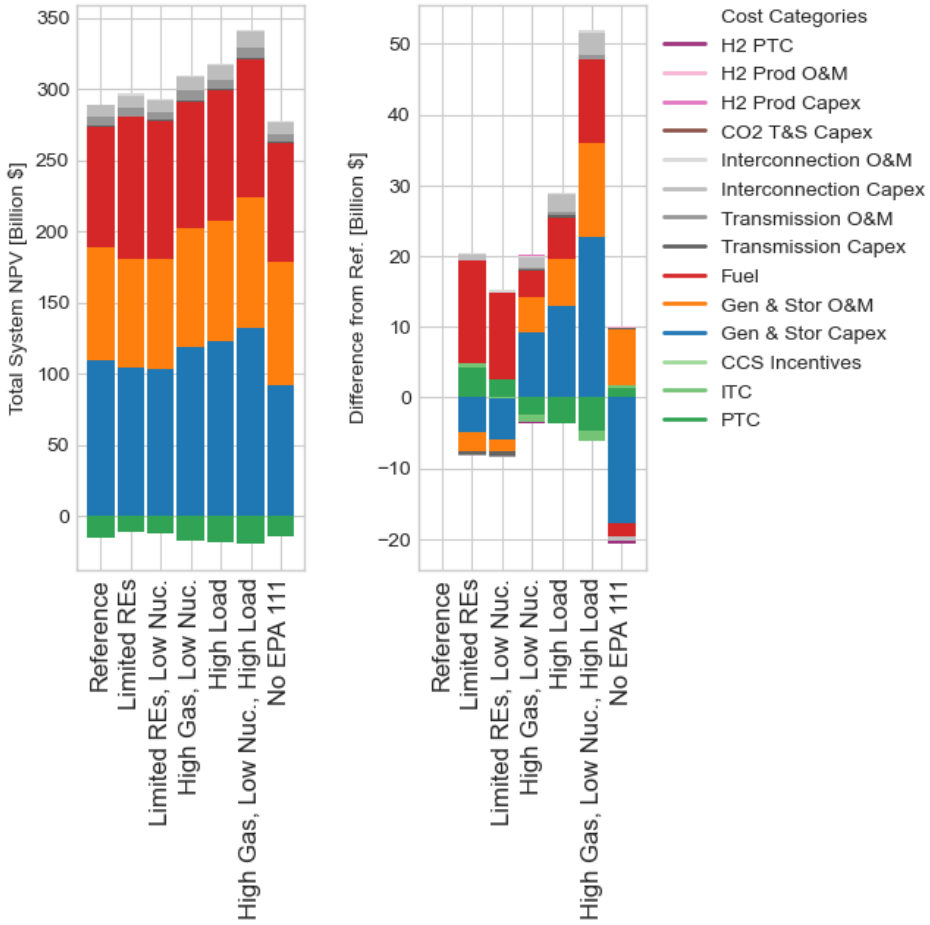
Without modeled EPA 111, generation shifts to coal.



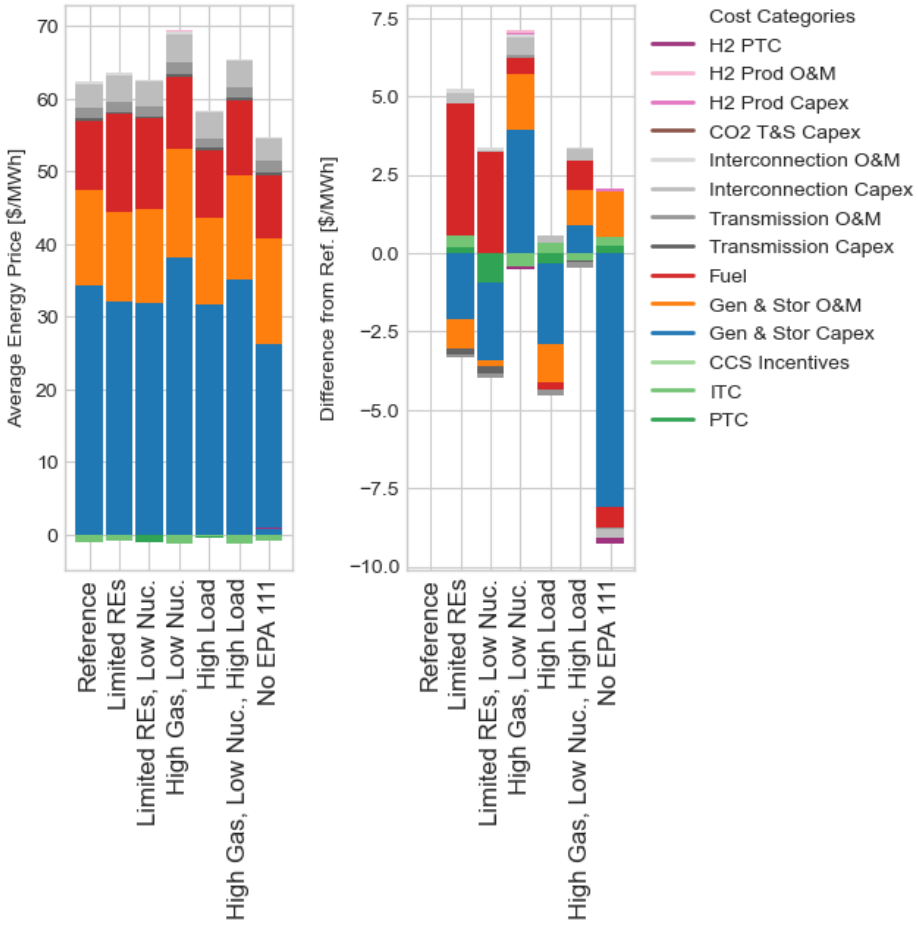
Scenario Set: Kentucky Islanded at County Resolution

High gas prices can have a significant impact on system costs.

System NPV



2050 Average Energy Price

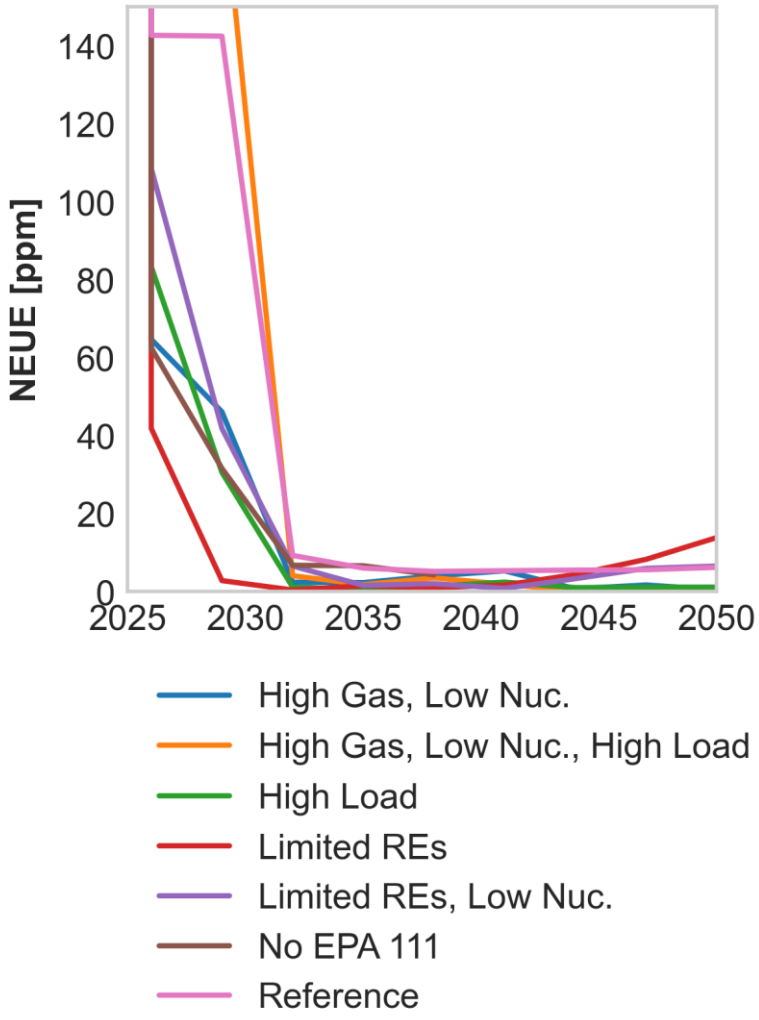


Scenario Set: Kentucky Islanded at County Resolution

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.
- 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.

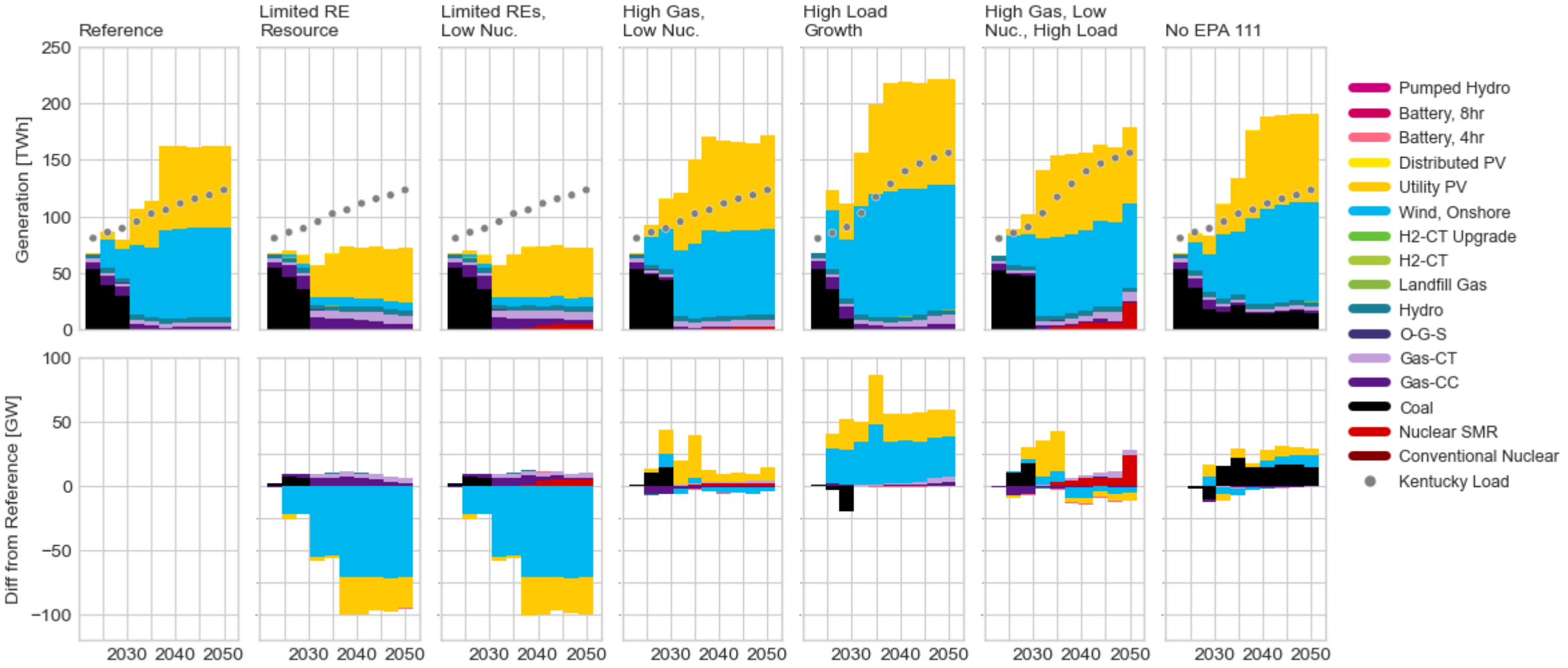


Scenario Set: Kentucky Islanded at County Resolution

KY within the EI relies more on renewables and peakers.

Scenario Set: Full Eastern Interconnection

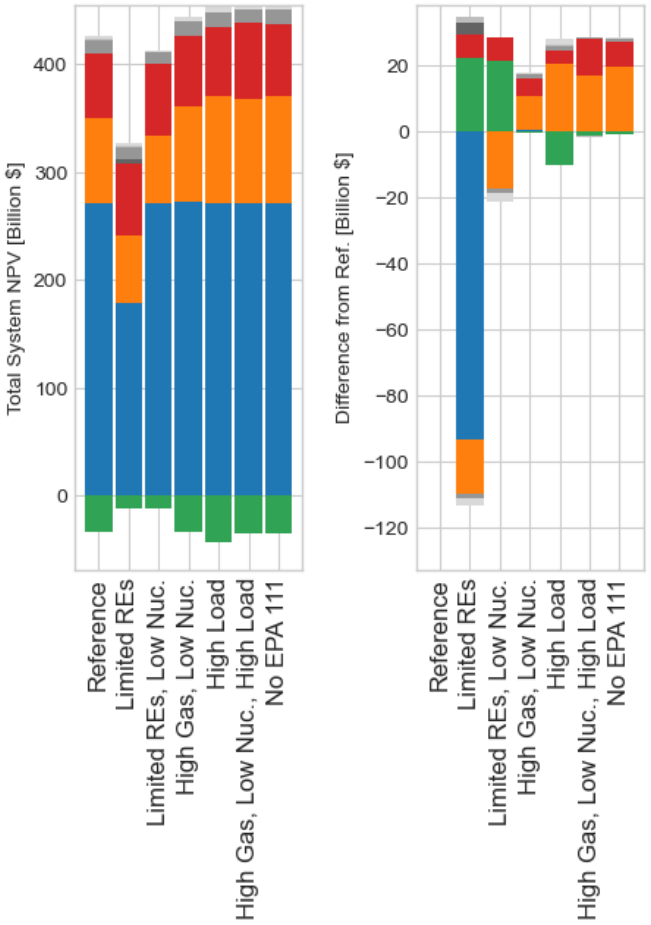
KY contributes RE generation to the EI when possible.



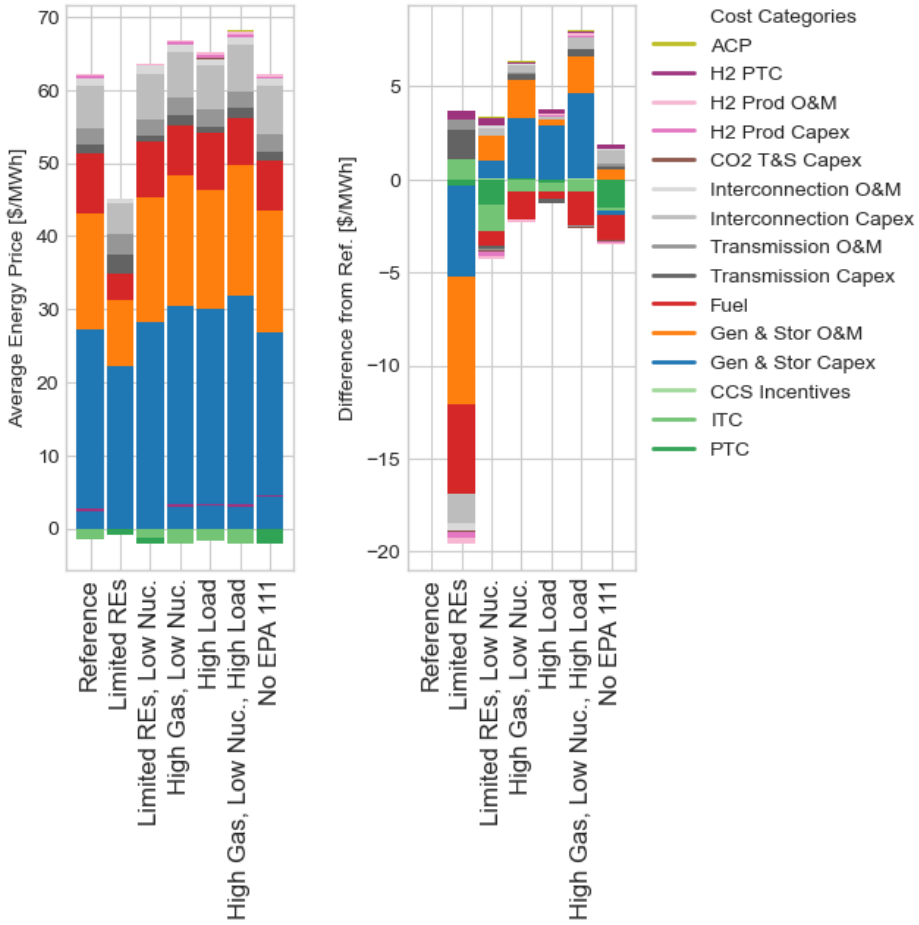
Scenario Set: Full Eastern Interconnection

System costs do not account for imports/exports.

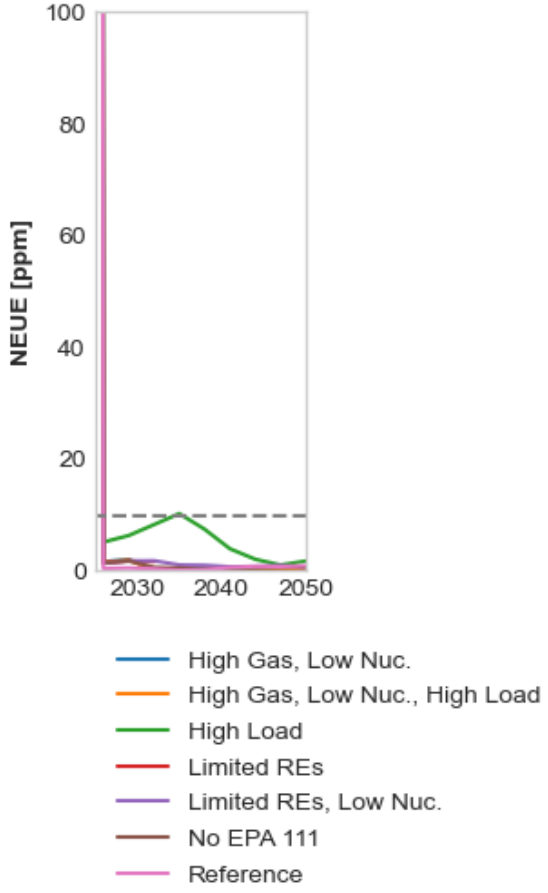
System NPV



2050 Average Energy Price

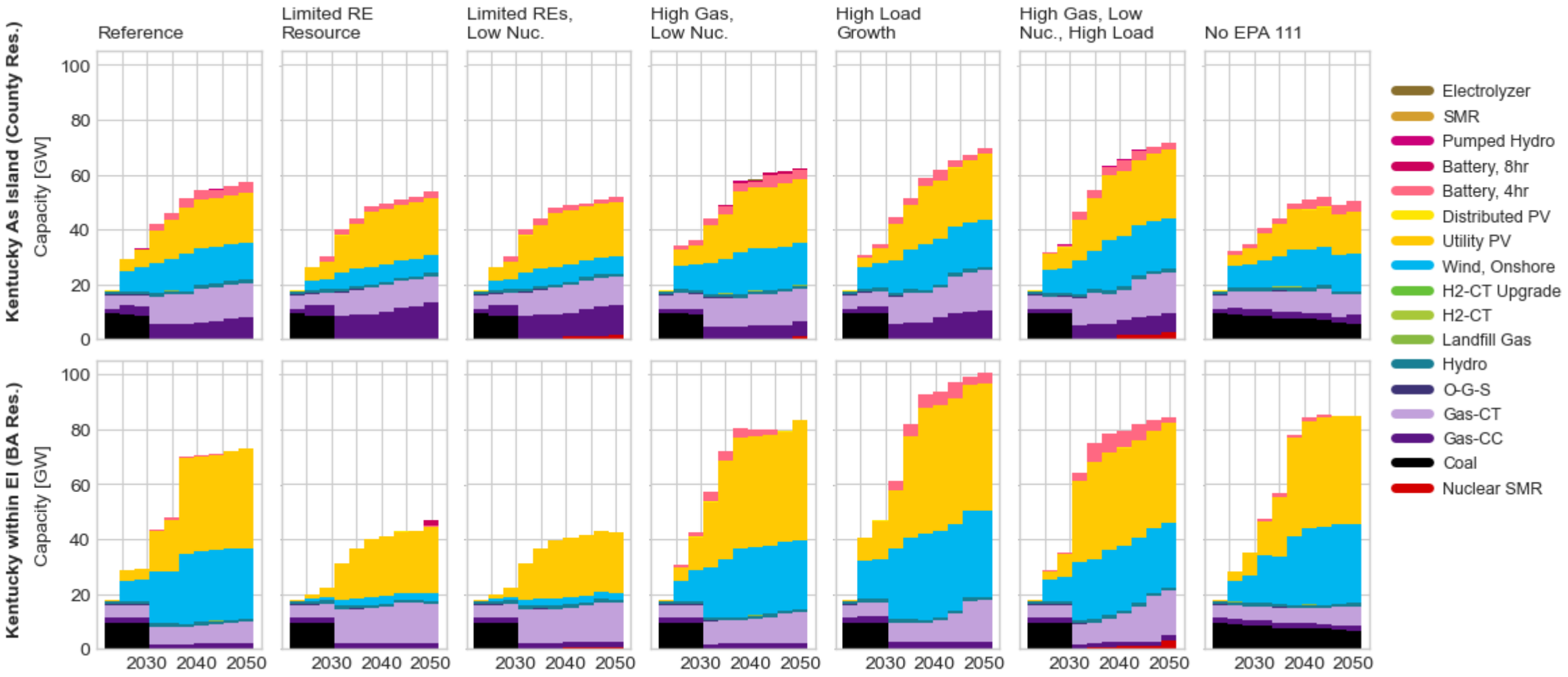


Reliability

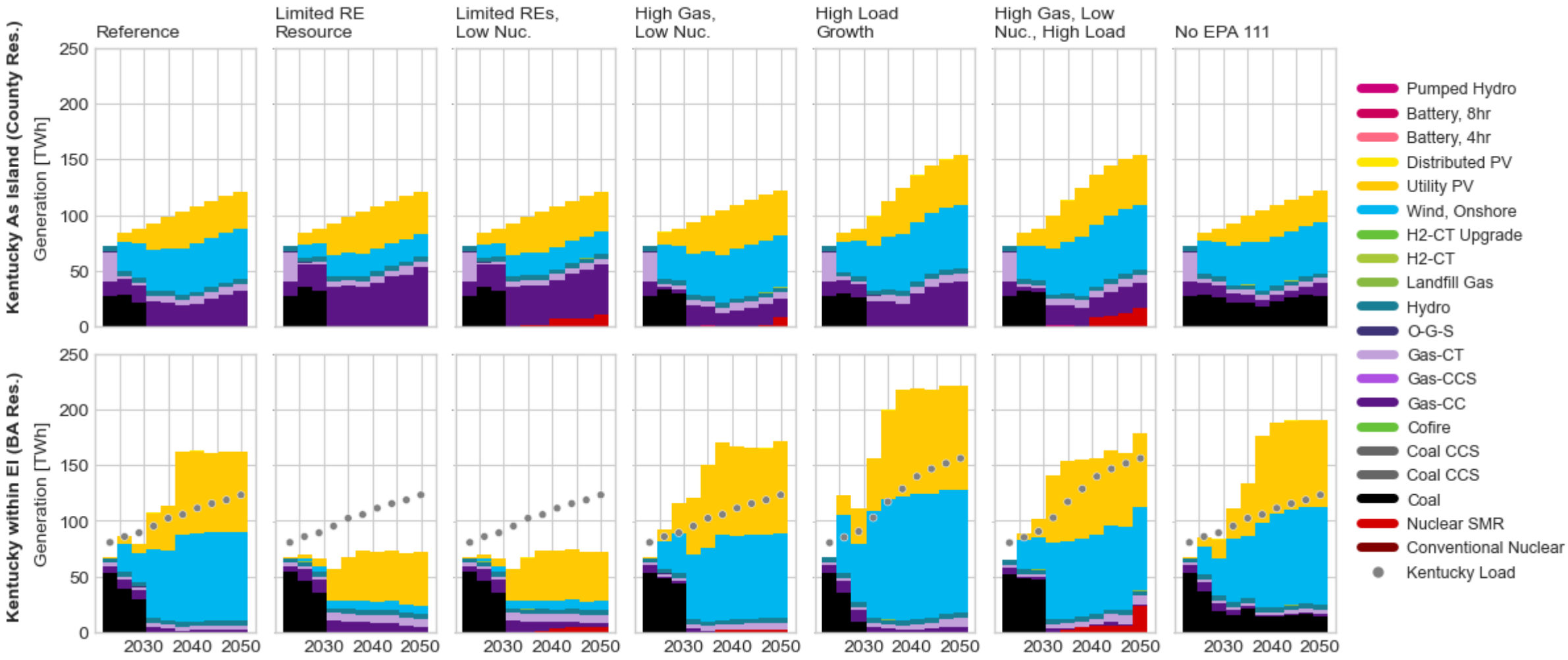


Scenario Set: Full Eastern Interconnection

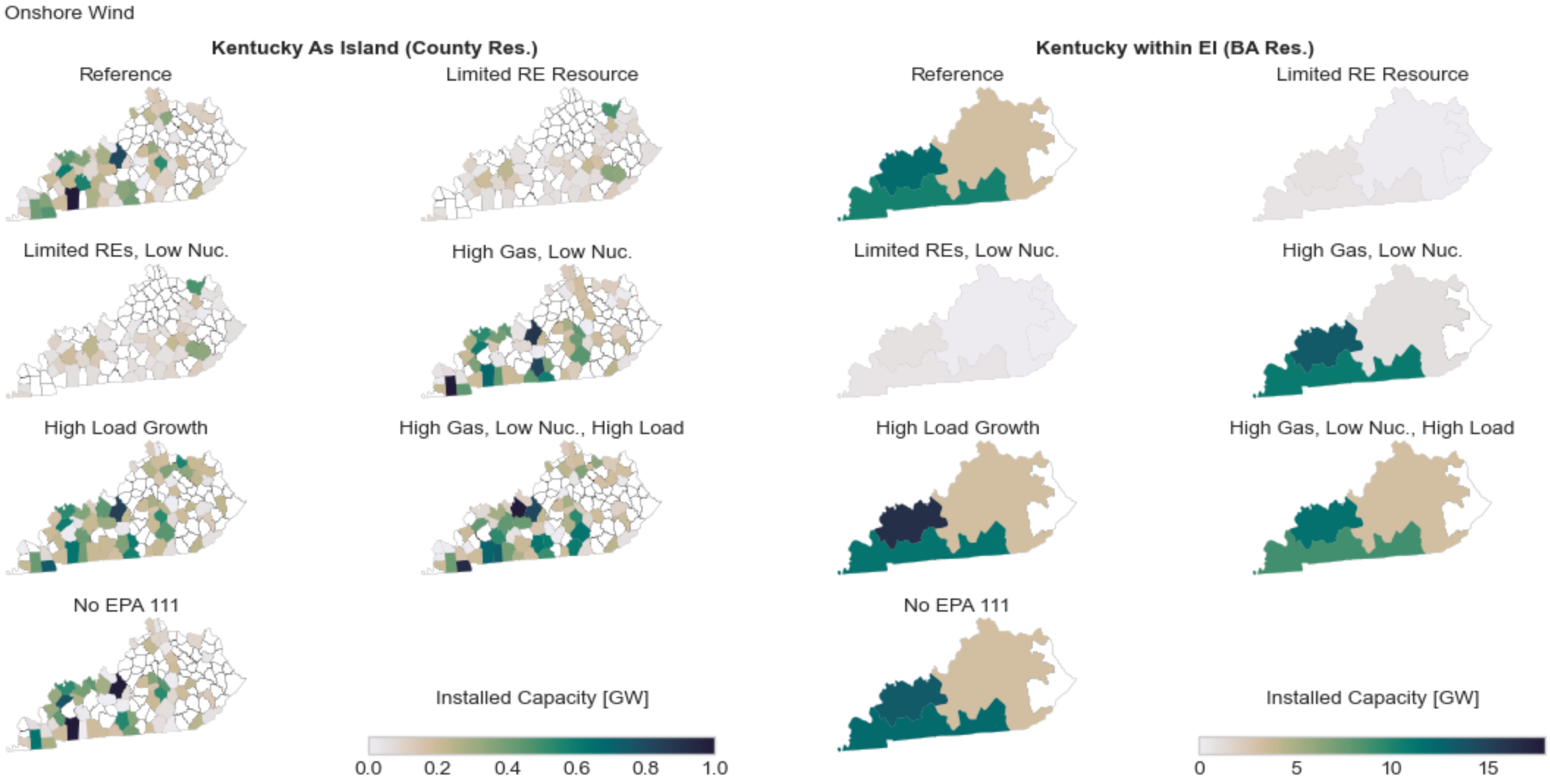
Interconnection cases are more sensitive system conditions.



Isolated KY cases rely more heavily on fossil assets for generation.

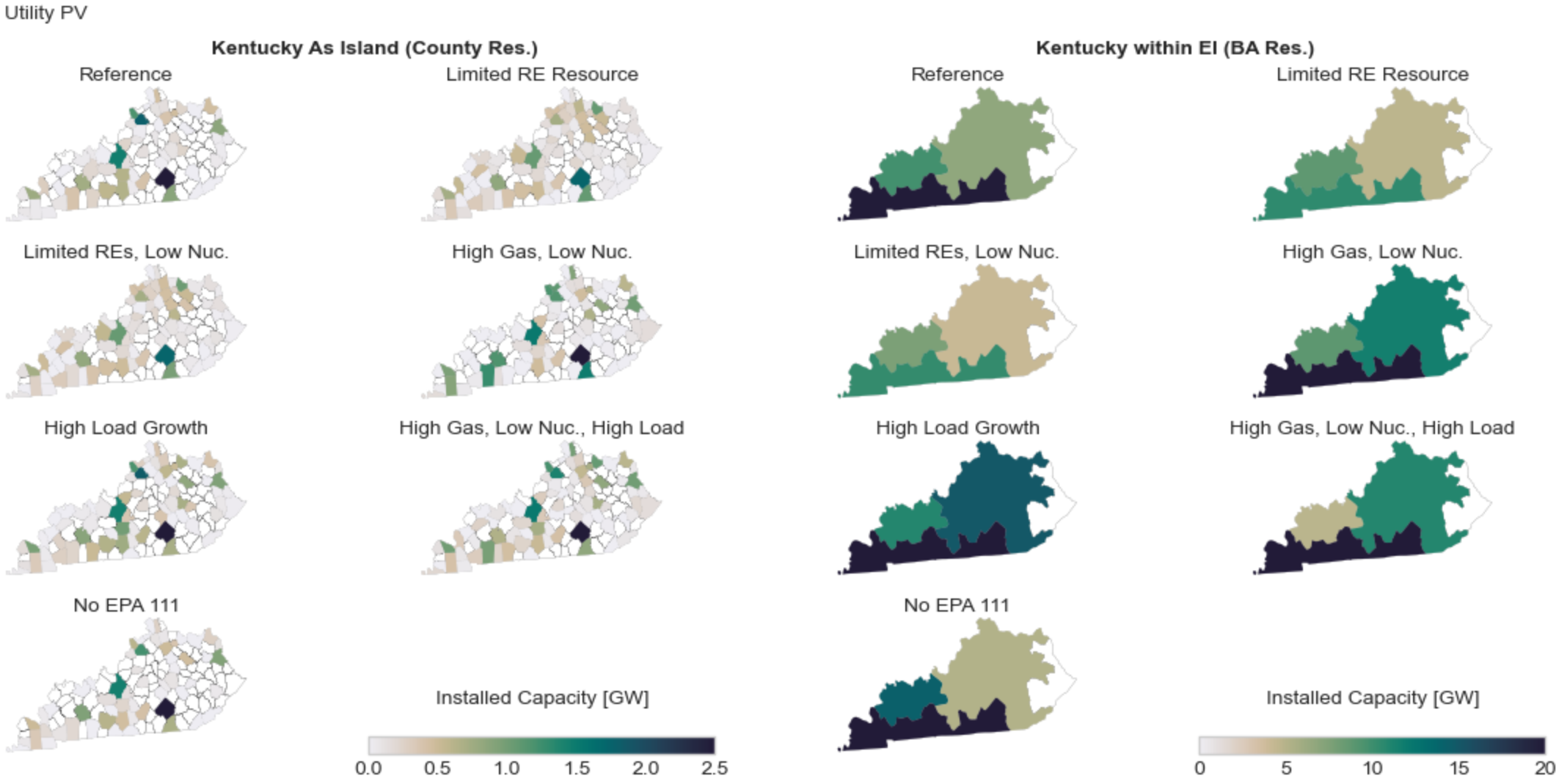


Limited siting reduces wind capacity in the highest resource areas.



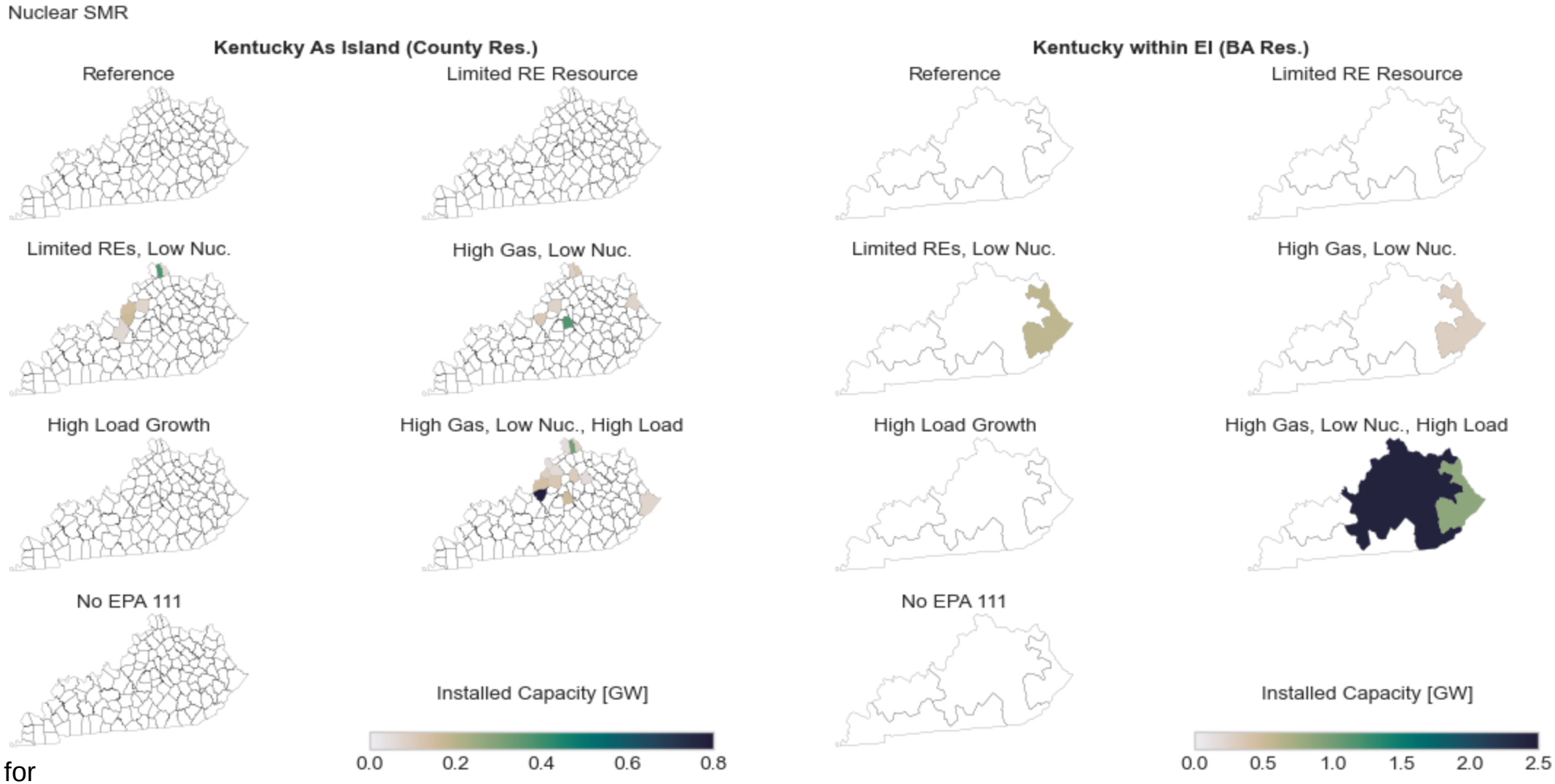
Results are for 2050

Limited siting does not significantly change PV deployment.



Results are for 2050

Nuclear SMR is primarily deployed near population centers.



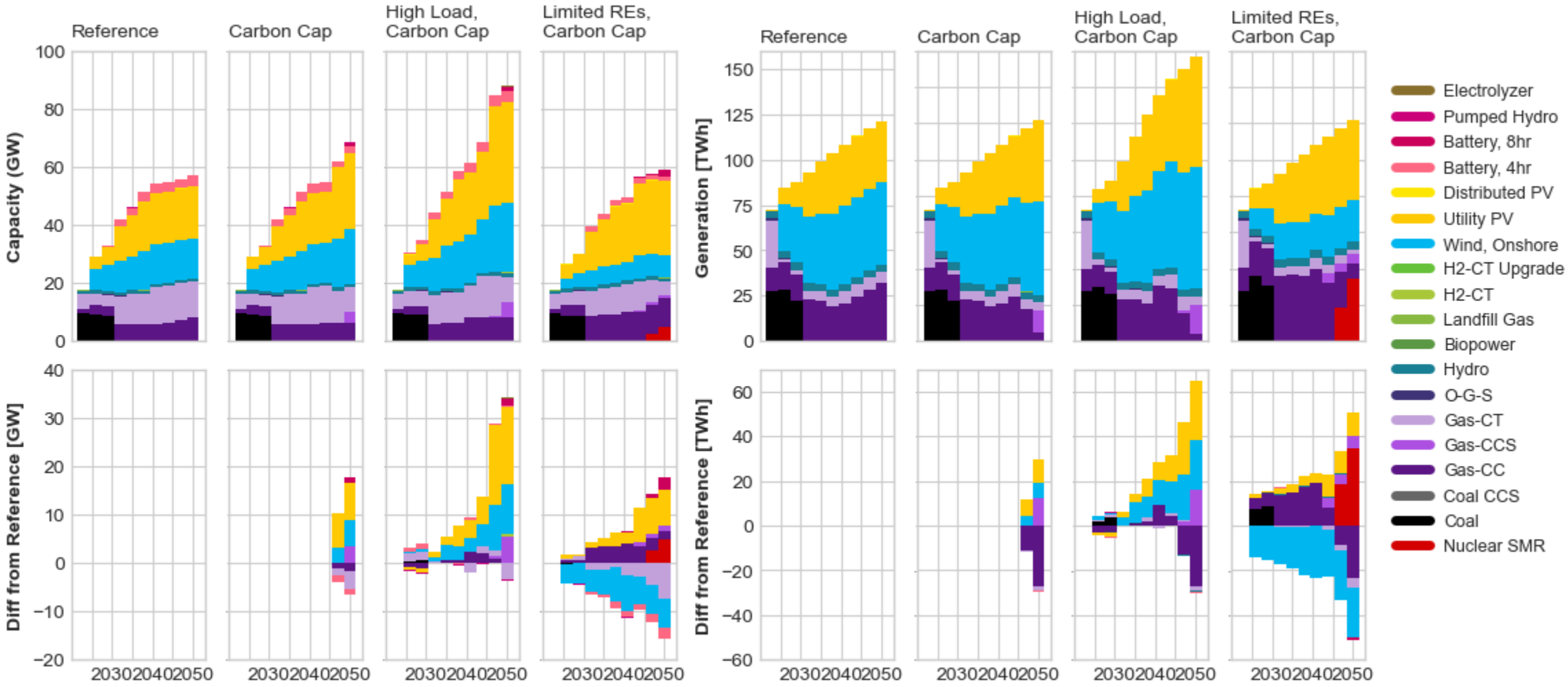
Filtering for
≥50 MW

Results are for 2050

Carbon limits incentivize CCS and nuclear SMR generation.

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

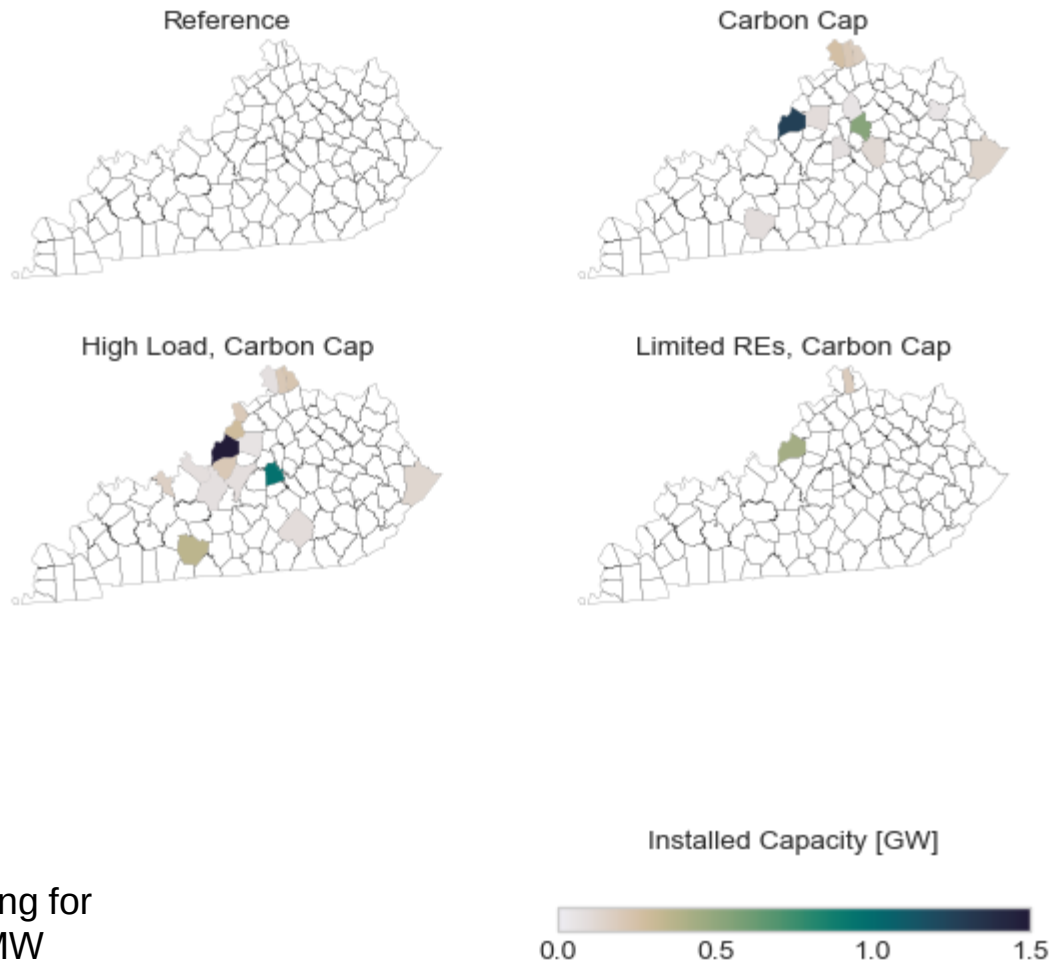
- Our Carbon Cap starts in 2023 and reduces total CO_2 by 95% in 2050.



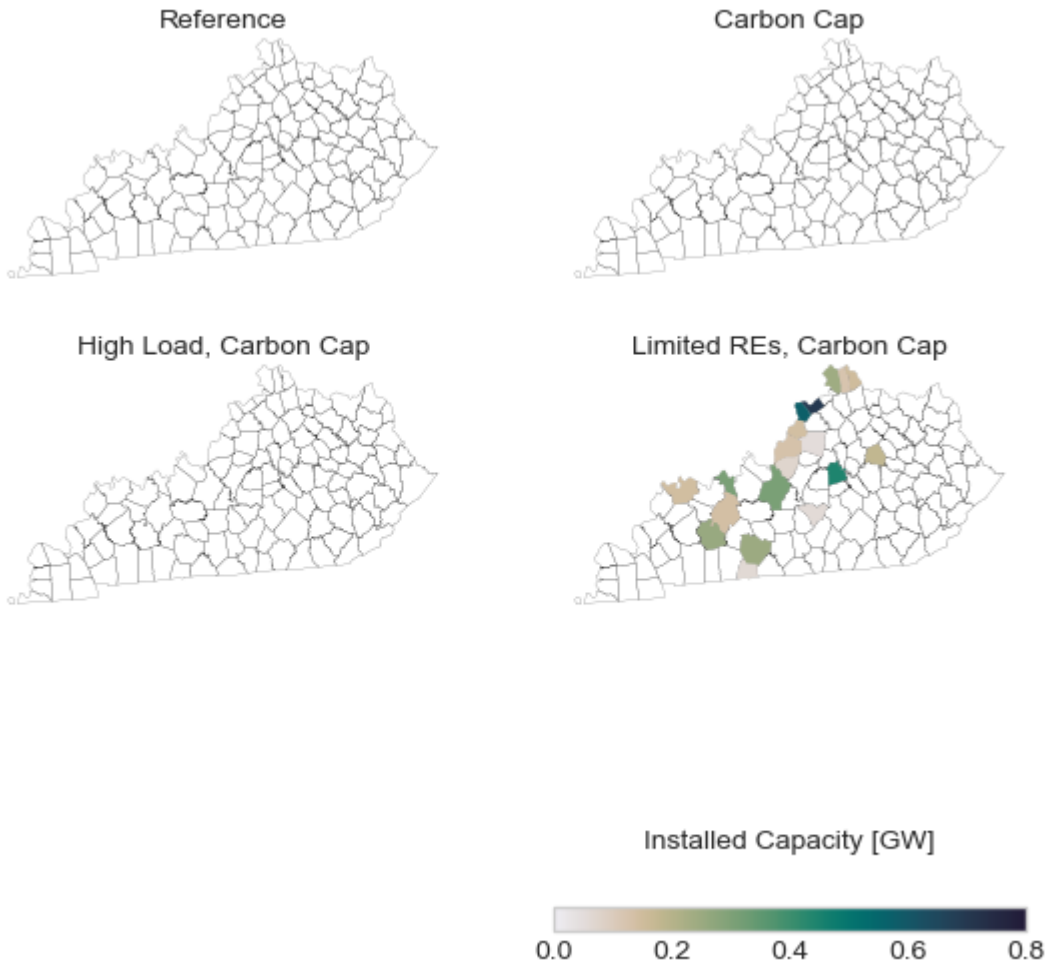
Scenario Set: Kentucky Islanded at County Resolution

In Carbon constrained cases, CCS and Nuclear SMR are deployed near population centers.

Fossil-CCS



Nuclear SMR

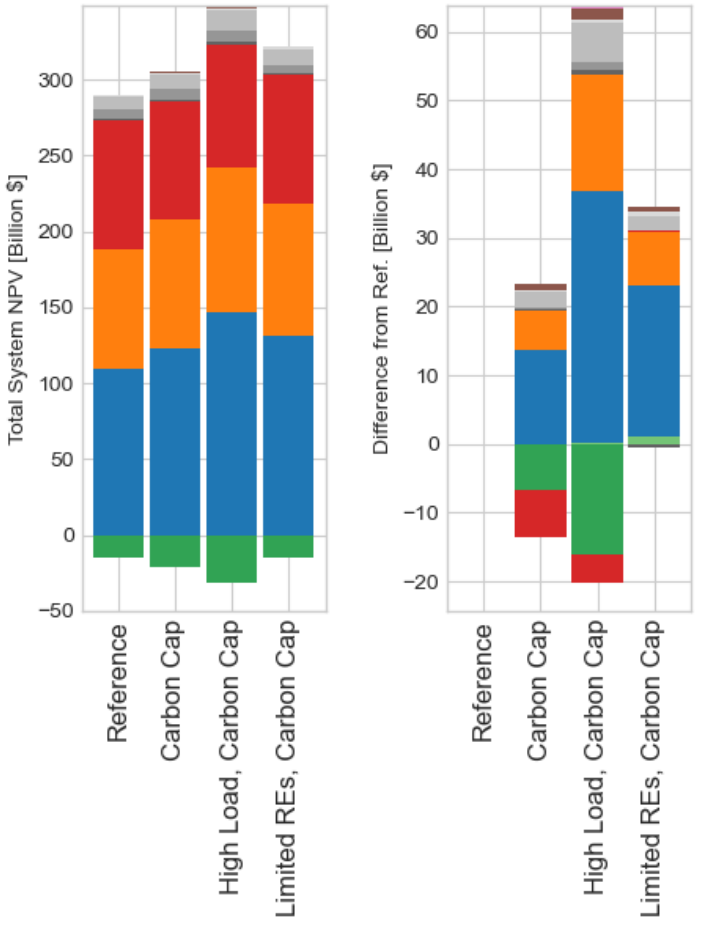


Filtering for ≥50 MW

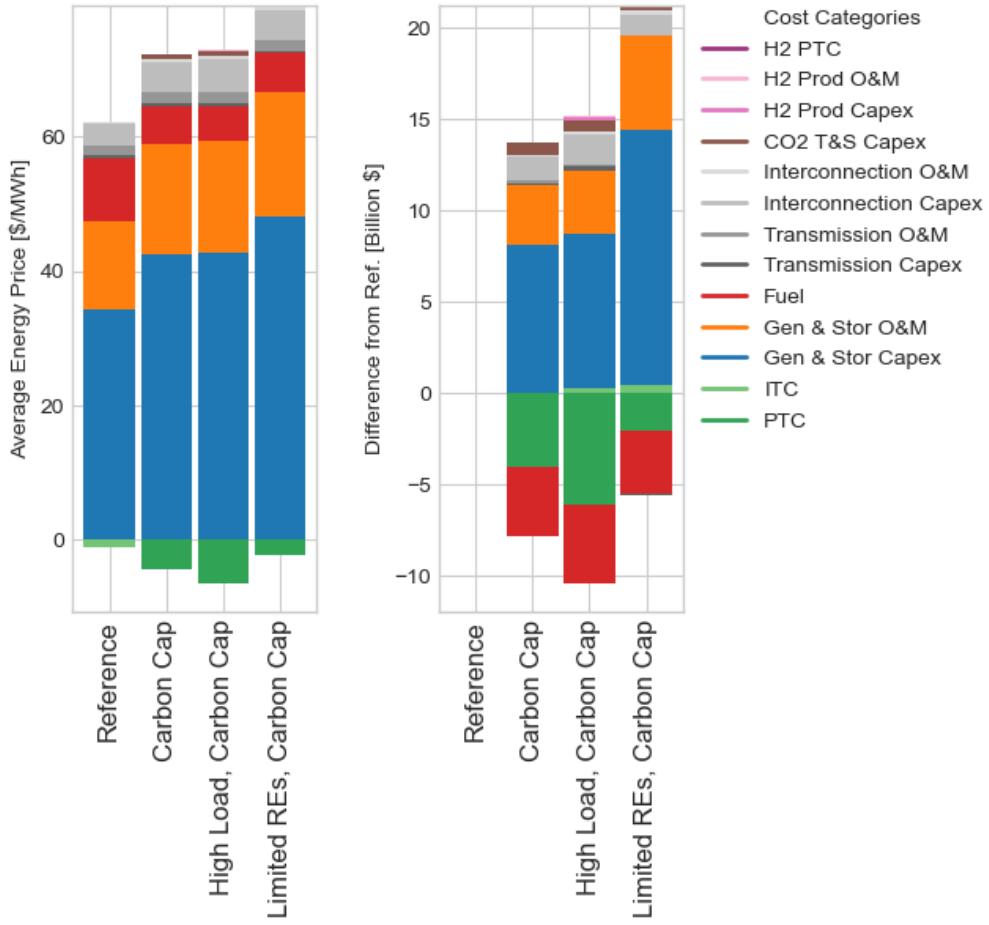
Results are for 2050

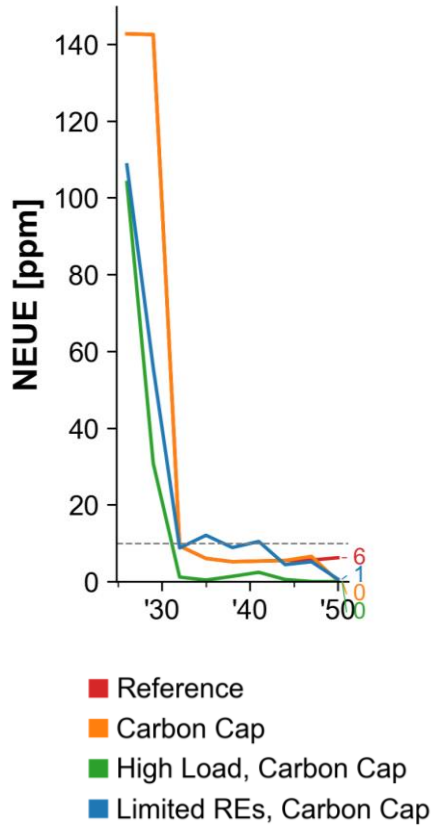
Gas-CCS and Nuclear SMR increase NPV by 1 to 10% and energy price by 9 to 25%.

System NPV



2050 Average Energy Price

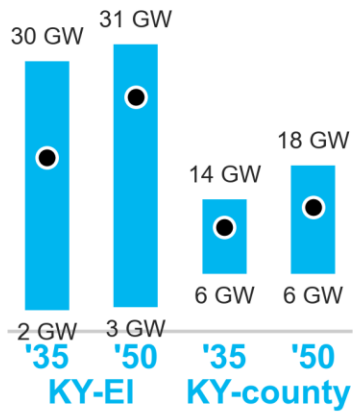




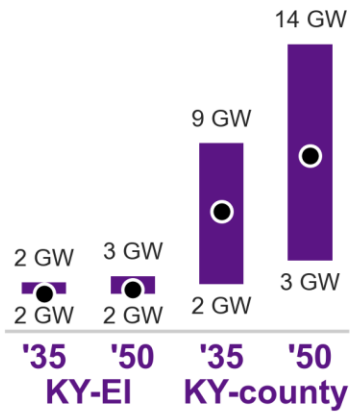
Scenario Set: Kentucky Islanded at County Resolution

Potential capacities for the future Kentucky power system.

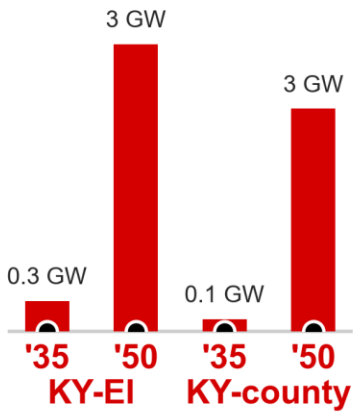
Wind



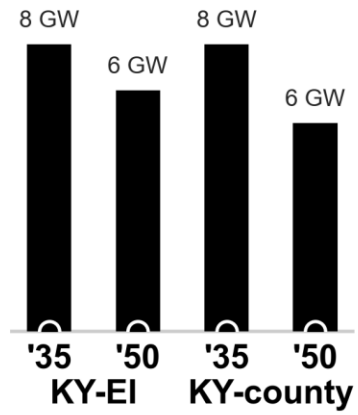
Gas Combined Cycle



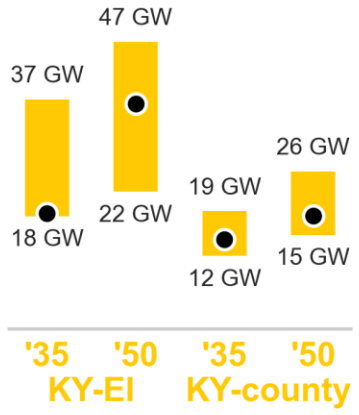
Nuclear SMR



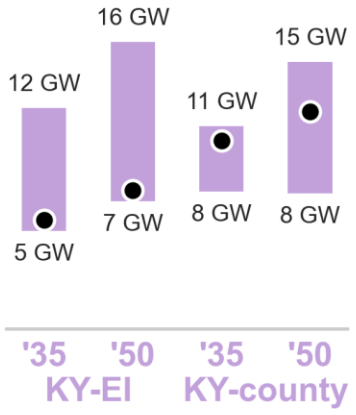
Coal



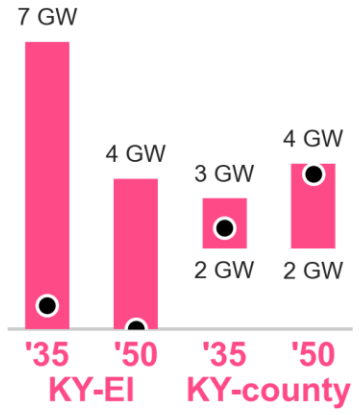
Solar



Gas Combustion Turbine



Battery Storage



KY-EI: Kentucky within the Eastern Interconnect

KY-county: Kentucky islanded at county resolution

Points denote *Reference* case result

Coal is only online in ‘35 and ‘50 without EPA 111.

Summary of Key Observations

- Wind appears to be cost competitive in Kentucky, but if it is hard to site the wind, 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 RE 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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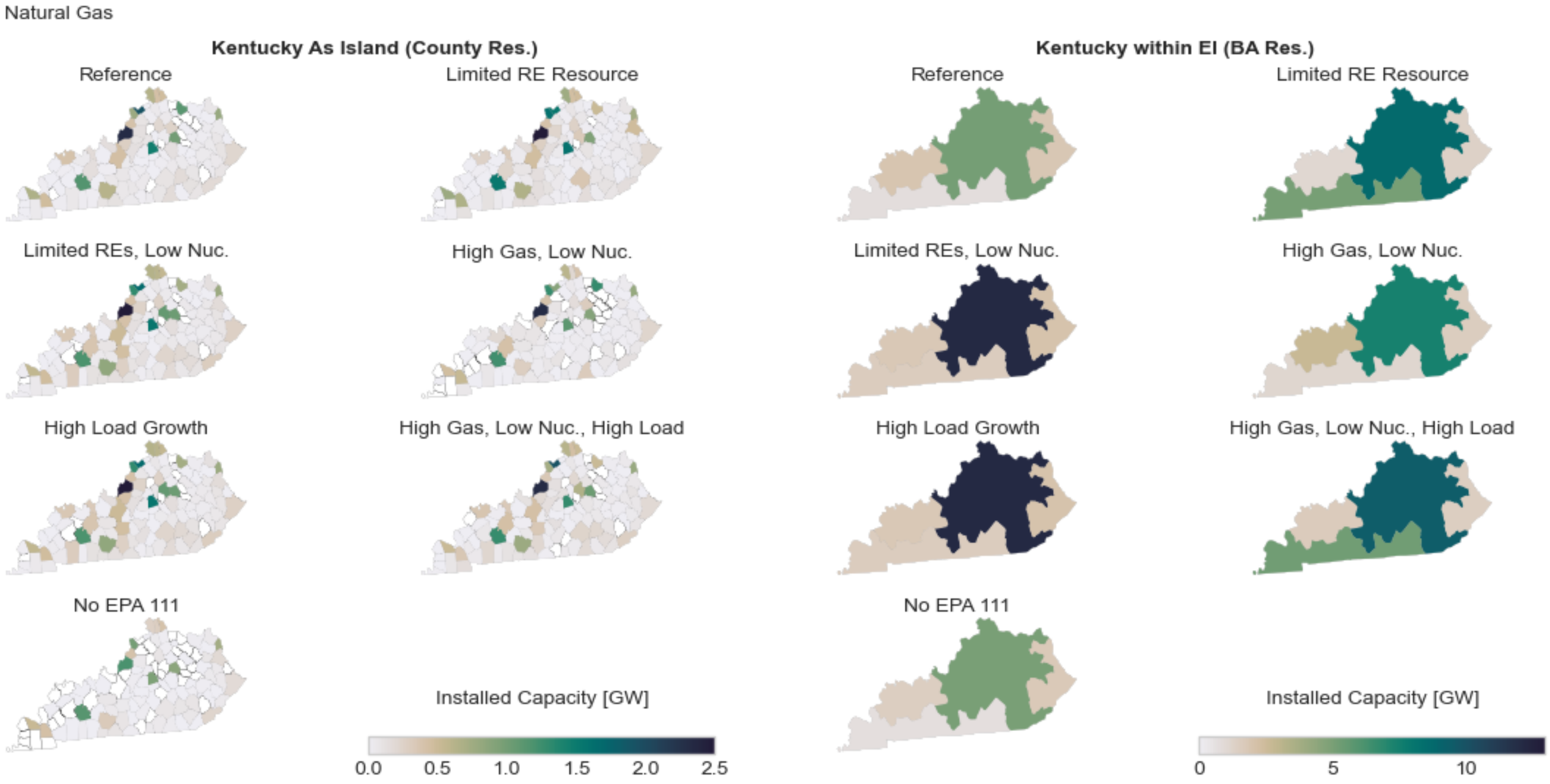
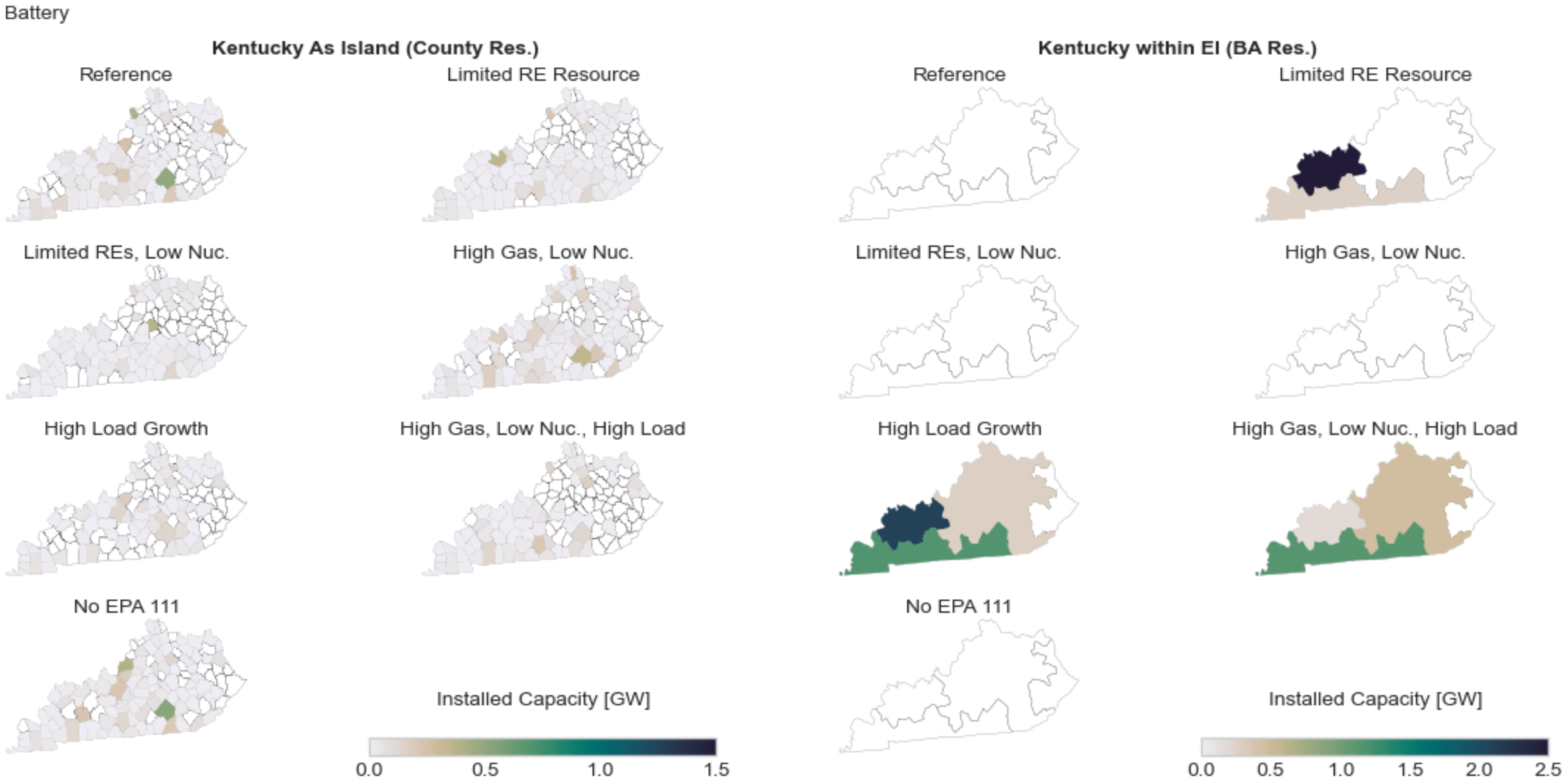
Gas siting and capacity is most sensitive to EPA 111 and coal rules.



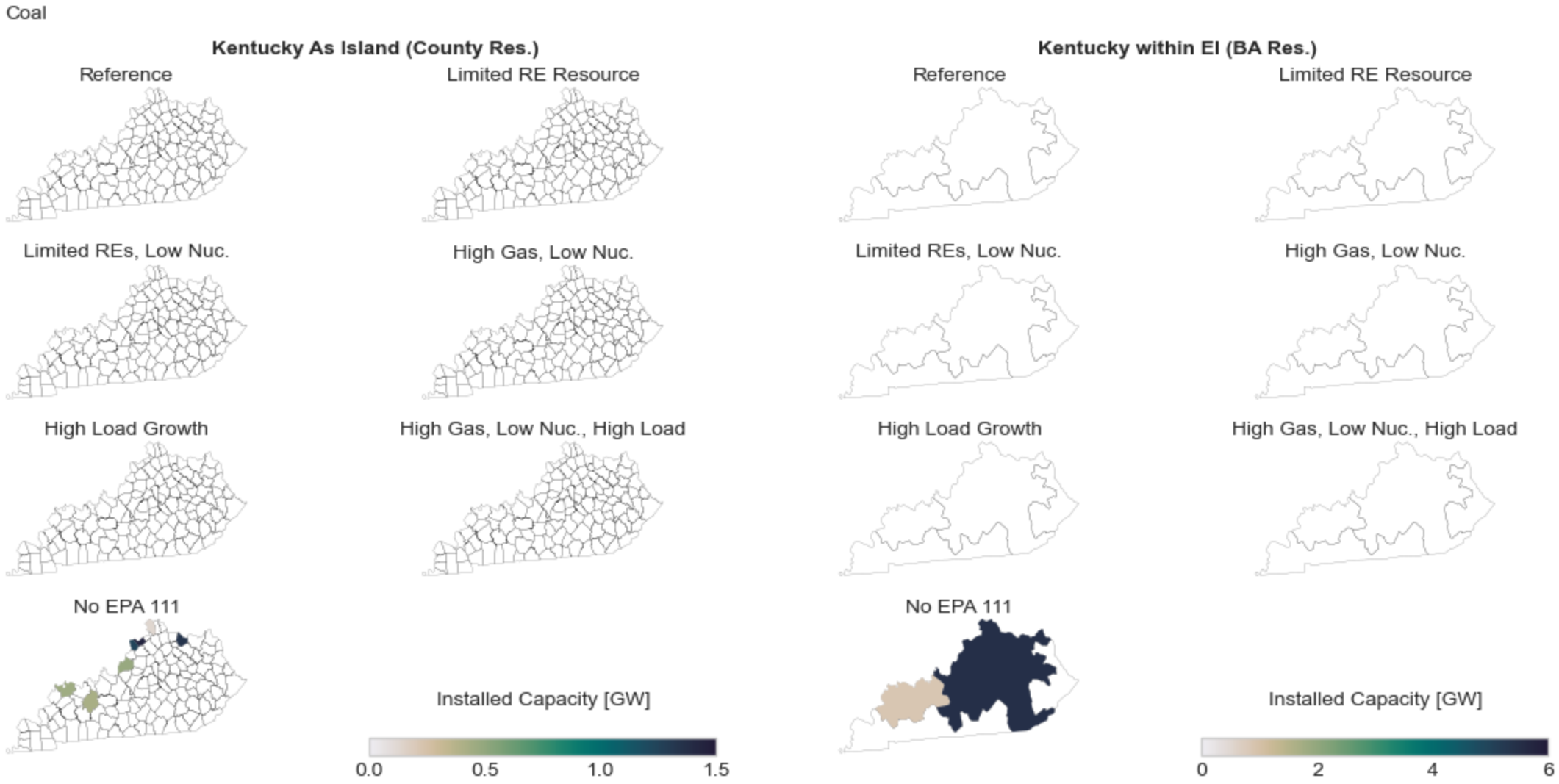
Results are for 2050

Map- Battery



Results are for 2050

Coal capacity remains only in isolated areas without EPA 111.



Results are for 2050