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Climate-Water-Electricity Interactions in the U.S. Under Alternative Decarbonized Futures

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Outline

1. Motivation for integrated climate-water-electricity analysis
2. Exploring hydropower availability reduction with a grid-only model
3. Integrated grid+hydrology modeling for power sector water risk assessment
4. Conclusions and insights

Climate change affects energy demand, thermal power plant performance, and water resources for cooling and hydropower.

- Rising temperatures
  - Higher electricity load with higher peaks
  - Reduced thermal plant efficiency
  - Cooling water discharge temperature limits
- Changing water cycle
  - Hydropower availability
  - Cooling water availability and quality
- Other short- and long-term impacts, e.g., wind/solar resource changes, extreme weather events

Innovative approaches are required to integrate climate-water-electricity models and data

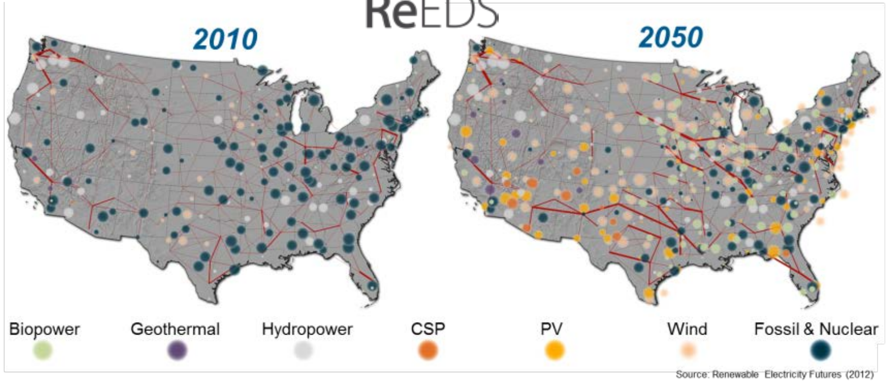
- Global climate model data must be downscaled and processed for use in water-energy models.
- Water and electricity models must represent climate impacts.
- Water and electricity models can be difficult to combine.

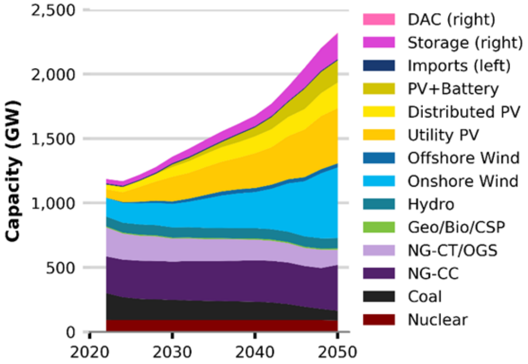
Craig et al., 2022 offers a great summary of climate-energy model disconnects:
https://www.sciencedirect.com/science/article/pii/S2542435122002379

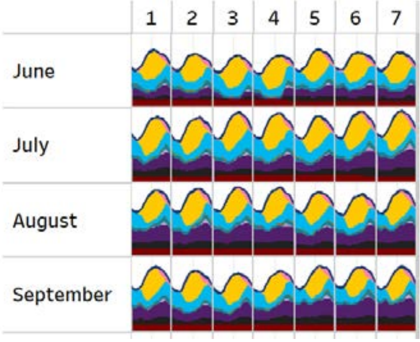
Exploring hydropower availability reduction with a grid-only model

A grid planning model can study first-order grid impacts of reduced hydropower availability

- Climate change and environmental constraints could reduce hydropower availability.
- NREL's Regional Energy Deployment System (ReEDS) model can explore alternative hydropower futures.
- ReEDS minimizes investment and operation of generation, storage, and transmission through 2050 for the contiguous U.S.
- Implementing hydropower availability scenarios represents multisectoral interactions without multimodel coupling.





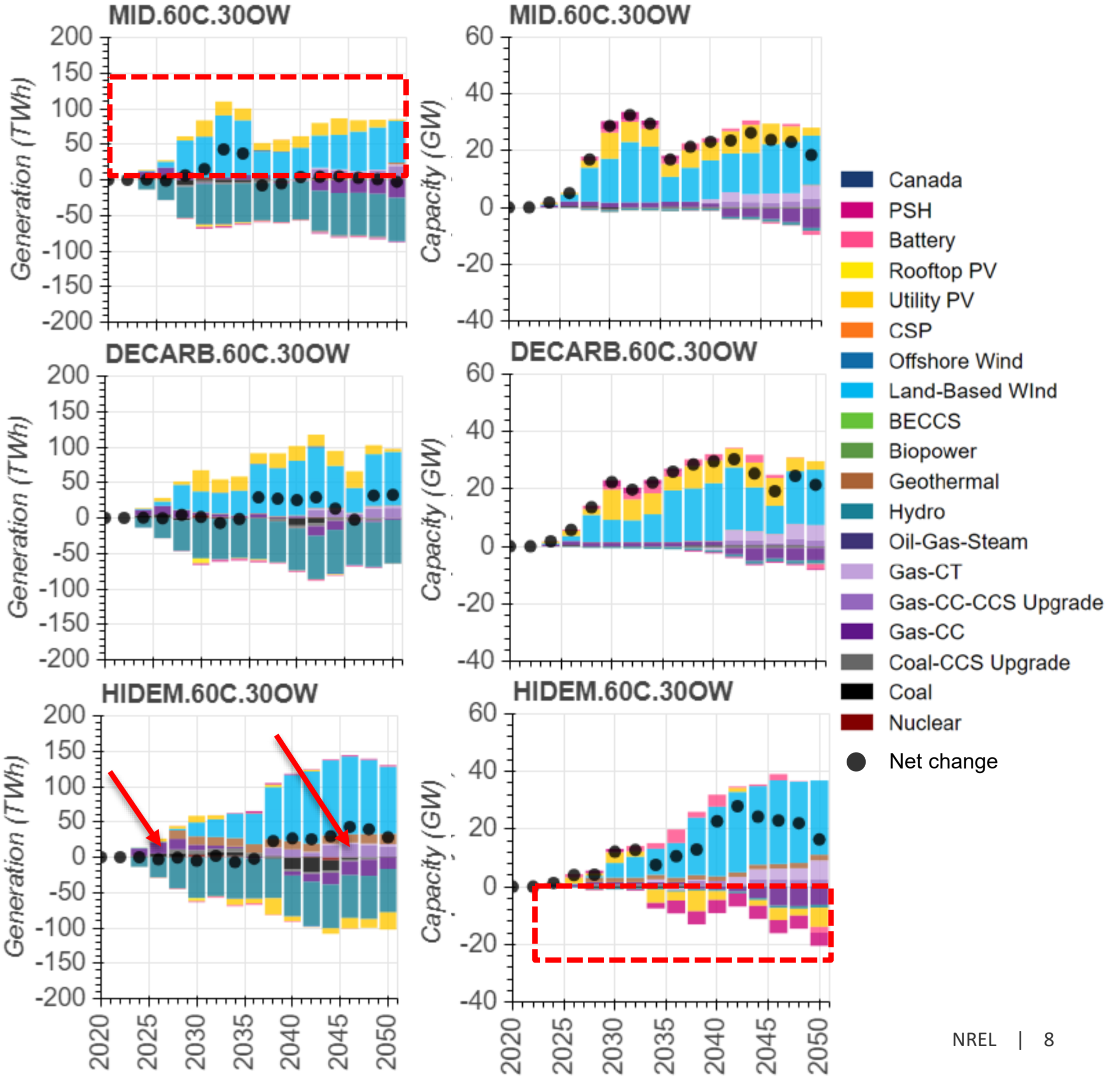


Scenarios include declining hydropower availability and alternative grid futures

- Focus on the U.S. Western Interconnect, where hydropower is more influential.
- Electricity scenarios vary decarbonization and demand.
  - MID: all default model assumptions from 2022 Standard Scenarios
  - DECARB: requires 95% CO2 reductions by 2050 relative to 2005
  - HIDEM: high electrification scenario from NREL Electricity Futures
- Declining hydropower scenarios reduce hydropower energy (not capacity) from 2022 to 2030 where it remains fixed thereafter.
  - 10/30/60% reductions in OR/WA (OW)
  - 30/60/90% reductions in CA (C)
  - Combination scenarios for each of the low/mid/high levels
  - Baseline scenario with constant hydropower availability for comparison

Reduced hydropower is offset by a range of technologies

- Lost hydropower is replaced largely by wind and solar PV.
- Near-term increase in gas and long-term increase in CCS can occur.
- High demand scenario has reduced PV & battery deployment.



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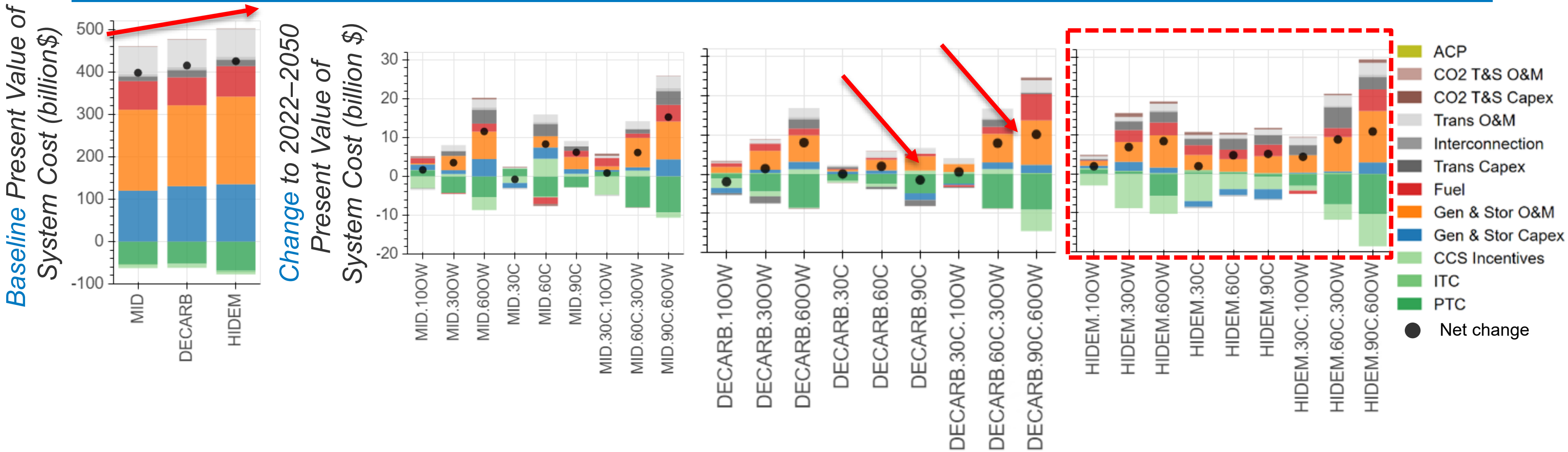
Changes to the grid mix affect overall grid economics



- Costs are higher with deeper decarbonization or higher demand.
- Reduced hydropower often increases system cost, but sometimes negligibly.
- Cost impacts are slightly greater with high demand.

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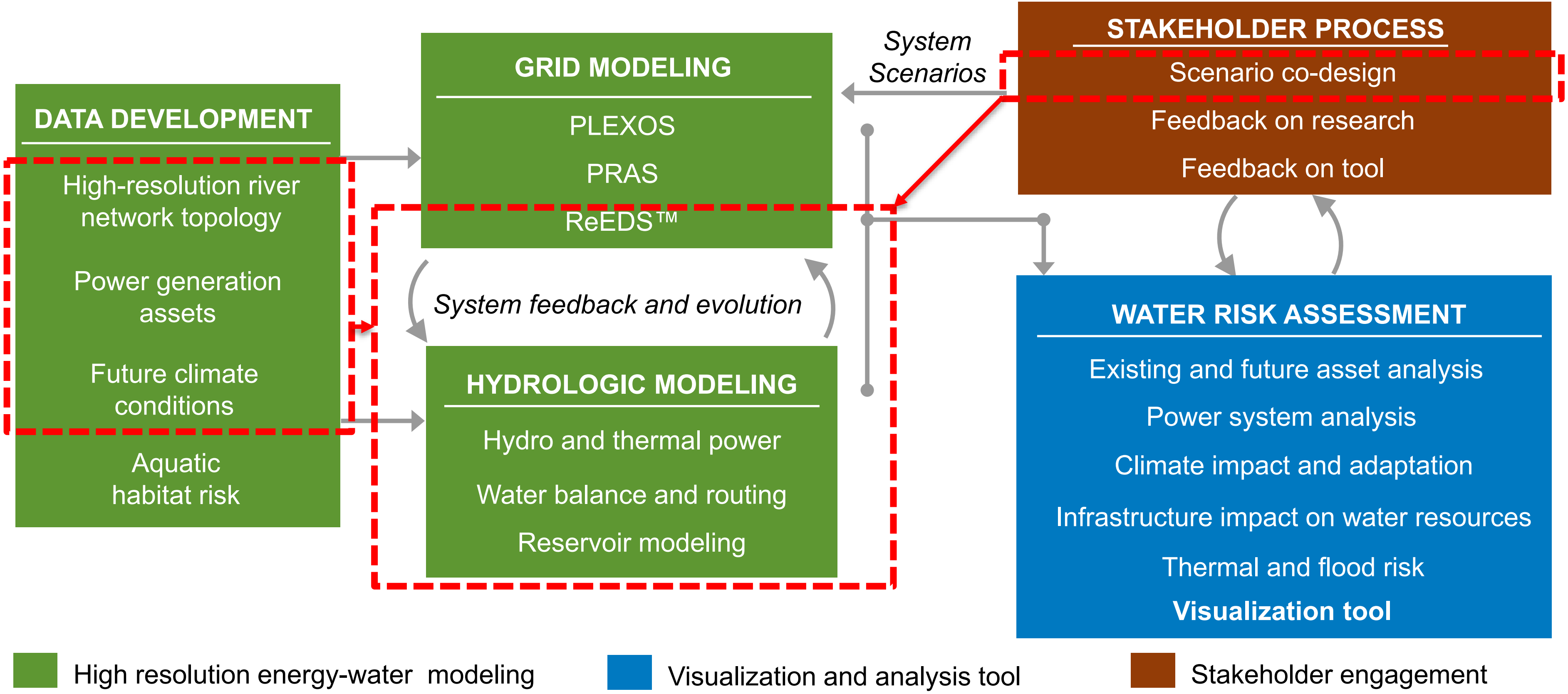
Integrated grid+hydrology modeling for power sector water risk assessment

An integrated multi-model workflow can incorporate climate-energy-water feedbacks



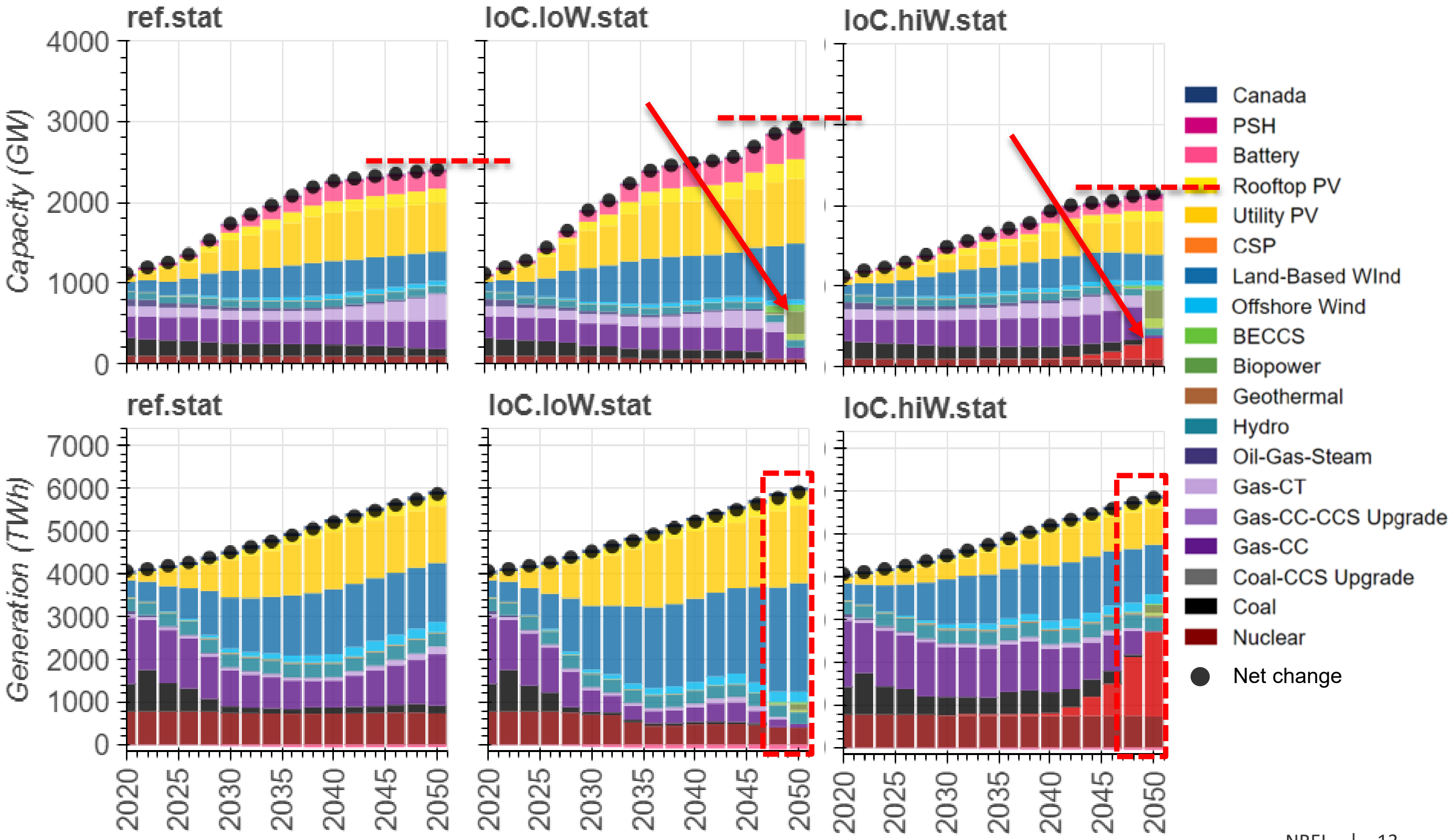
Ongoing analysis explores a wide range of climate and electricity futures

- 6 Climate scenarios span a range of temperature and precipitation futures: **ACC**ESS-CM2, **BCC**-CSM2-MR, **CNR**M-ESM2-1, **MPI**-ESM1-2-H4, **MRI**-ESM2-0, **Nor**ESM2-MM (all using SSP5-85) are compared to **stat**ic historical climate scenarios.
- Electricity scenarios span vary load, carbon emissions, and water use.

Electricity Scenario	Description
Mid case (**ref**)	Default input data and assumptions
Low Carbon (**loC**)-Low Water Use (**loW**)	Low-cost wind, solar, batteries; 100% CO_2 reduction in 2050
loC-High Water Use (**hiW**)	loC + high-cost wind, solar, batteries; low-cost small modular nuclear, CCS
High Demand (**hiD**)	High electricity demand driven by electrification
hiD-loC-loW	hiD + loC + loW assumptions
hiD-loC-hiW	hiD + loC + hiW assumptions

Electricity scenarios have disparate water and emissions impacts

- Different scenarios utilize different technologies (e.g., H_2, nuclear-SMR).
- Total capacity varies with wind & PV competitiveness.
- Water use could be very different between a high-renewables vs. a high-nuclear grid.



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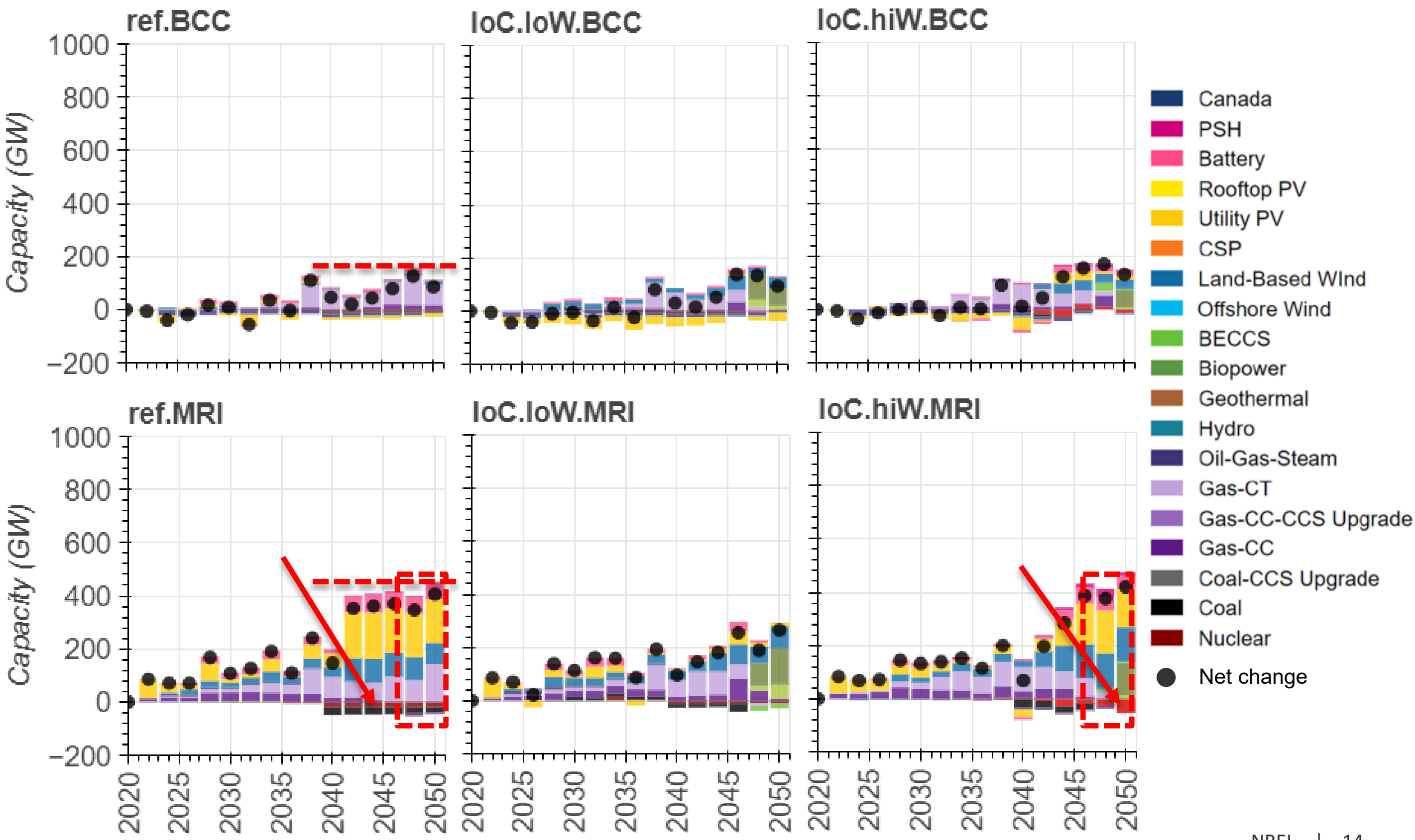
The response to future temperature rise depends on electricity scenario and temperature pathway

- Temp change sets the impact magnitude.
- Technology-specific impacts depend on the grid mix.
- Higher fossil & nuclear capacity factors amplify their *generation* impacts relative to capacity.



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The next analysis phase will feed back asset-level climate-water constraints to the grid model

1. Downscale temperature projections for ReEDS.
2. Run ReEDS with future temperature to produce grid infrastructure without considering water impacts.
3. Run hydrology and thermal/hydropower asset models with future climate-water impacts on future ReEDS infrastructure. Assess generator availability relative to the ReEDS solution.
4. Feed back adjusted availability factors to ReEDS and re-run to produce climate-water impacted grid.

Complete (steps 1–2)

In Progress (step 3)

Next (step 4)

Results will reveal asset and regional climate-water risks on power system investment and operation

Conclusions and Insights

1. Multisystem/multisector insights are possible without complex model coupling, but coupling enables richer exploration of feedbacks.
2. Reduced hydropower availability affects fossil and renewable technologies in nuanced and scenario-specific ways.
3. The decarbonization strategy can strongly influence how climate change impacts the grid.

Thank You. Questions?

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