Question 1

Ten year vision: Key questions

Given that the coupled electricity-water-land system is co-evolving over time in response to a range of different forces…

- Will future electricity infrastructure be more or less reliable, resilient?
- What are the costs and benefits of electric sector resilience investments?
- What might be feasible or desirable given other concerns and tradeoffs (e.g., desire to not just be resilient but also sustainable, flexible, etc.)?
- Will key constraints emerge (e.g., limits related to power plant siting)?
- Will human responses feed back to climate and/or hydrology in a significant way (i.e., that demands accounting for these in models)?

Specific Question: What are the costs, benefits, co-benefits, and tradeoffs associated with specific actions or investments that could be taken to enhance the resilience of the WECC electric grid against increases in droughts?

Key Issues

Costs = generally easy to quantify for near-term infrastructure investments, harder for longer-term investments or policy/regulatory/institutional changes

Benefits = avoided costs, specifically with respect to drought. Generally hard due to uncertainties in future climate as well as other influences on system evolution (e.g., technological change, resource utilization and availability, etc.)

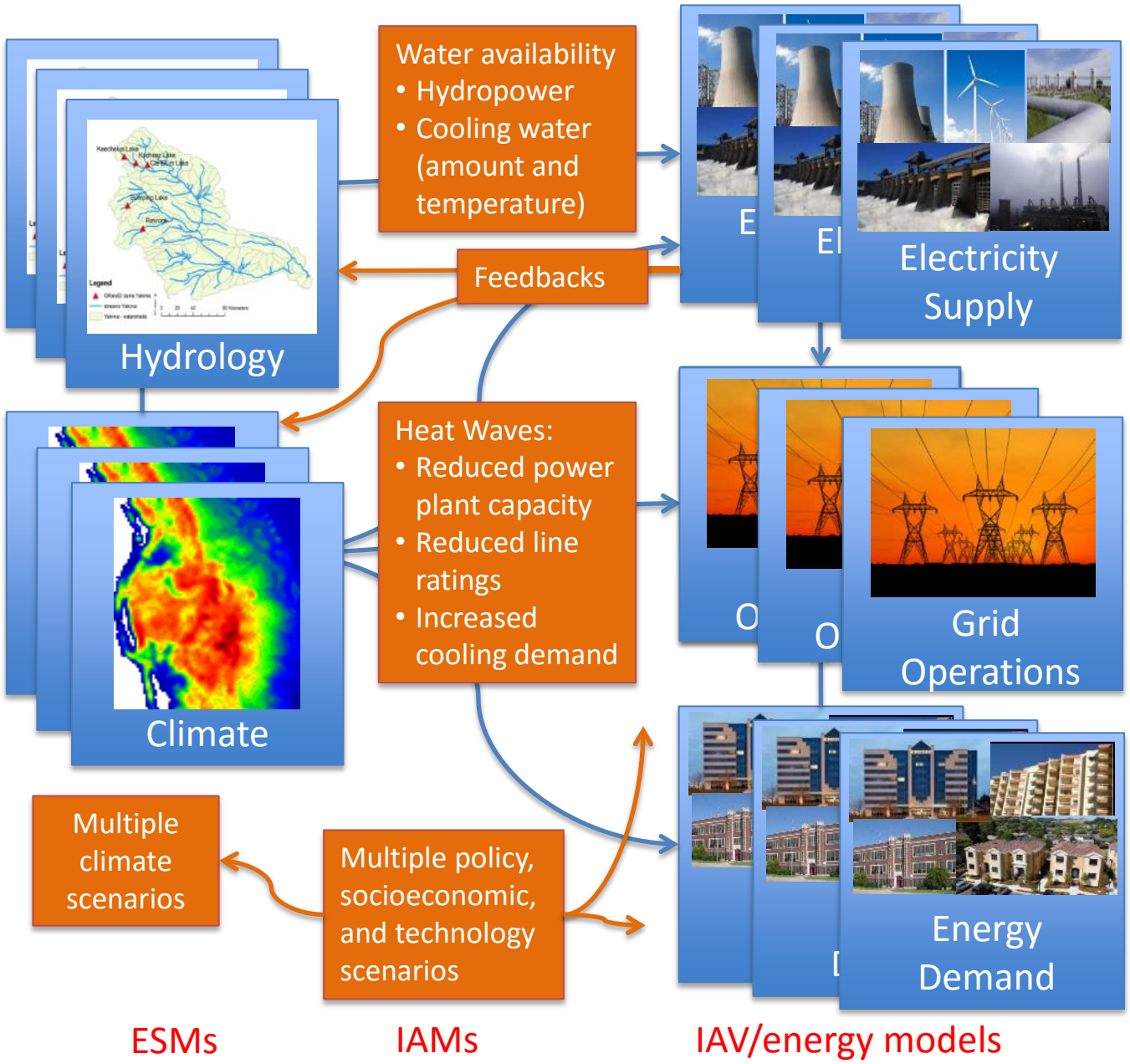
Co-benefits = resilience against other hazards (e.g., heat waves), benefits to other metrics of electric system performance (reliability, flexibility, security)

Tradeoffs = negative effects on other metrics of system performance or on other systems/sectors

Specific actions or investments = infrastructure hardening, relocation, or build-out (e.g., additional transmission), policy or regulatory changes, etc.

Question 2

Future Infrastructure



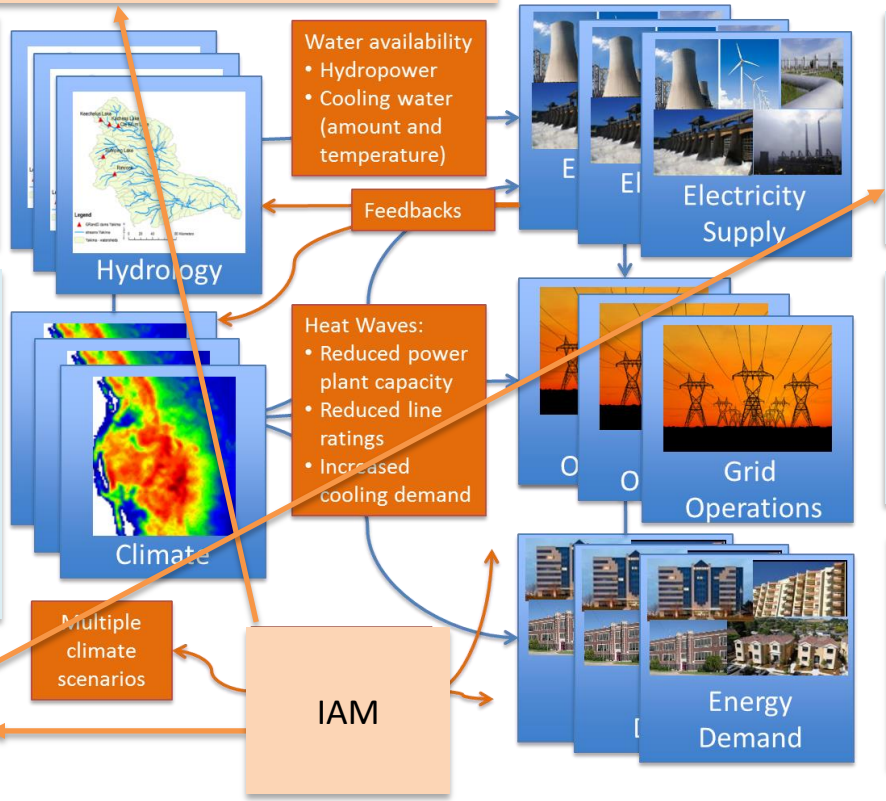
Key Challenge: Defining Boundaries

Other demands for water: Agriculture, domestic, flood control, fish passage (includes water regulations/rights/allocation rules)

Includes reservoir operation rules, river routing, water management, influence of LULCC

Climate information with uncertainty characterization: ESMs, RGCMs, pattern scaling, case studies/scenarios

LULCC: Agriculture and bioenergy (especially water demand)



Includes power plant siting, different technologies (including renewables, distributed generation)

Includes water and temp deratings, system operation rules (including load shedding, etc.), ability to add new transmission

Includes demand-side management, energy storage, changes in building characteristics/efficiency, electrification of transport

Local feedbacks (e.g., LULCC or hydrology/mgmt. feeding back on local climate?)

Spatially explicit population growth and socioeconomic development (drives water and energy demands)

Other non-climate extreme events (e.g., major infrastructure failures)

Some additional detail on what we would need to do to address specific science question?

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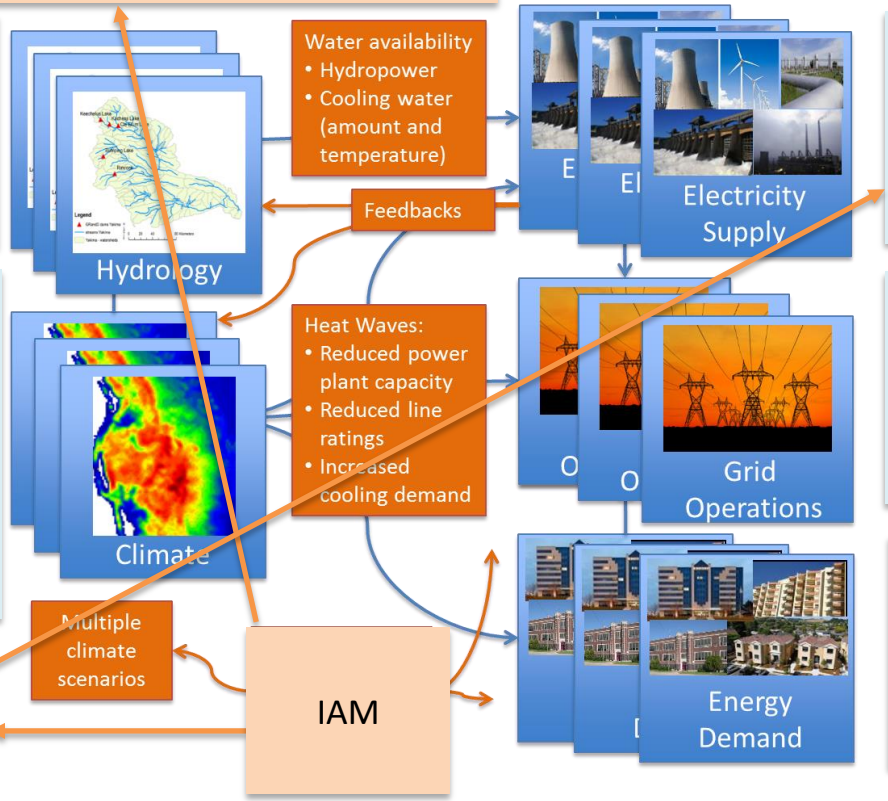

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LULCC: Agriculture and bioenergy (especially water demand)

Includes demand-side management, energy storage, changes in building characteristics/efficiency, electrification of transport

Need additional tools for coupling, downscaling, etc.

Local feedbacks (e.g., LULCC or hydrology/mgmt. feeding back on local climate?)

Spatially explicit population growth and socioeconomic development (drives water and energy demands)

Other non-climate extreme events (e.g., major infrastructure failures)

Question 3

How would we make progress toward the ten-year vision?

- Given all the needs and uncertainties, we would start with the specific question that we are trying to answer (WECC reliability/resilience), identify available modeling tools that are available to address different aspects of this question, and the known uncertainties and sensitivities with respect to the question we are trying to answer.
- Then, identify an initial set of models and couplings we could use to do initial sensitivity tests to understand the key influences on WECC reliability/resilience, to identify and prioritize which things to build out in more details, which additional things to account for, etc.
- and, at the same time, begin exploring these for other regions and use cases.
- Systematically build out additional components and coupling tools and methodologies.

Question 4

Key gaps: Many are General

- Spatial allocation of future infrastructure, including flexibility/adaptability of those mechanisms
- If IAMs are the integrating framework, may be a disconnect if they cannot represent extreme events (i.e., the things to which the system is adapting)…Need better coupling/consistency between models representing long-term trends with models that can represent extremes & shocks
- Information on climate change (e.g., frequency/occurrence of droughts) at the appropriate scales, and whether climate models can accurately and robustly represent the events that cause greatest impact to electricity system (& related systems), including correlation of extreme events spatially and temporally (e.g., how widespread is a given drought?). Could use a focused research program exploring how distribution of extreme events are evolving in time in different climate models.
- Need ways to test system resilience/performance under multiple different climate regimes and extreme events, and under several different configurations of the system
- Combinations of extreme events that could layer on top of each other (e.g., groundwater depletion coupled with extreme drought coupled with another disruptive event)
- Future technology change/innovation, especially disruptive ones (e.g., large-scale storage?)
- Accounting for political and behavioral constraints (e.g., in water management models) and policy regimes and institutional constraints (including hierarchy of regulatory and governance)
- How human preferences/biases will shape adaptation choices
- When you bring in other models/constraints (e.g., representations of agriculture), need to make sure they are using the same assumptions
- Importance of “hidden” assumptions (e.g., discount rates)
- How do you systematically quantify the many different uncertainties?
- Reconciling different timescales (e.g., operational decisions versus long-range planning/design)
- What are the best ways to actually “couple” these models together?