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GLOBAL CHANGE INTERSECTORAL MODELING SYSTEM

Uncovering Key Drivers of Future Virtual Water Trade and Global Water Use

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Neal Graham, Tom Wild, Gokul Iyer, Jonathan Lamontagne, Pralit Patel

Pacific Northwest NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY BATTELLE

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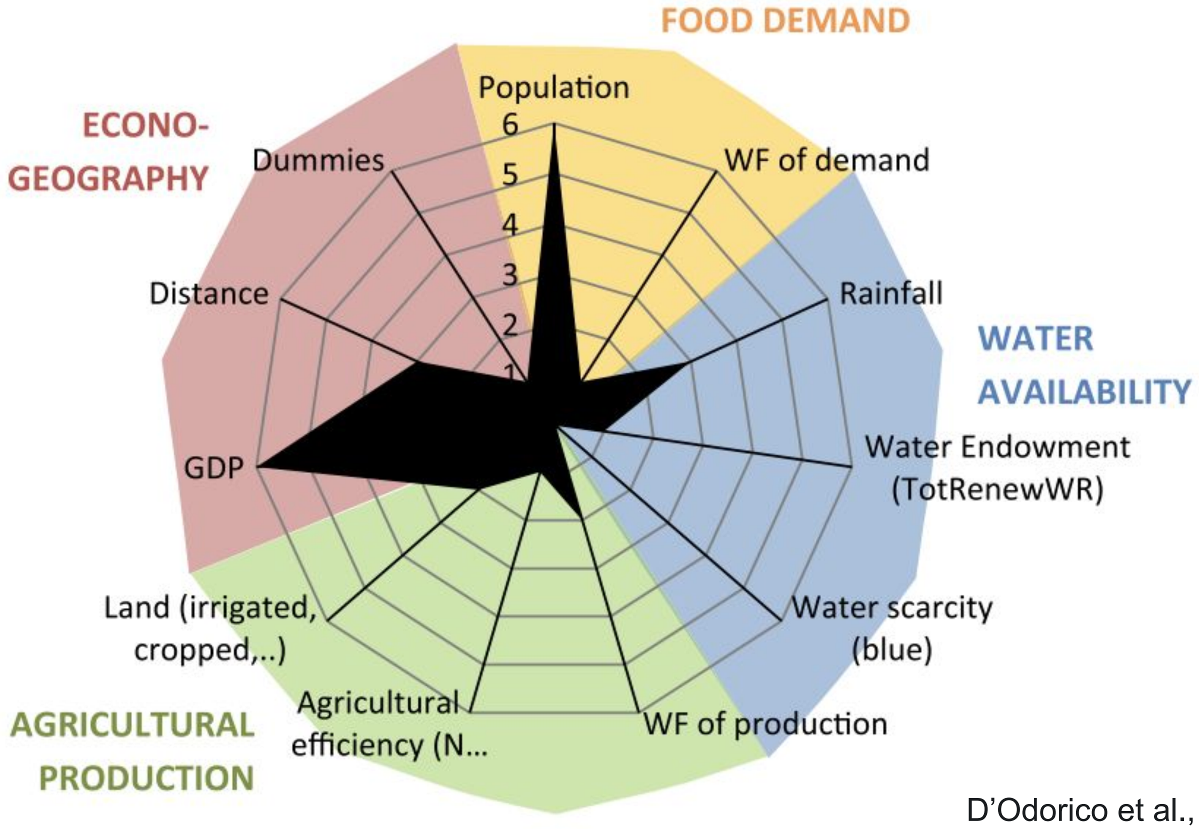
Introduction – Virtual Water Trade in History

- International trade redistributes water around the world, virtually, to allow regions to meet demands while having limited internal water resources or inadequate comparative advantages of land and labor productivity.

- Projected future growth, globalization, and continued market integration will drive further agricultural trade.

- Future projections of change significantly lack in the literature.



D'Odorico et al., 2019, *ERL*

Figure 13. Drivers of VW trade identified in the publications reviewed in section 7. The radial coordinate expresses the number of publications reporting a significant dependence on each variable. Details are provided in the supplementary information (table S1 is available online at stacks.iop.org/ERL/14/053001/mmedia).

Soil moisture and evapotranspiration consumed in crop growth

Fresh surface runoff and groundwater consumed in the production of a good or service

Adopted and modified from: *watercalculator.org*

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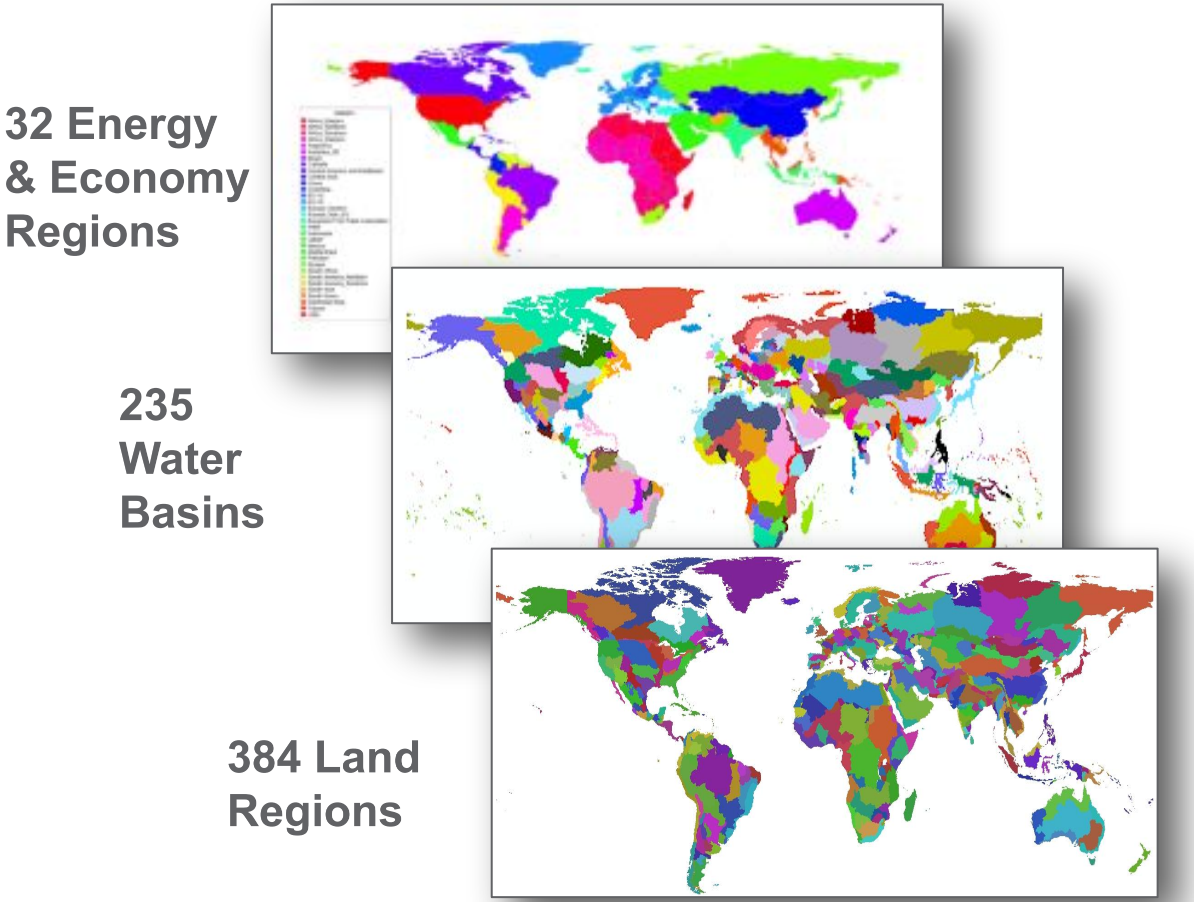
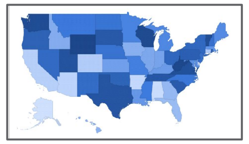
Goal – Increase the Robustness of our Projections using the Global Change Analysis Model

- ***Leveraging a Scenario Discovery Framework we ask:***
    - ***What are the main drivers of change for global and regional agricultural water use utilization and future virtual water trade across a large ensemble of uncertain futures?***
- GCAM is a ***multisector, multi-regional, dynamic model*** that ***economically and physically links*** energy, agriculture and water production, consumption, and trade.
- GCAM models ***dynamic demand growth*** in response to regional population and economic activity.
- GCAM includes ***technology detail in energy*** production, transformation and final demand sectors.
- GCAM includes ***physical representations of crop management practices*** in the agriculture sector.
    - Includes all commercial and natural lands in each land region.
- GCAM includes ***dynamic economic modeling of the water*** sector linked to energy and agriculture.

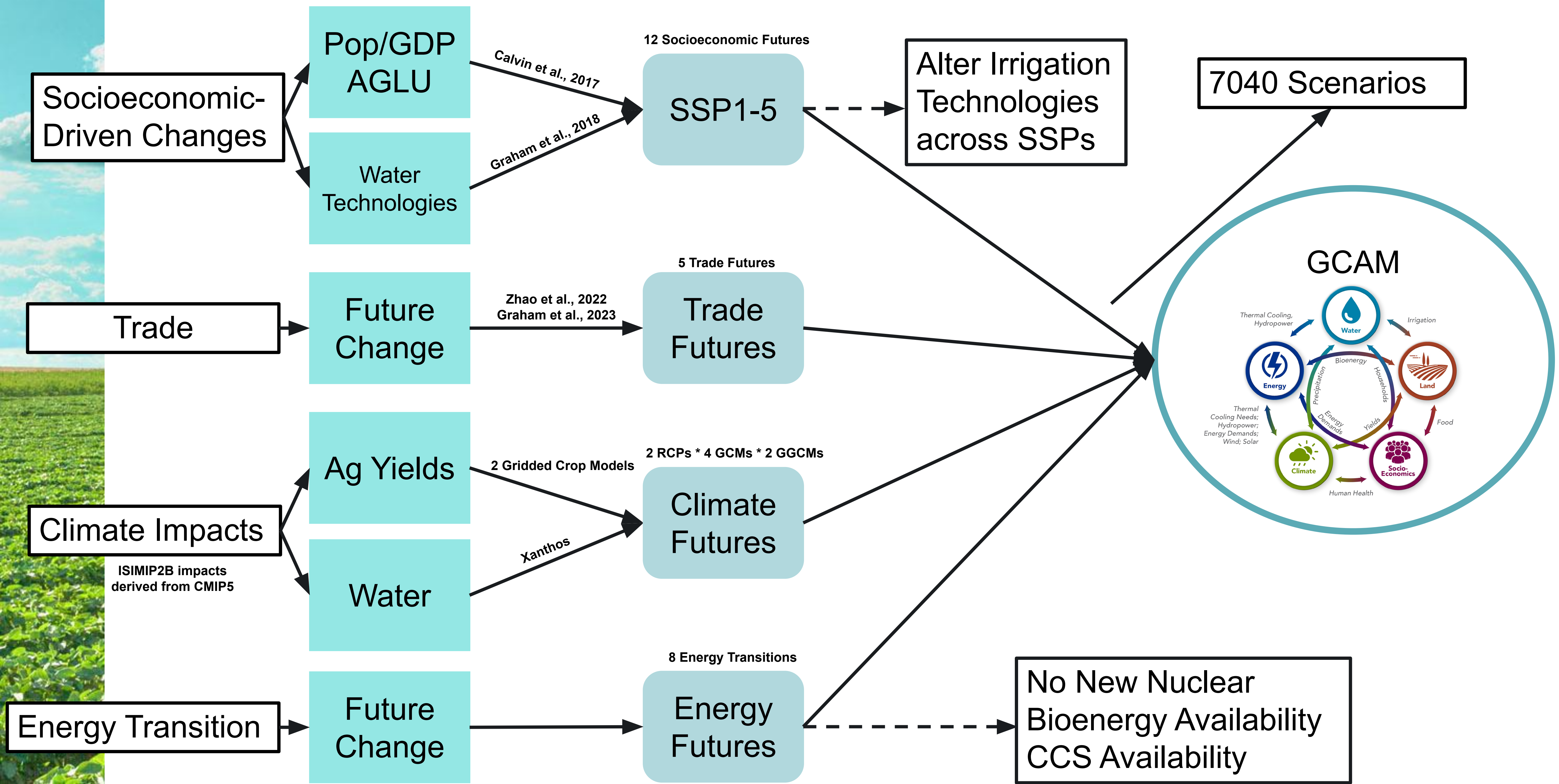
Global Coverage



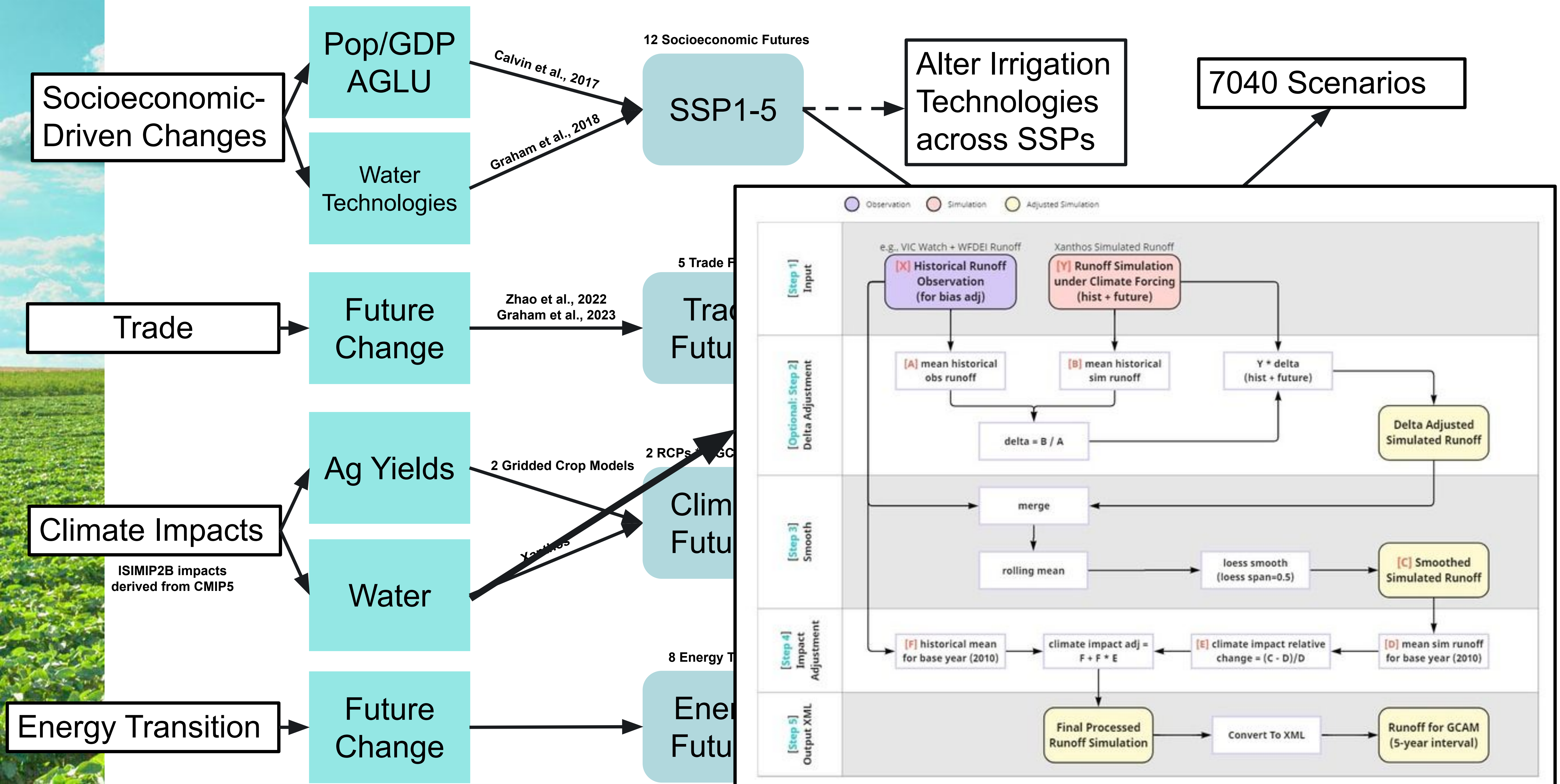


GCAM-USA (50 State)

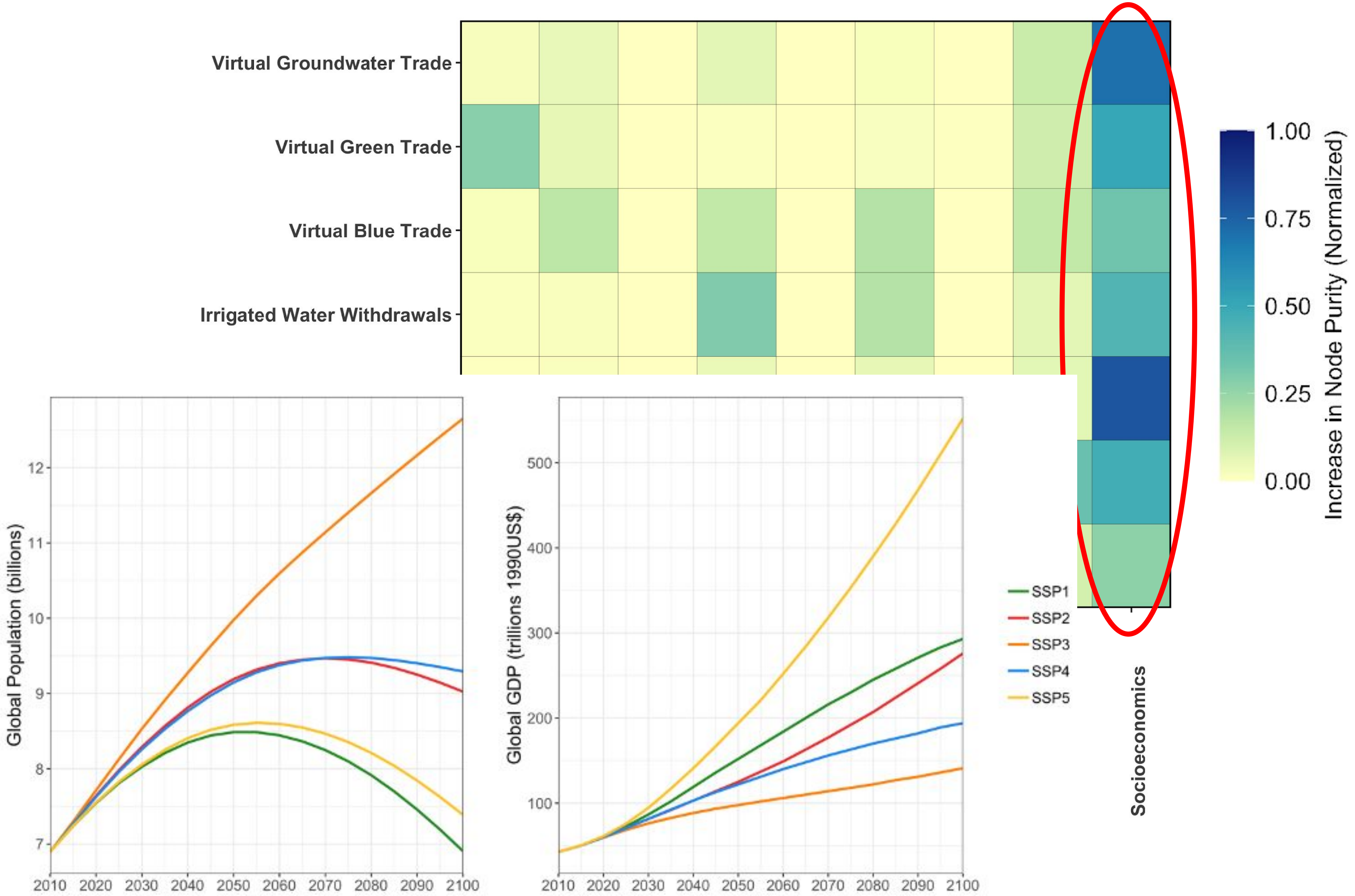
Scenario Discovery Workflow



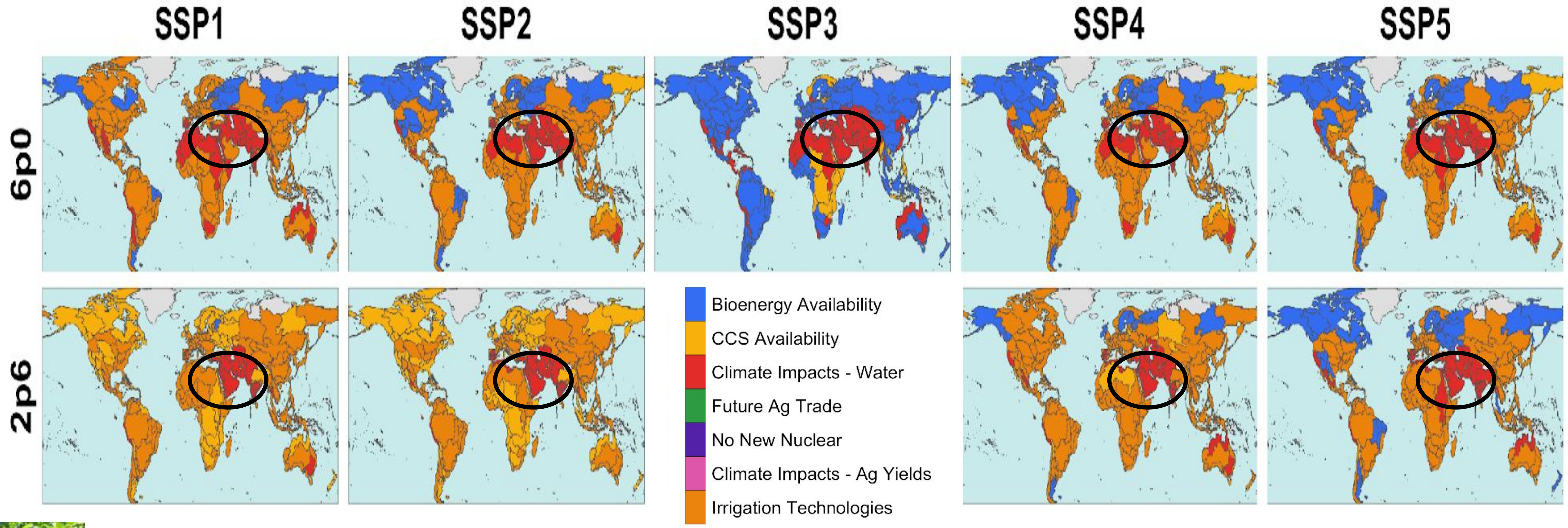
Scenario Discovery Workflow



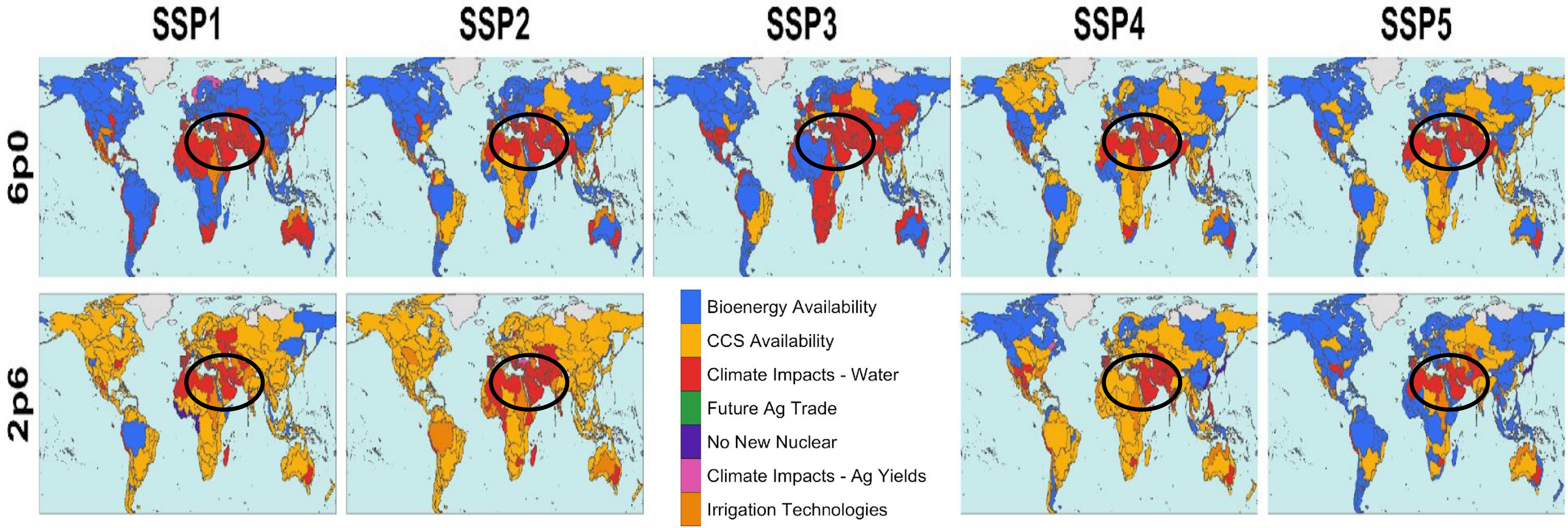
Global drivers of change are dominated by socioeconomic divergences in the SSPs, but the story becomes increasingly complex with more refined scenario selection



Irrigation Water Withdrawals are largely driven by the accessibility of higher efficiency technologies and the water savings associated with such adoption



In some basins, despite compounding influences, the main drivers of change for multiple metrics remain consistent across SSPs and RCPs, highlighting the importance of select drivers in some regions



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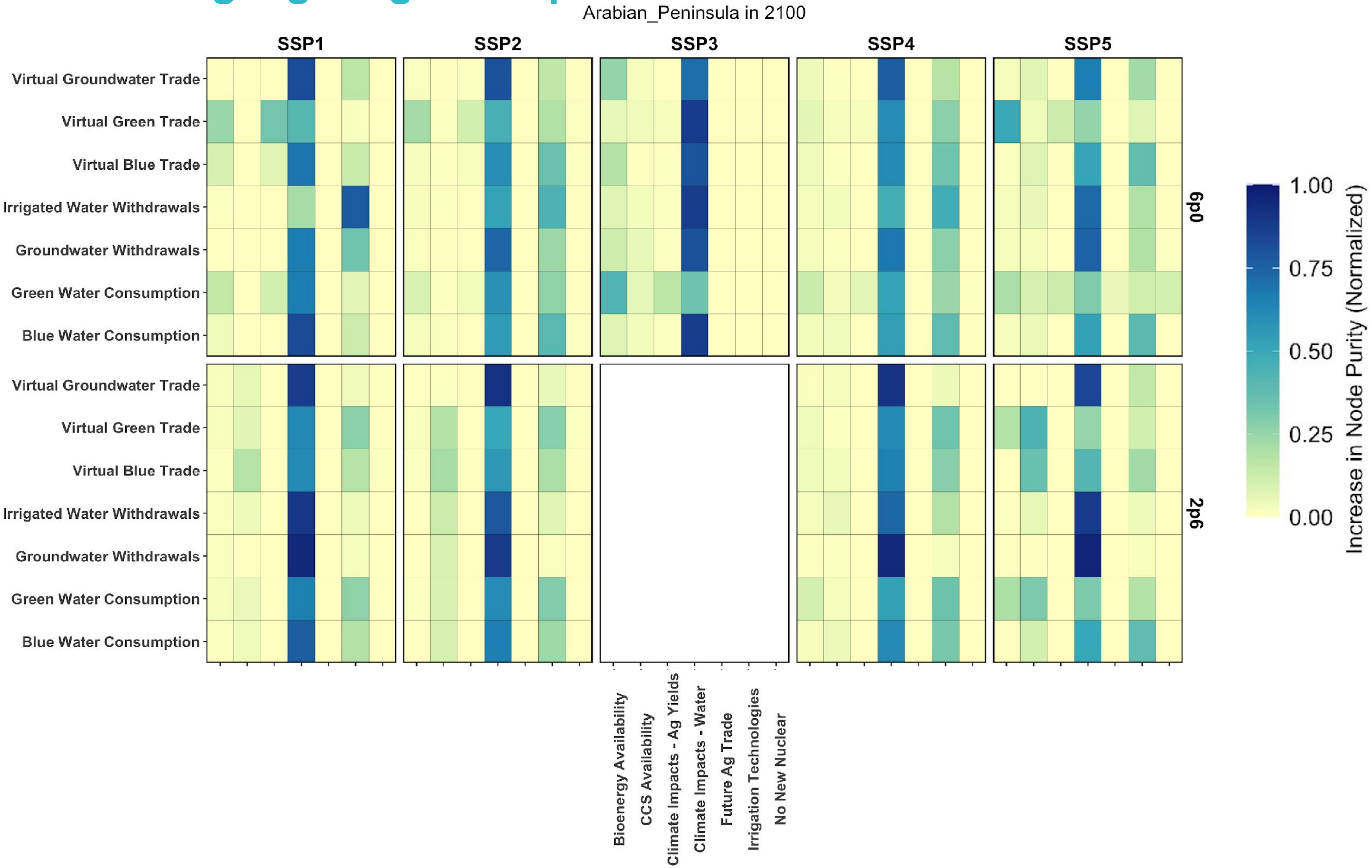
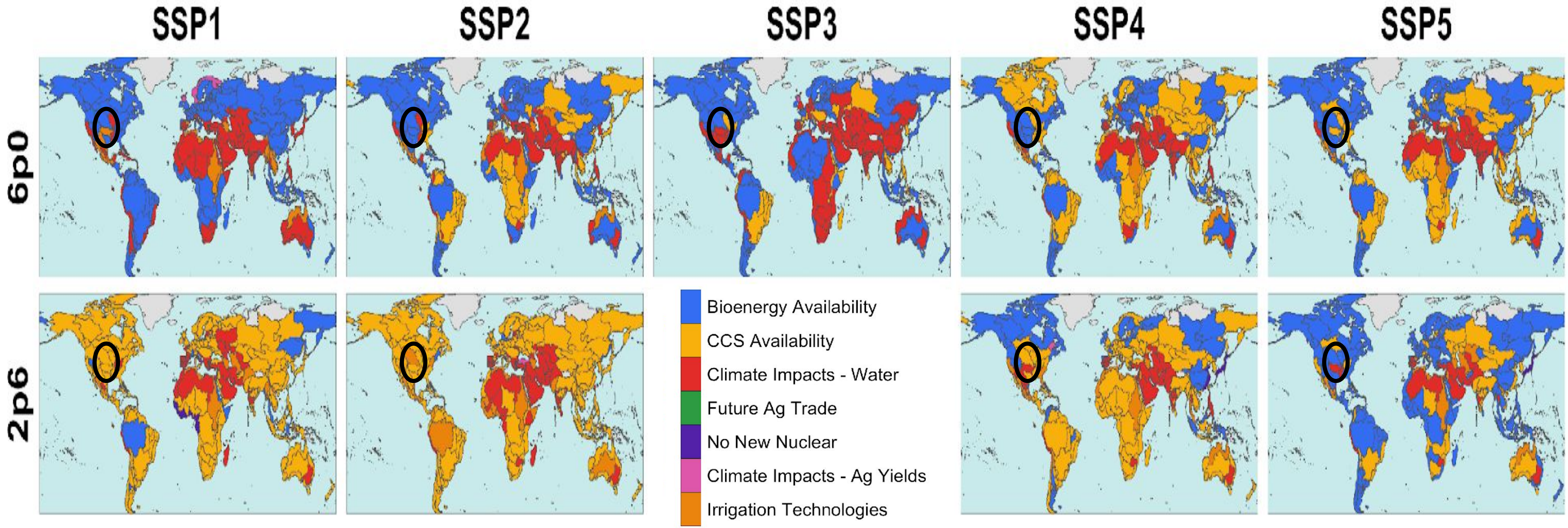


Virtual Blue Water Trade can have differing main drivers in a basin, depending on socioeconomic and climatic conditions – highlighting regional sensitivities to such dynamics



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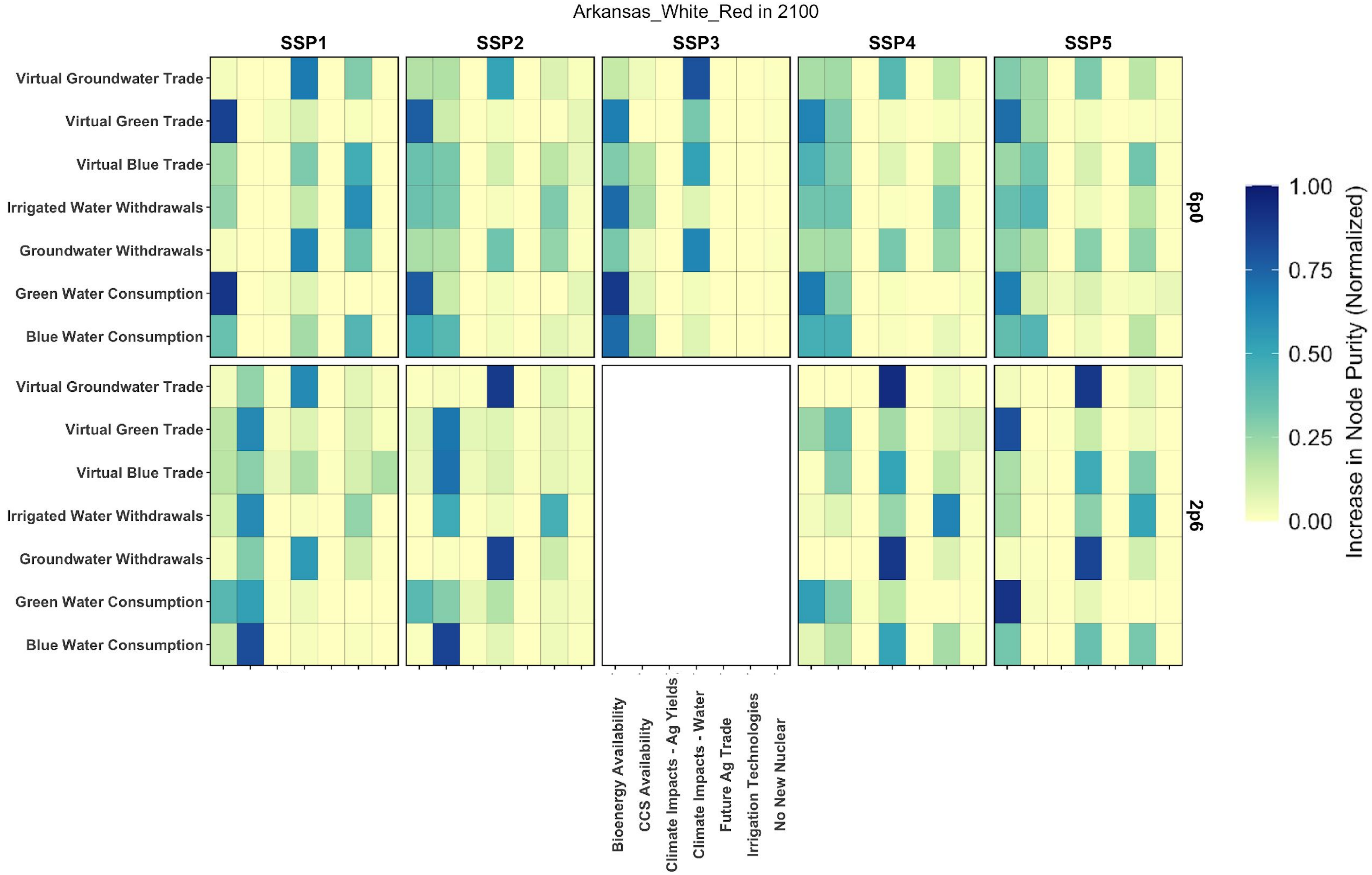

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Conclusions & Future Work

- First such study to examine a large suite of future uncertainty to uncover key drivers in water utilization and trade.
- While drivers show regional heterogeneity, ***dry areas are shown to often be driven by the climate-driven water supply responses*** while other basins show differences across socioeconomic and climate futures.
- Such basin-level differences allows us to further our exploration to understand the multisectoral drivers behind these changes in water.
  - Agricultural demand & production
  - Energy demand and mix
  - Regional trade
- Despite the differences across basins at the end of the century, ***it is important to understand how these drivers change in time.***

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Thank you

Neal T. Graham
neal.graham@pnnl.gov

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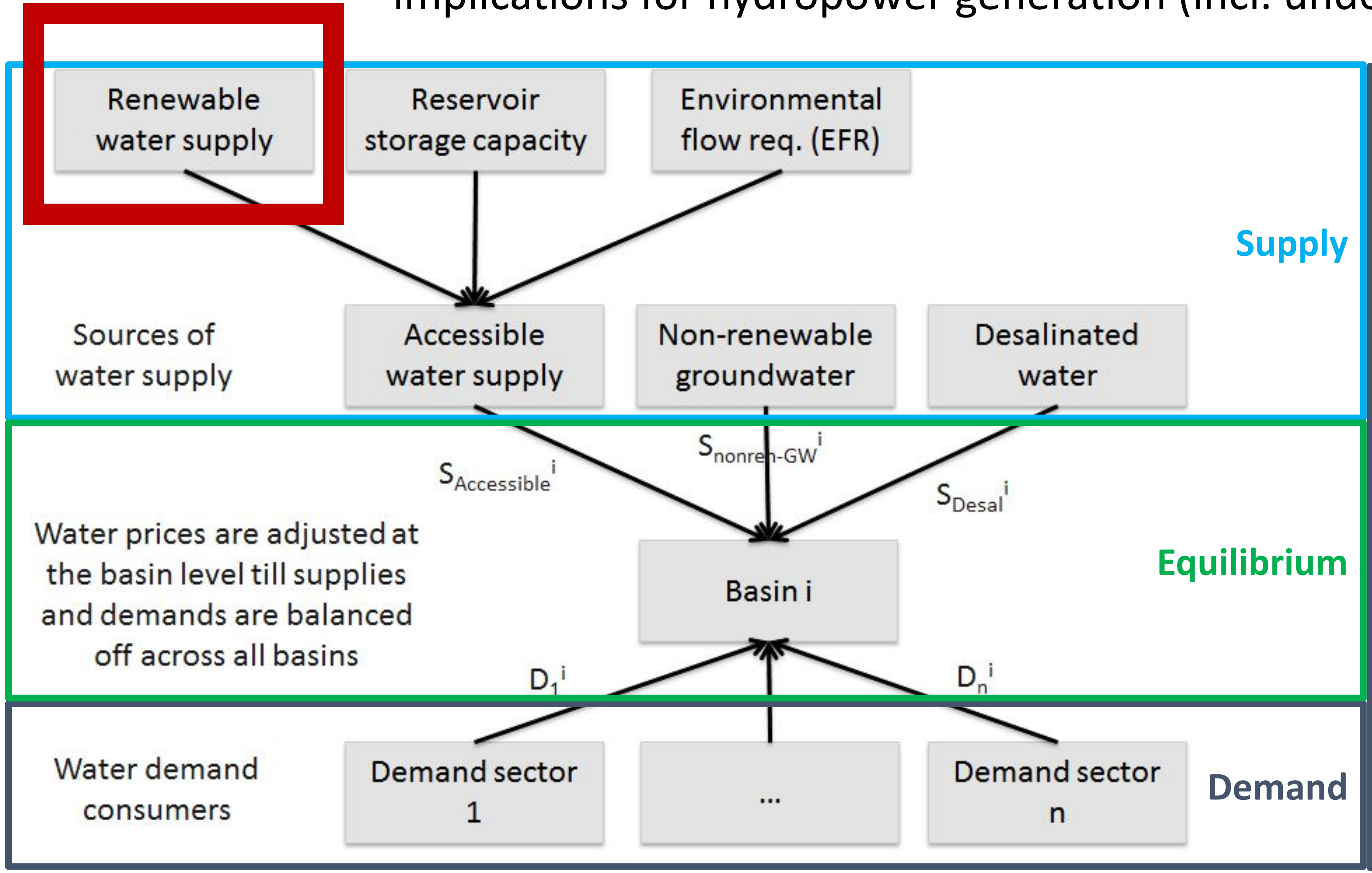
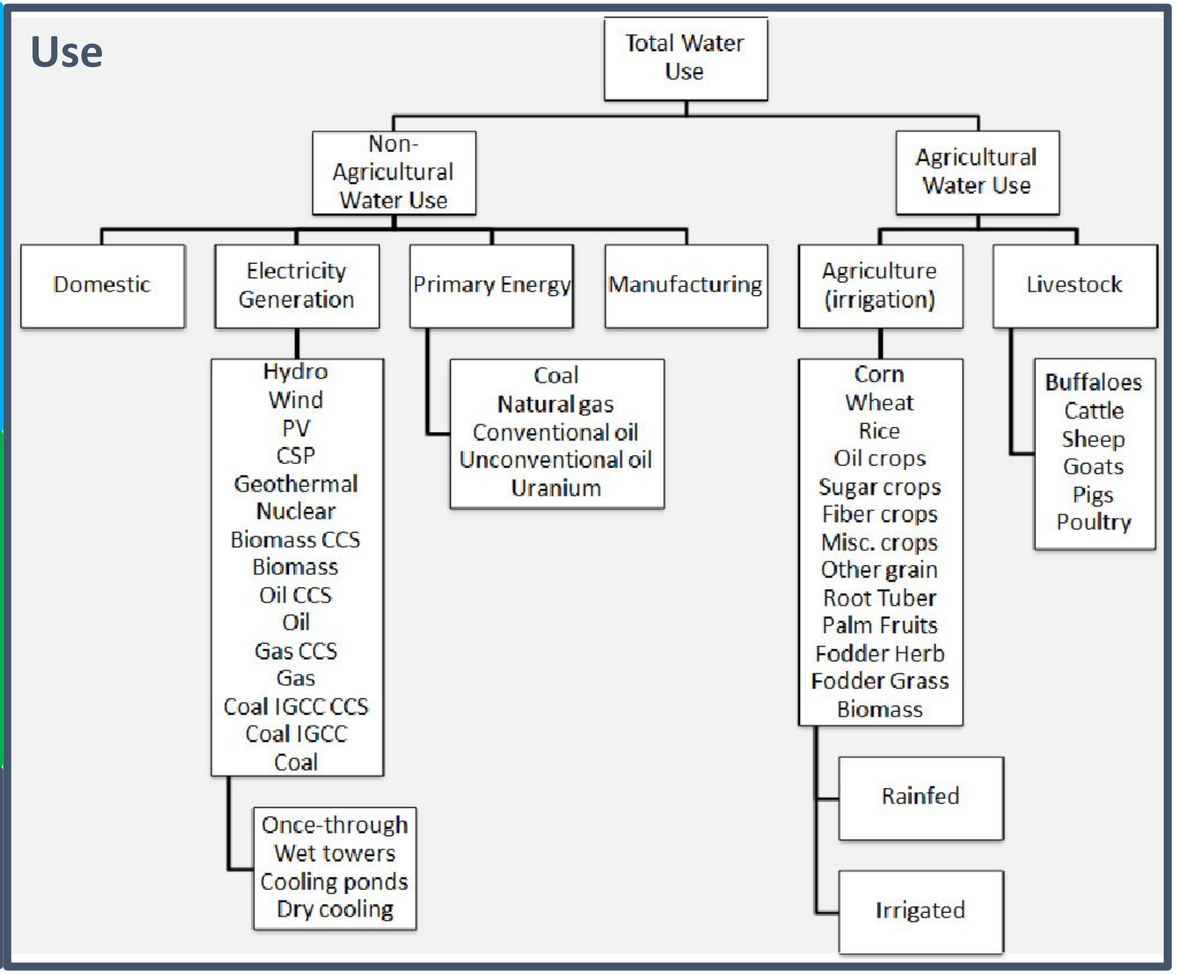
Water Demand and Supply are Balanced Across 235 Global River Basins. Water demands by tech. (incl. hydro) are tracked. Water availability produced by a separate hydrology model.

We have a hydrology model that generates information about renewable water supply, <u>and</u> its implications for hydropower generation (incl. under climate change)





Kim et. al (2016)

Water prices allow us to capture two key dynamics: increasing shadow price with increasing scarcity; and preferential water allocation to classes of users (e.g., agriculture versus electricity)

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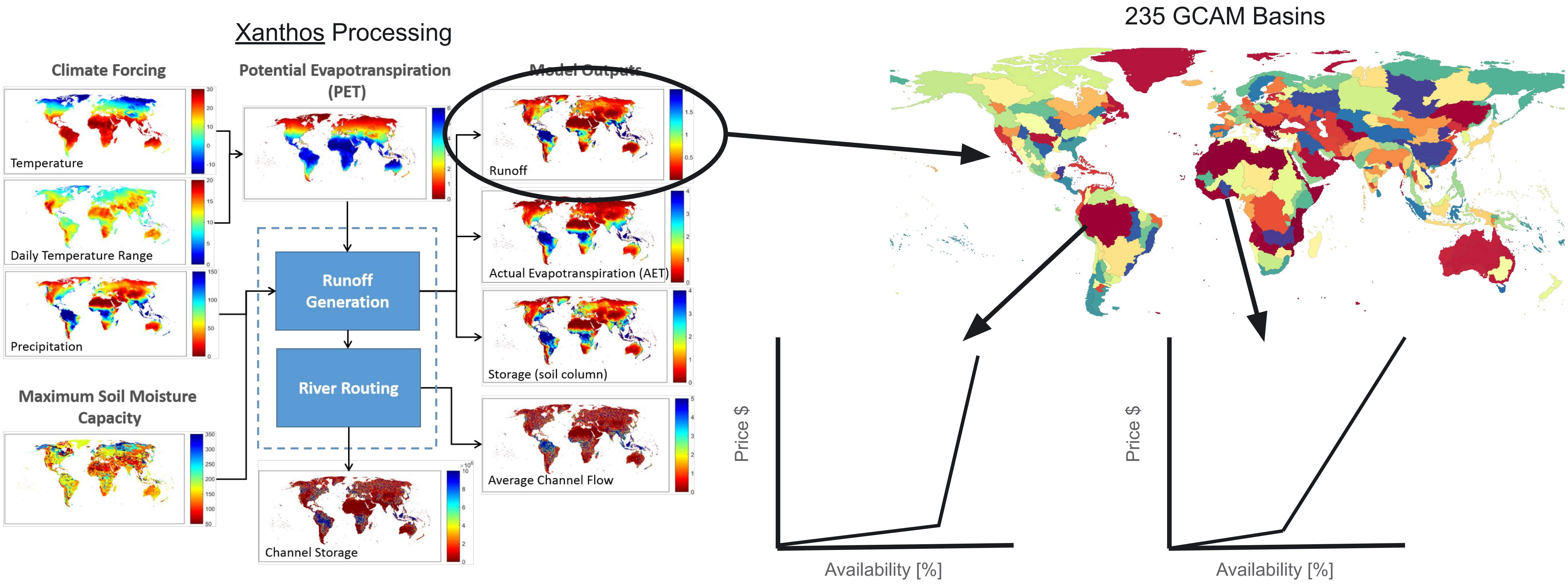
Surface Water Supply and Cost Curves in GCAM



1. Calculate maximum runoff and accessible water* for each year using Xanthos and 1970-2015 WATCH data
2. Aggregate 0.5º gridded data to 5-year moving averages at GCAM basin scale.
3A. For basins with no historical nonrenewable groundwater depletion find the accessible percentage of maximum runoff (accessible/runoff) ***cost curve inflection point***
3B. For basins with historical nonrenewable groundwater extraction, back calculate accessible portion by $\frac{(Demands - Depletion)}{runoff}$ averaged over historical years ***cost curve inflection point***
4. Set initial supply grades (0%, accessible percent, 100%) and cost grades (~0, 0.001, 10), then interpolate for 20 total grades

Groundwater Supply and Cost Curves in GCAM

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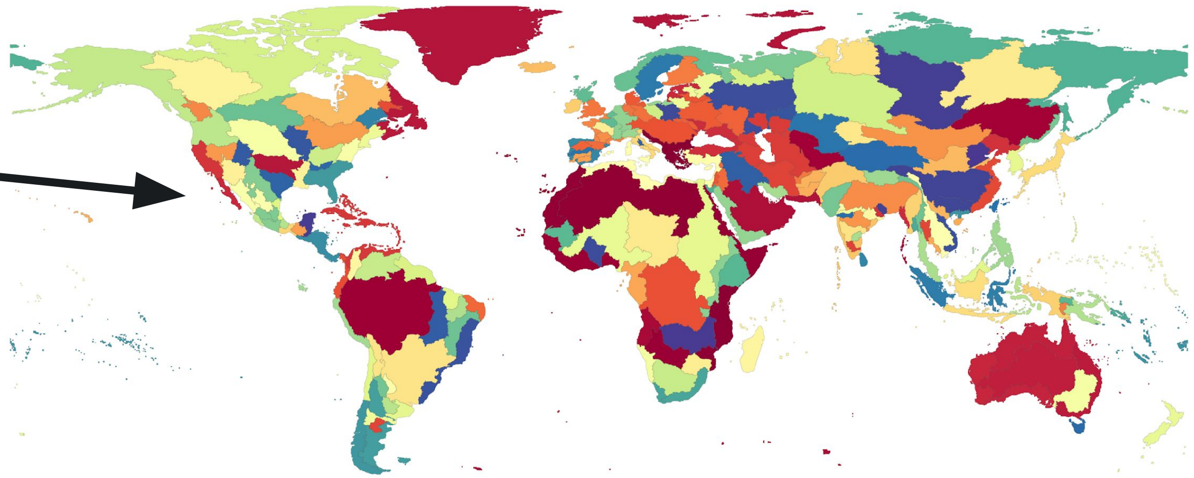
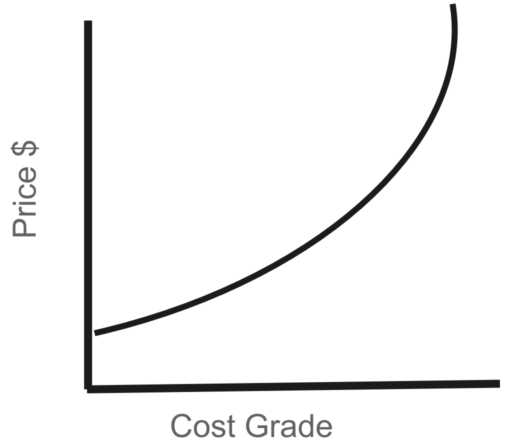
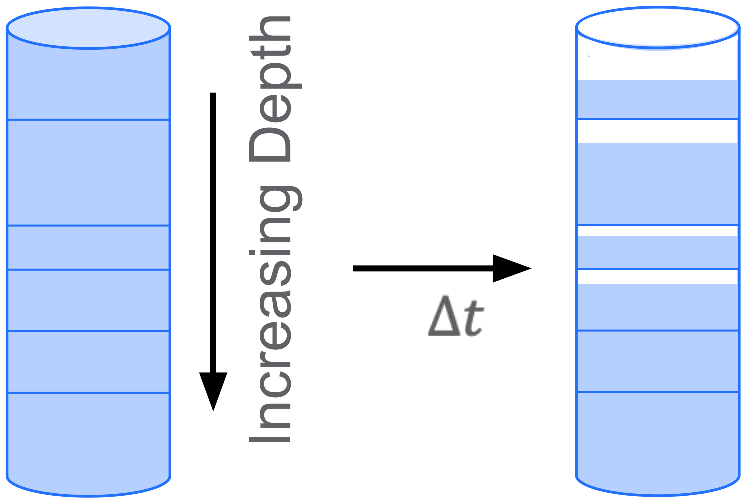
Superwell

- Derived unit cost of groundwater extraction over time at 50km grid cells
- Estimates of groundwater availability from previous studies on porosity, depth-to-groundwater, and aquifer thickness in addition to WHYMAP
- Constrained to only allow for 25% use of all physical water estimated in aquifer
- Calculations within require an assumption of confined aquifer, however results assumed to be from unconfined aquifer







1. Aggregate unit costs from Superwell 50km grid to GCAM basin scale and transform into 24 unique cost grades
2. Historical groundwater depletion from WaterGap is placed into grade_hist which is pulled during historical calibration
3. Added to GCAM as a subresource with price interactions with renewable water cost curves.

Surface Water and Groundwater Price Interaction

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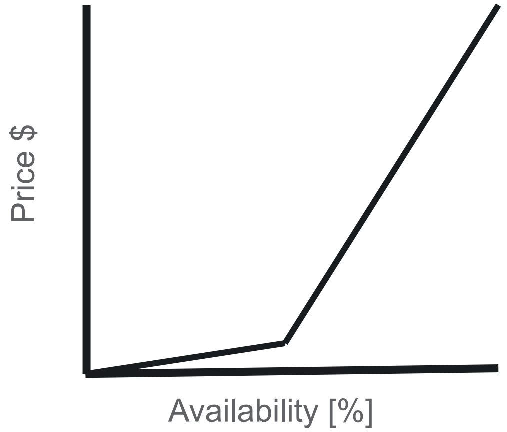
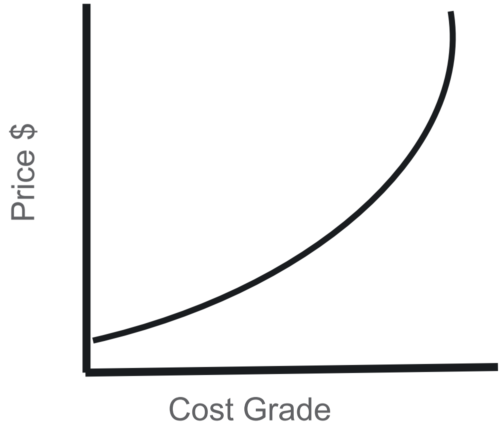
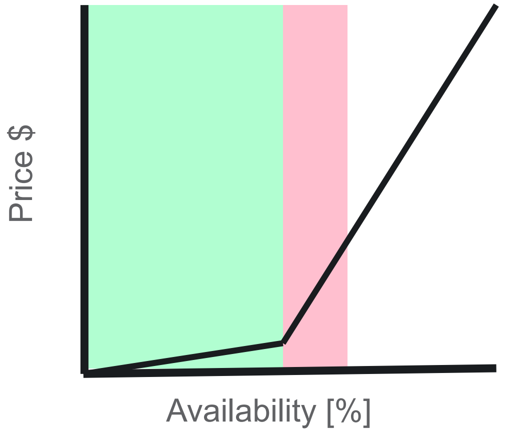
Renewable Cost Curve
Basin A

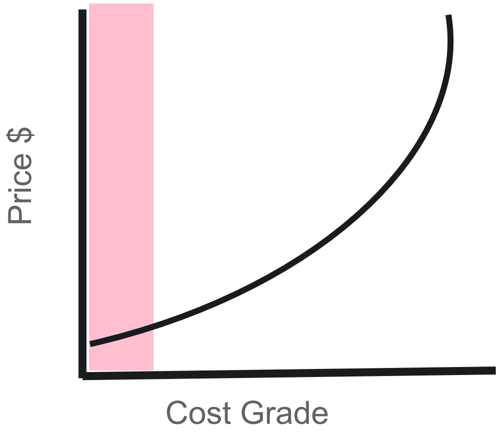


Groundwater Cost Curve
Basin A



1. Water withdrawals come from cheap renewable sources first.
2. If demands exceed the accessible portion in any given timestep, a price interaction between groundwater and renewable water occurs where water is drawn from the cheaper source first.





Surface Water and Groundwater Price Interaction

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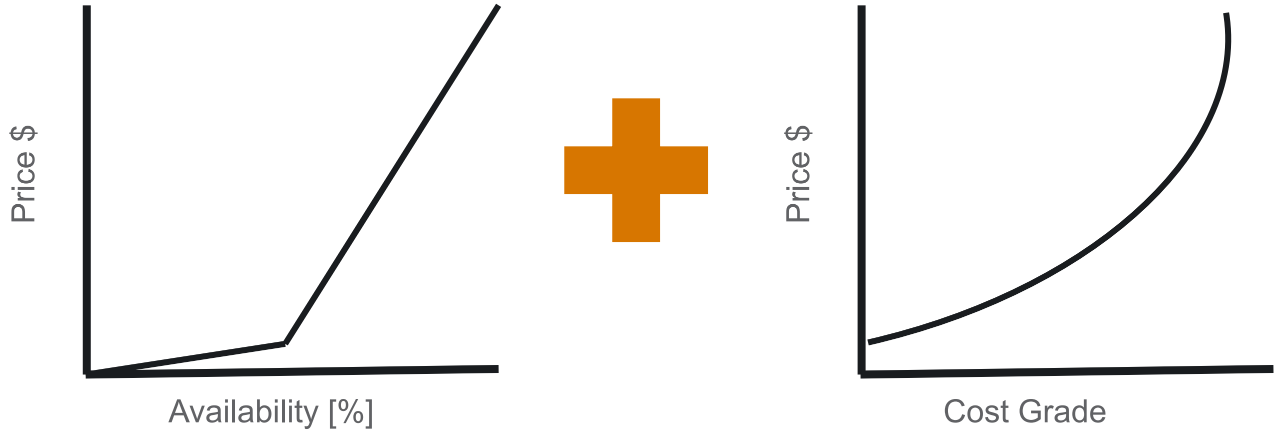
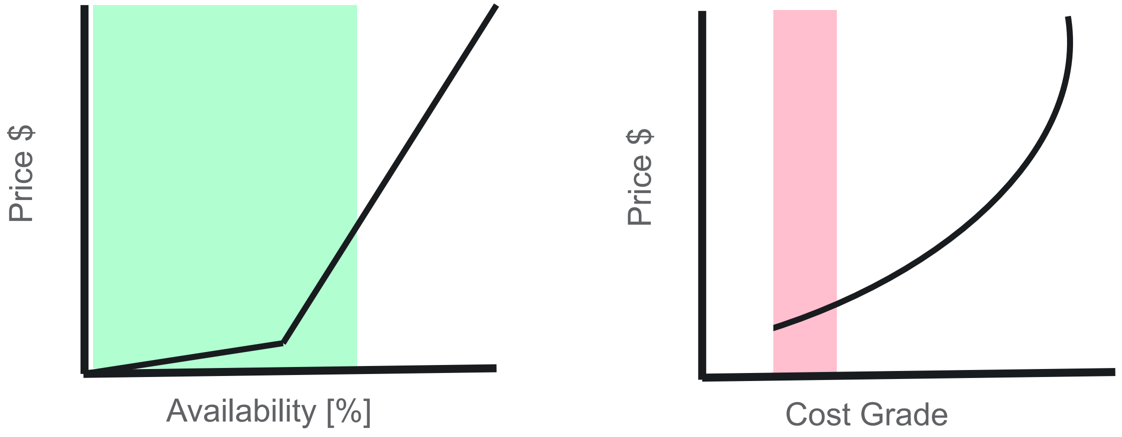
Renewable cost curve
Basin A

Groundwater cost curve
Basin A





1. Water withdrawals come from cheap renewable sources first.
2. If demands exceed the accessible portion in any given timestep, a price interaction between groundwater and renewable water occurs where water is drawn from the cheaper source first.
3. As groundwater is exhausted in low-cost grades, the point of interaction between renewable and groundwater is pushed to higher prices
4. More water than is deemed accessible must be pulled in order to start the price interaction with groundwater

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Sectoral Water Demands in GCAM

- Total Water Use
  - Non-Agricultural Water Use
    - Domestic
    - Electricity Generation
      - Hydropower
      - Wind
      - PV
      - CSP
      - Geothermal
      - Nuclear
      - Biomass (+CCS)
      - Oil (+CCS)
      - Gas (+CCS)
      - Coal (+CCS)
        - Once-Through
        - Dry Cooling
        - Cooling Ponds
        - Wet Towers
    - Primary Energy
      - Coal
      - Natural Gas
      - Conventional Oil
      - Unconventional Oil
      - Uranium
    - Manufacturing
  - Agricultural Water Use
    - Irrigation
      - Corn
      - FiberCrop
      - FodderGrass
      - FodderHerb
      - Fruits
      - Legumes
      - MiscCrop
      - NutsSeeds
      - OilCrop
      - OilPalm
      - OtherGrain
      - Rice
      - RootTuber
      - Soybean
      - SugarCrop
      - Vegetables
      - Wheat
      - Biomas
    - Livestock
      - Beef
      - Dairy
      - Pork
      - Poultry
      - SheepGoat

Virtual Water within GCAM

- Ag production is separated into Irrigated (IRR) or Rainfed (RFD) to calculate trade and virtual water trade at the basin level, *b*, for crop *c*.
  - As demand is calculated at regional scales, proportionate values of production and water are used to downscale to basin level

- Groundwater contributions to virtual water trade are calculated based on the proportion of nonrenewable groundwater depletion, *GWD to* blue water withdrawals, *BWW*, within the specified basin

Virtual Water Trade

$$VBE_{b,c}(t) = BWC_{b,c}(t) * \left(\frac{E_{b,c,IRR}(t)}{P_{b,c,IRR}(t)}\right)$$

$$VGE_{b,c}(t) = GWC_{b,c}(t) * \left(\frac{E_{b,c,RFD}(t)}{P_{b,c,RFD}(t)}\right)$$

Virtual Groundwater Trade

$$VGWE_{b,c}(t) = VBE_{b,c}(t) * \frac{GWD_b(t)}{BWW_b(t)}$$

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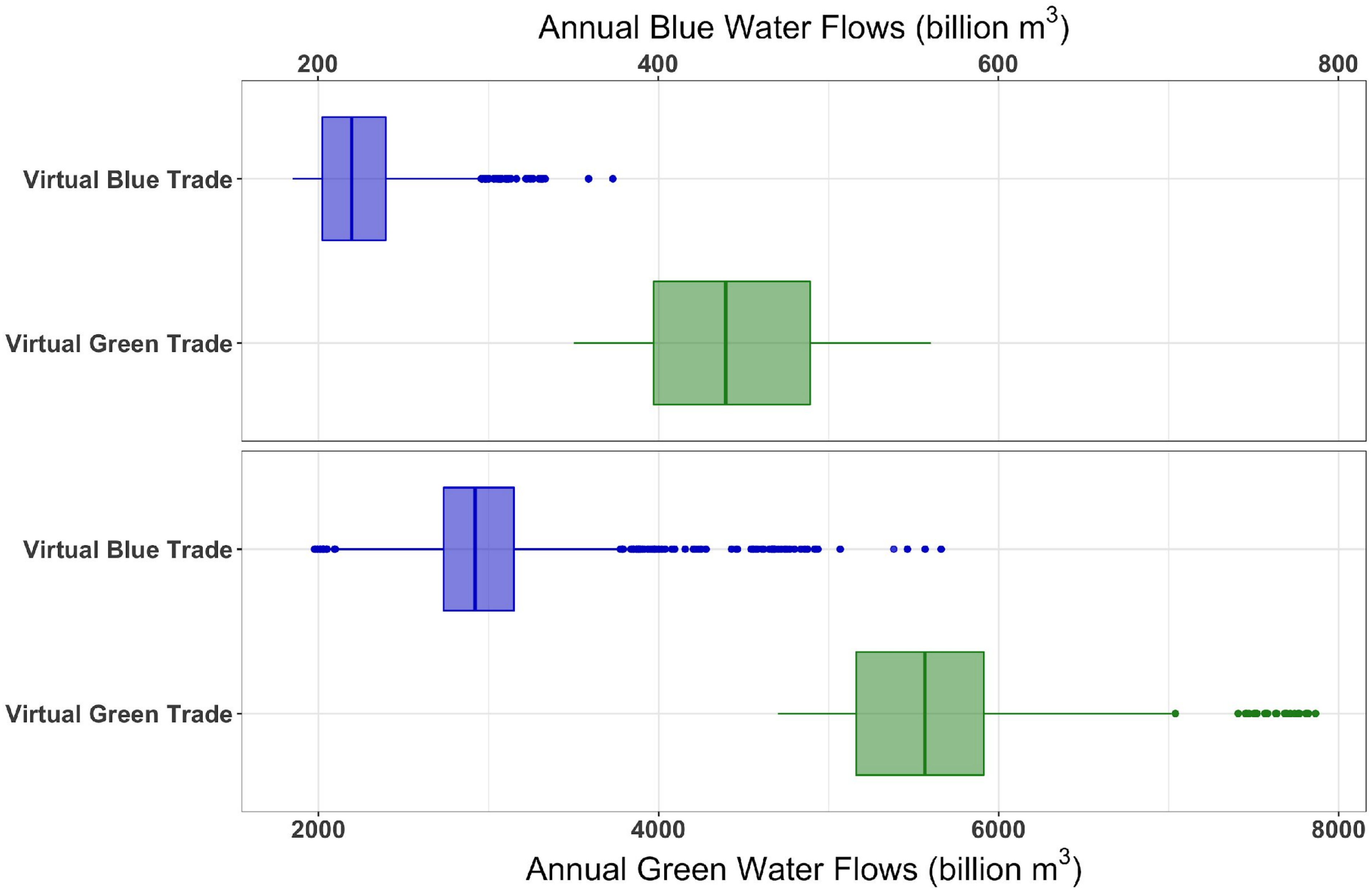
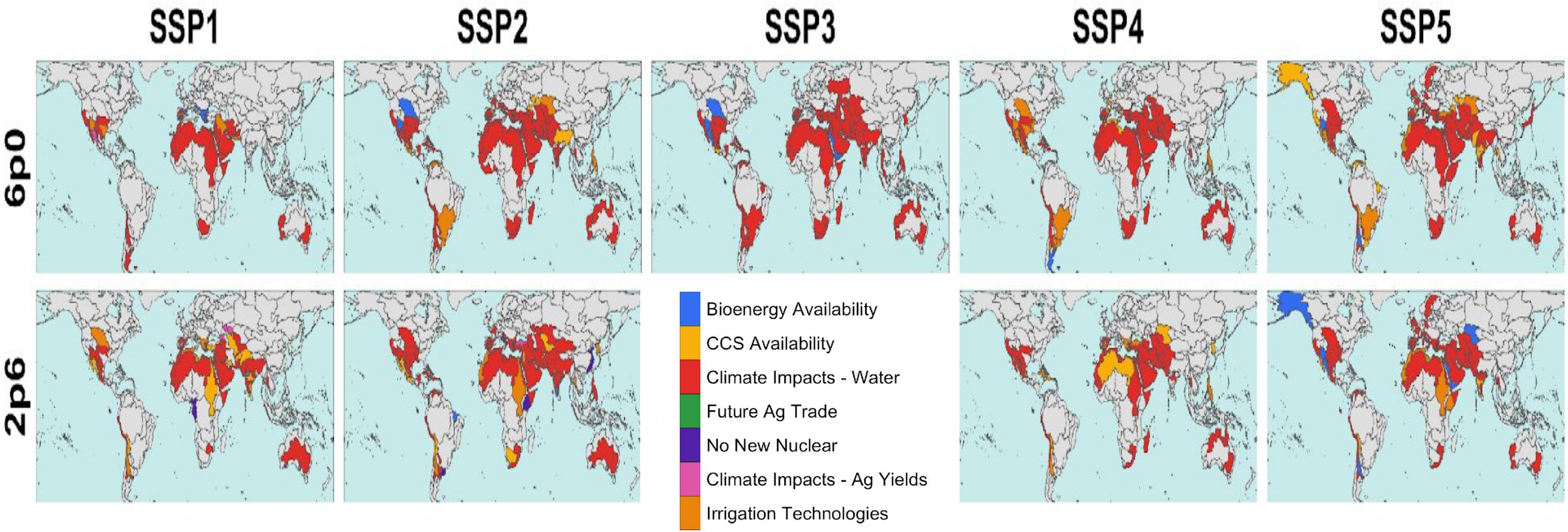
Future Virtual Water Trade Projections



2050

2100

Main Drivers of Nonrenewable Groundwater Withdrawals (2100)



Mean Global Electricity Generation