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DEEP DIVE FOUR: **Decarbonization Impacts on Energy and Economic Equity**

Hosted by: Stephanie Waldhoff
Panelists: Brian O'Neill, Ying Zhang, Sumitrra Ganguli, and Stefan Rose

August 7, 2023

PNNL

Motivation

- How will consumers' energy security be impacted by a transition to a net-zero emissions economy?
- What types of jobs will be created or lost? Where will those jobs be located?
- What are the implications for consumers' incomes?
- How will disadvantaged communities be affected?

This research was supported by the Grid Operations, Decarbonization, Environmental and Energy Equity Platform (GODEEEP) Investment, under the Laboratory Directed Research and Development (LDRD) Program at Pacific Northwest National Laboratory (PNNL).

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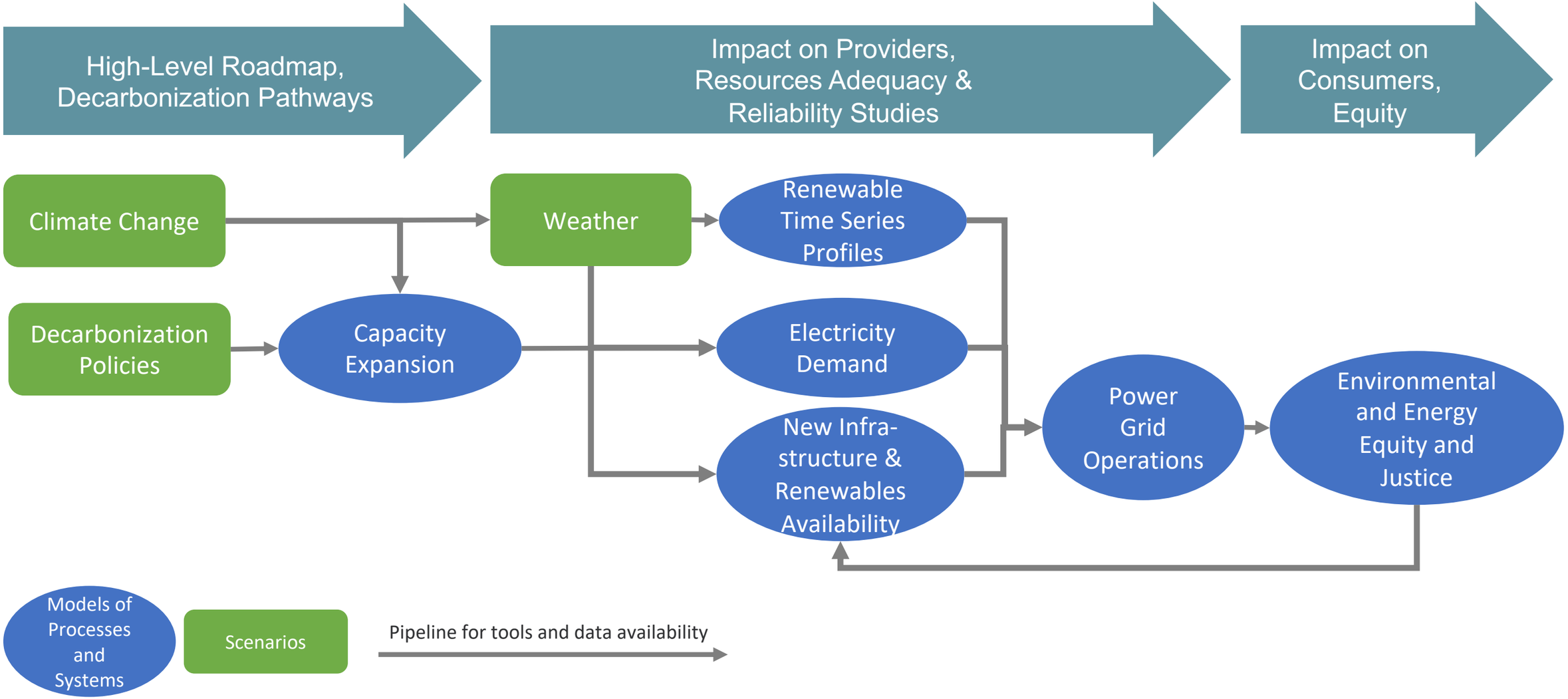
GODEEEP framework



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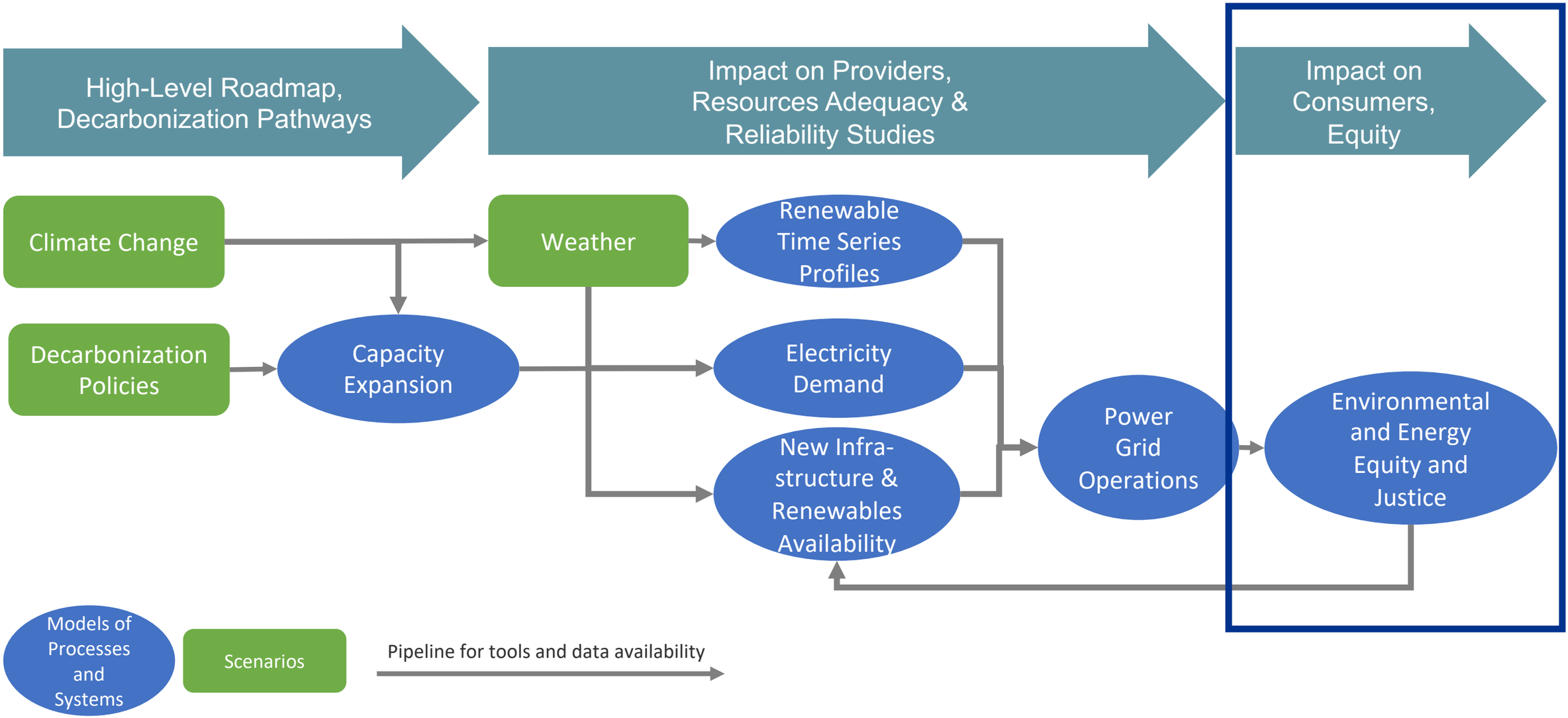
GODEEEP framework



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GODEEEP equity research: telescoping analysis to cross scales

State → County → Census Block

GODEEEP equity research: multiple metrics of energy & economic security

State → County → Census Block

Jobs

Income

Disadvantaged Community Status

Residential Energy Security: Income Deciles

Models of Processes and Systems

Scenarios

Outcomes

Pipeline for tools and data availability

GODEEEP equity research: novel inputs to scenario research

State

County

Census Block

Income Distribution: Income Deciles

Population and Income

Jobs

Income

Residential Energy Security: Income Deciles

Disadvantaged Community Status

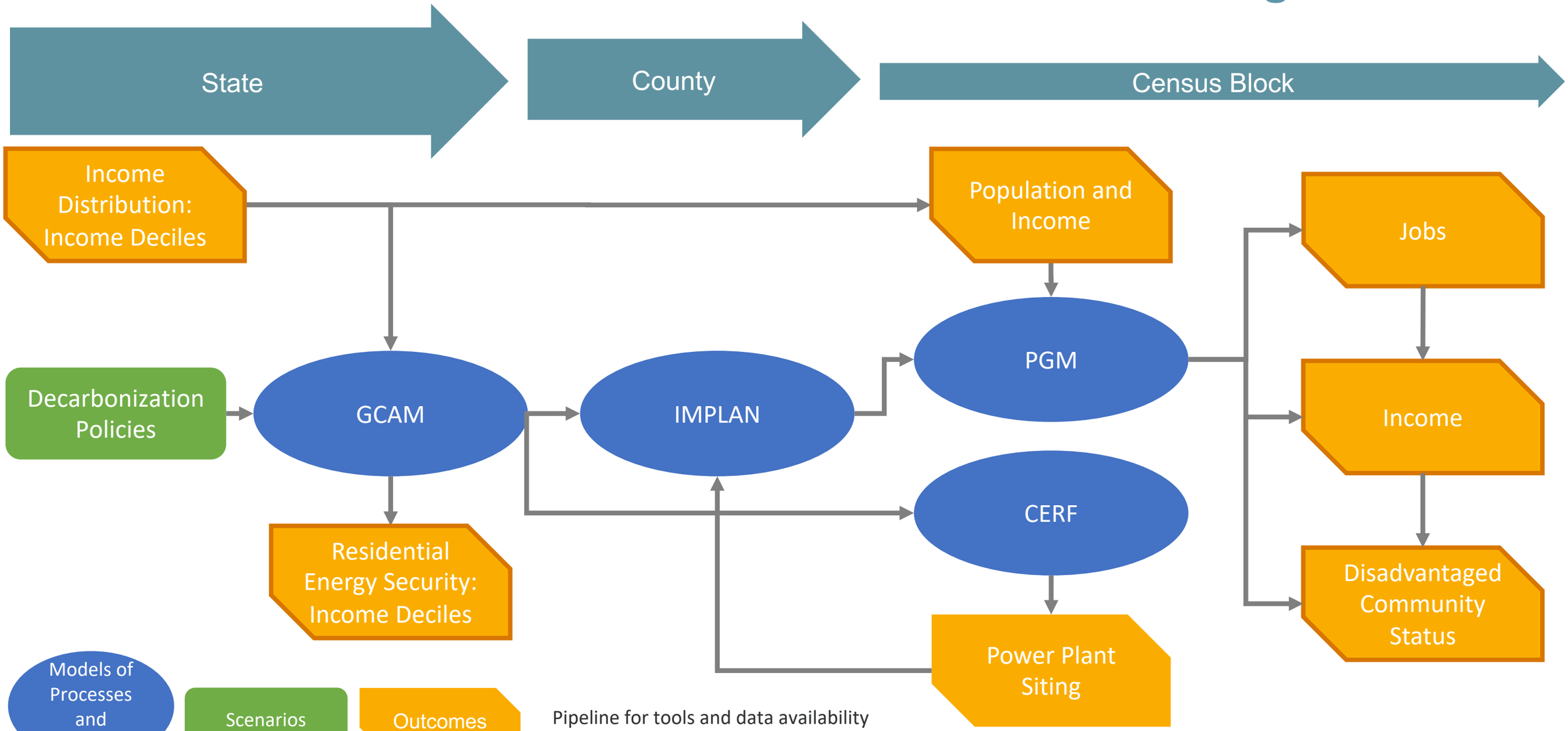
Models of Processes and Systems

Scenarios

Outcomes

Pipeline for tools and data availability

GODEEEP equity research: fully consistent modeling framework



Visualizing and interacting with GODEEP results

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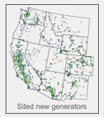
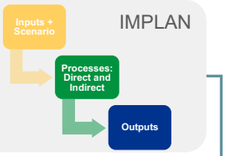
GCAM-USA

CERF



IMPLAN



Satiation gap* in heating service: 2045, Decile 1

Under the Net Zero scenario, increases in electricity prices decrease heating consumption for the lowest income group

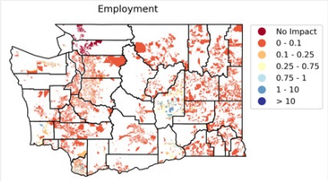
Reference

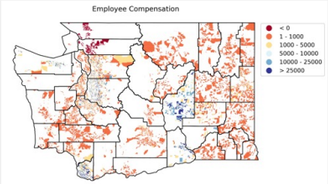
Net Zero w/o CCS - Reference

** Difference between heating consumption and the "ideal" heating or "satiation" level.*

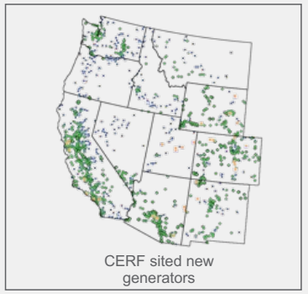
Employment and income changes in Washington State: 2035

Employment and income are impacted by both direct and indirect effects of decarbonization



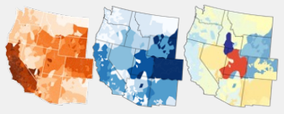


Energy Justice-Visualization and Impact Analysis (EJ-VIA) tool



CERF sited new generators

New climate-sensitive time series GridView results

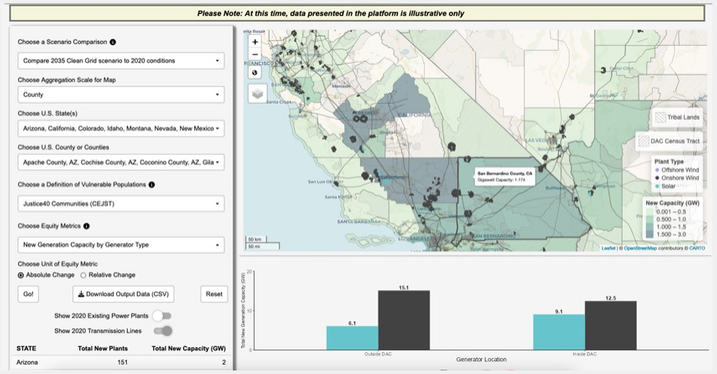


Multiscale

- Region
- State
- DAC census tracts
- Census block

Multi-metric

- Power plant emissions (CO_2, SO_X, NO_X, and PM2.5)
- Power plant capacity and locations (new, operational, and retired)
- Unserved energy
- Wholesale electricity costs



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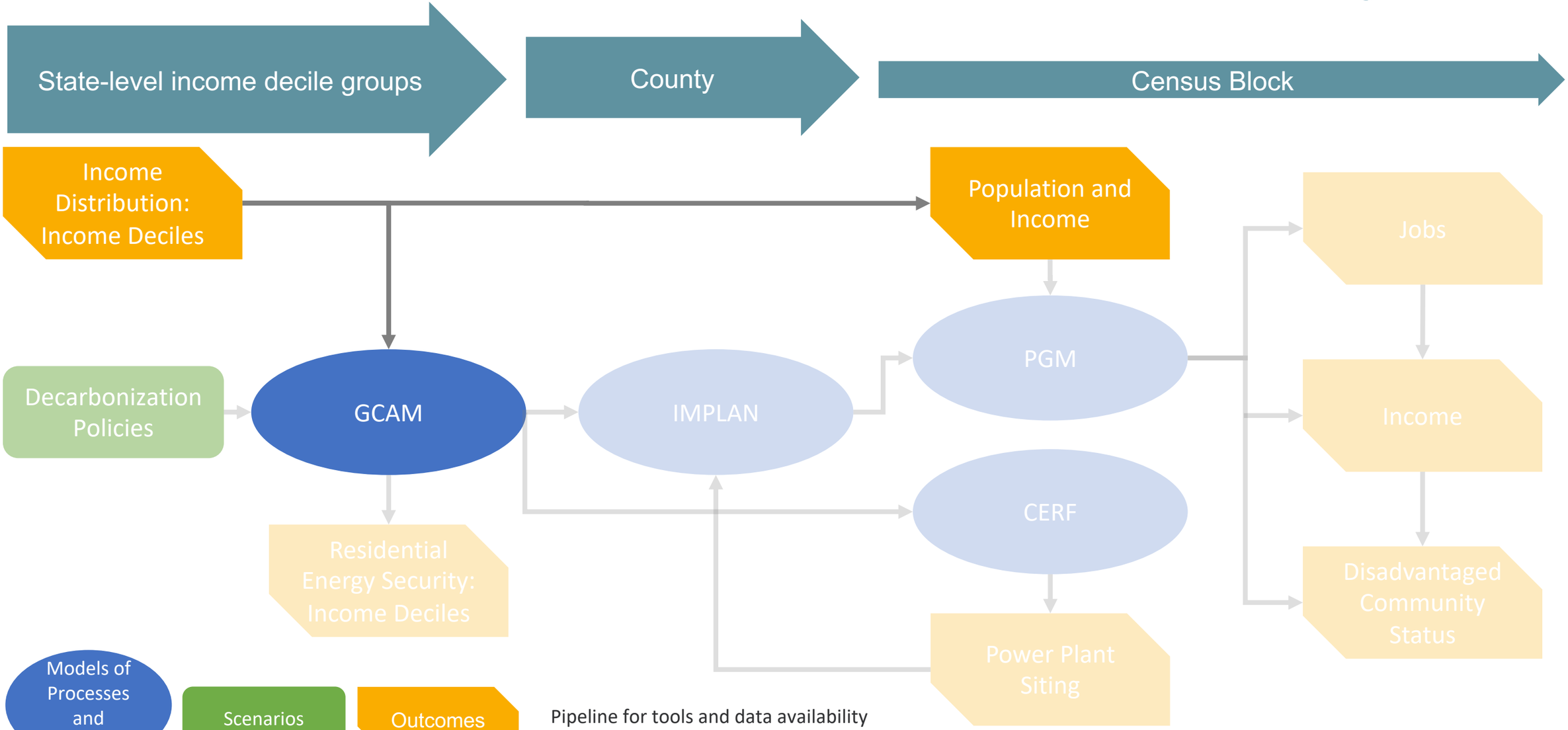
Outline

- Socioeconomic projections – Brian O'Neill
- Residential energy security – Ying Zhang
- Jobs, income, and DAC status – Sumitrra Ganguli
- EJ-VIA demonstration – Stefan Rose

Socioeconomic projections



Dimensions of population heterogeneity

Age

Sex

Urban/rural

Race/ethnicity

Income → Our focus

Education

Health status

Etc.

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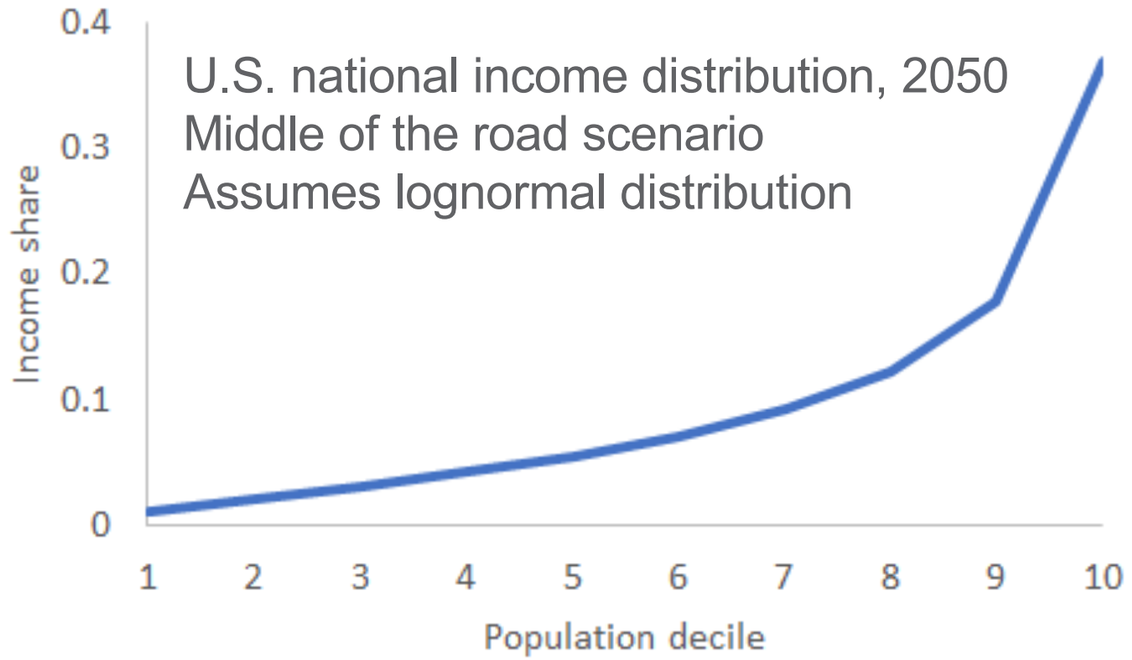
Objectives and challenges

Objective: Define three 21st century socioeconomic scenarios that go beyond the current state-of-the-art in global change modeling to include projections for multiple income groups at the state scale in the United States.



Challenges:

- Projections of income distribution do not exist at the scale of U.S. states
- Currently available projections are primarily at the national scale
- New models and data development are needed

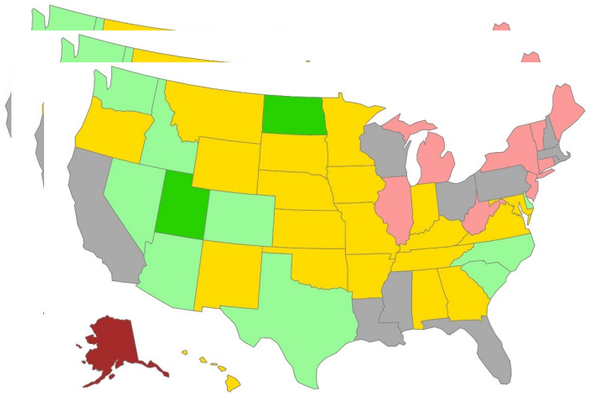
Overall approach

Jiang et al., 2020
(IM3 SFA)

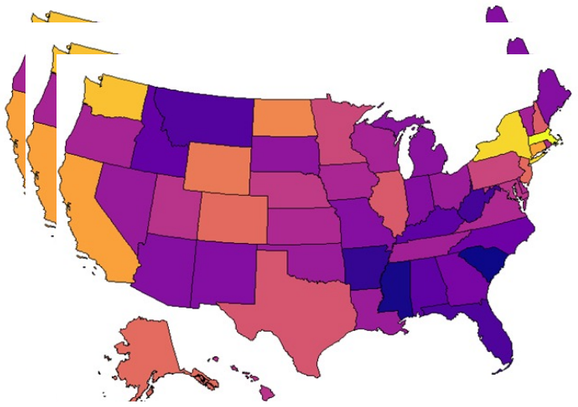
Dellink et al., 2017
DOE (EIA)

Requires:
Data:
Income, taxes
Model:
Changing
income shares

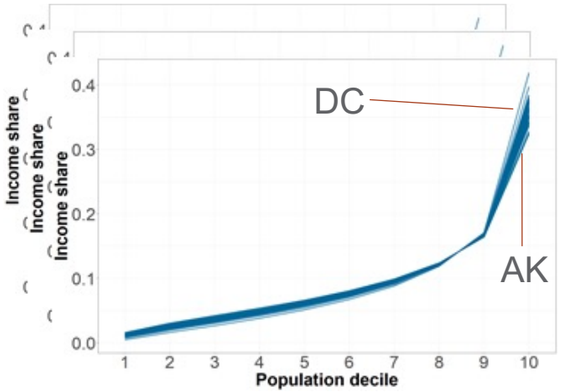
Population by state



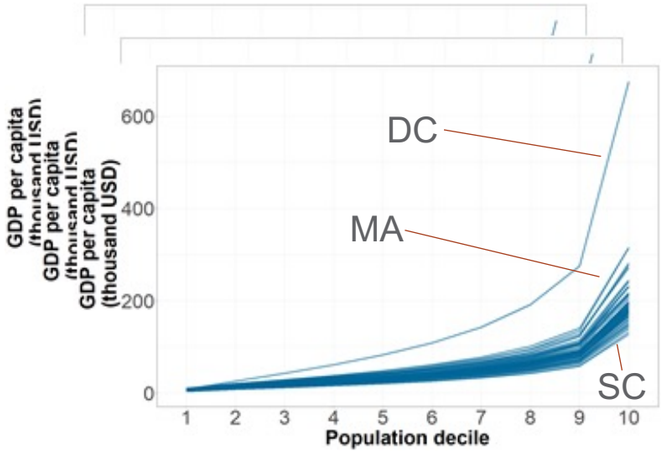
GDP per capita by state



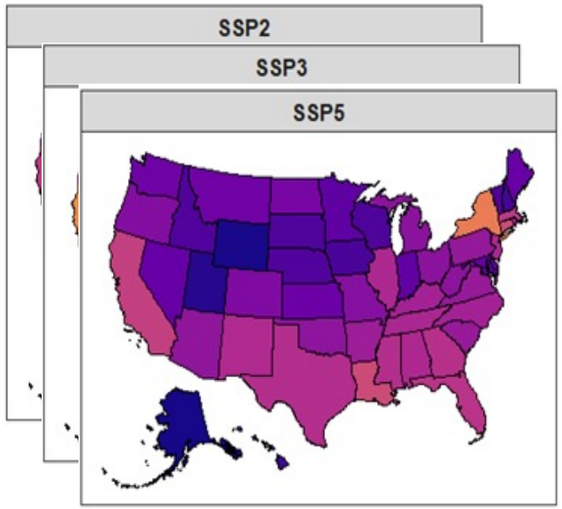
Deciles of income shares by state



Deciles of income by state



Income inequality metrics by state



Approach

Projection model

- Non-parametric approach, fit to national data 1965-2015
- Component weights projected by:
  - a -> Gini coefficient
  - b -> Labor share of income, lagged inequality

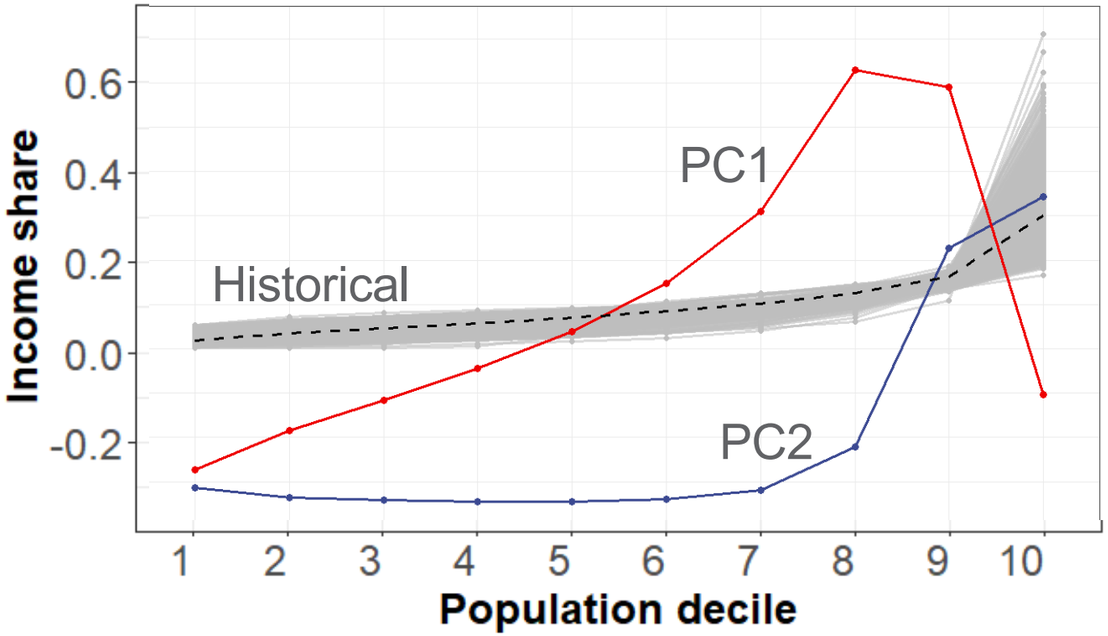
Base year data

- American Community Survey (gross income by quintile)
- Congressional Budget Office (federal tax adjustment)
- Brookings Institution (state tax adjustment)

Validation

Two principal components represent the data

Income distribution (country, year) = a * PC1 + b * PC2



Results – 2050: variations across states and scenarios

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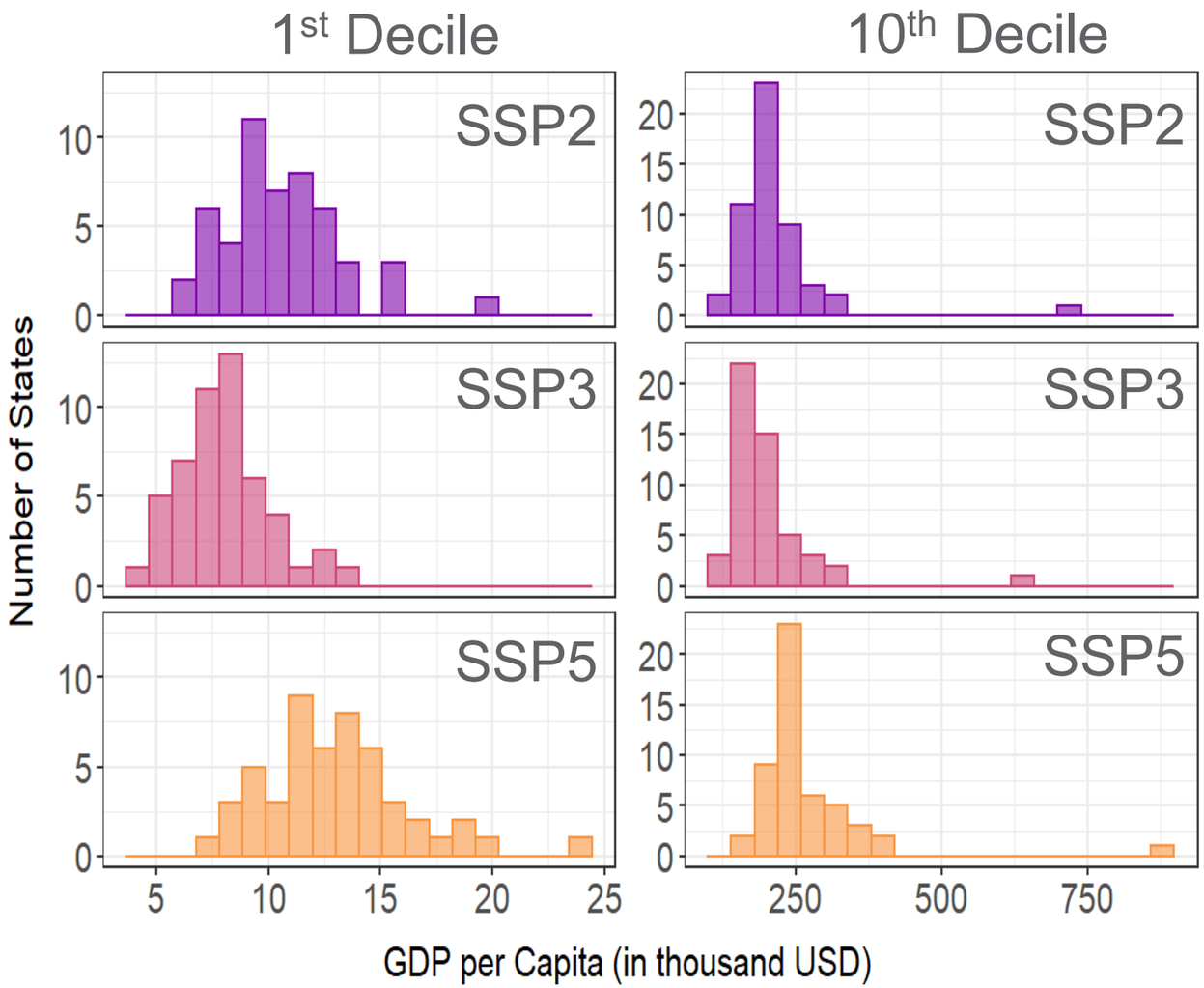
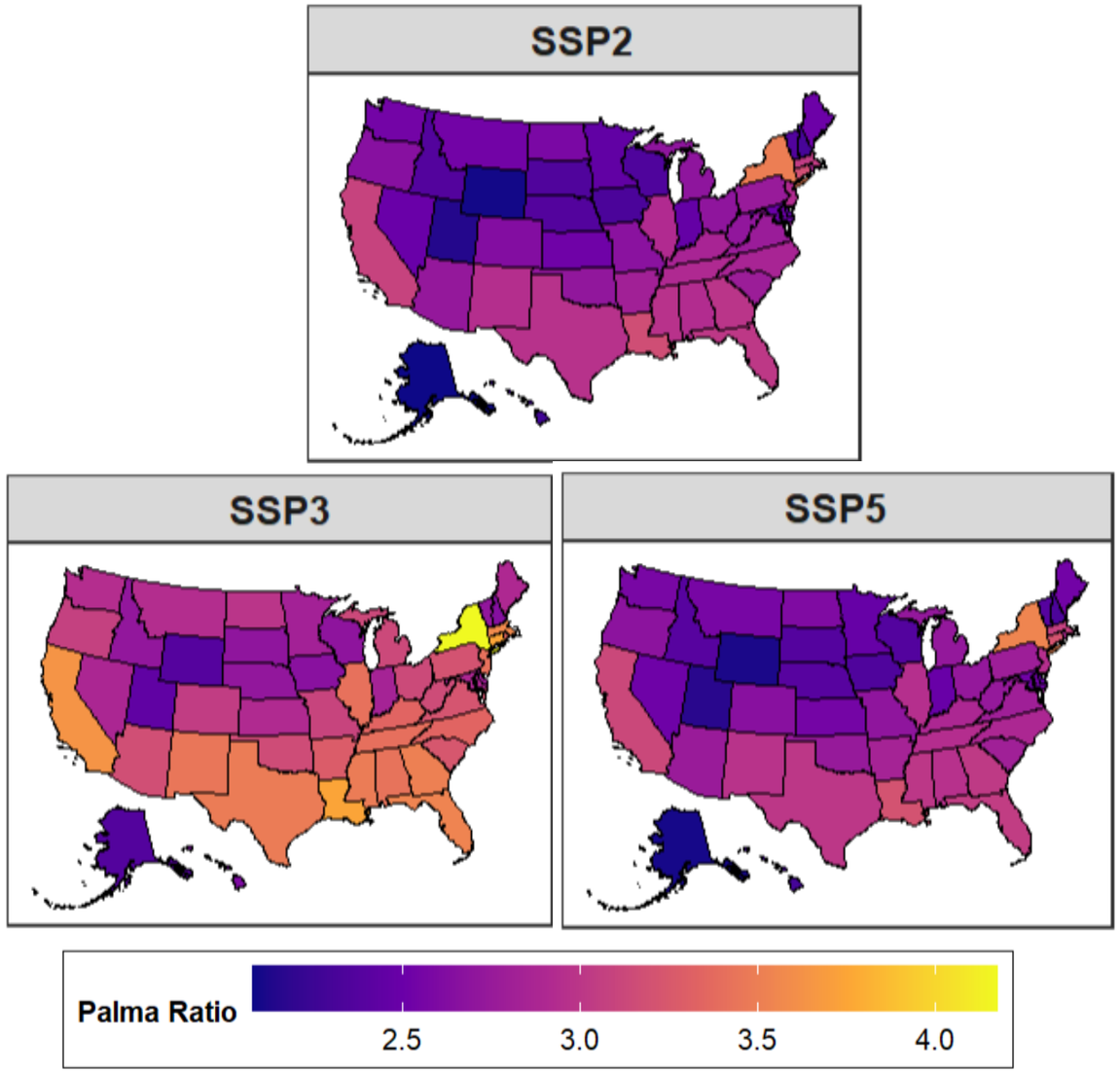
Absolute income levels by state

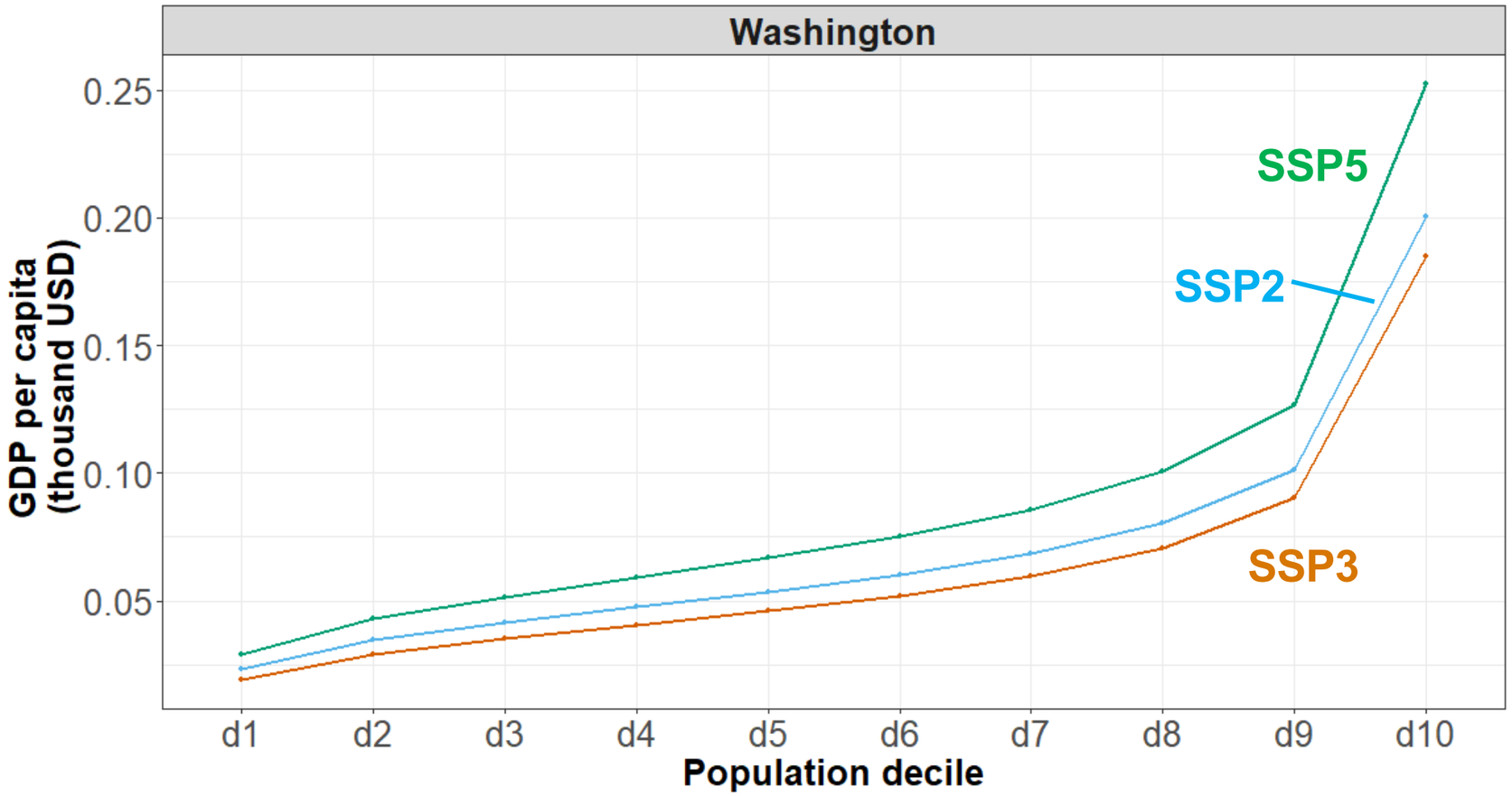


Metric of inequality

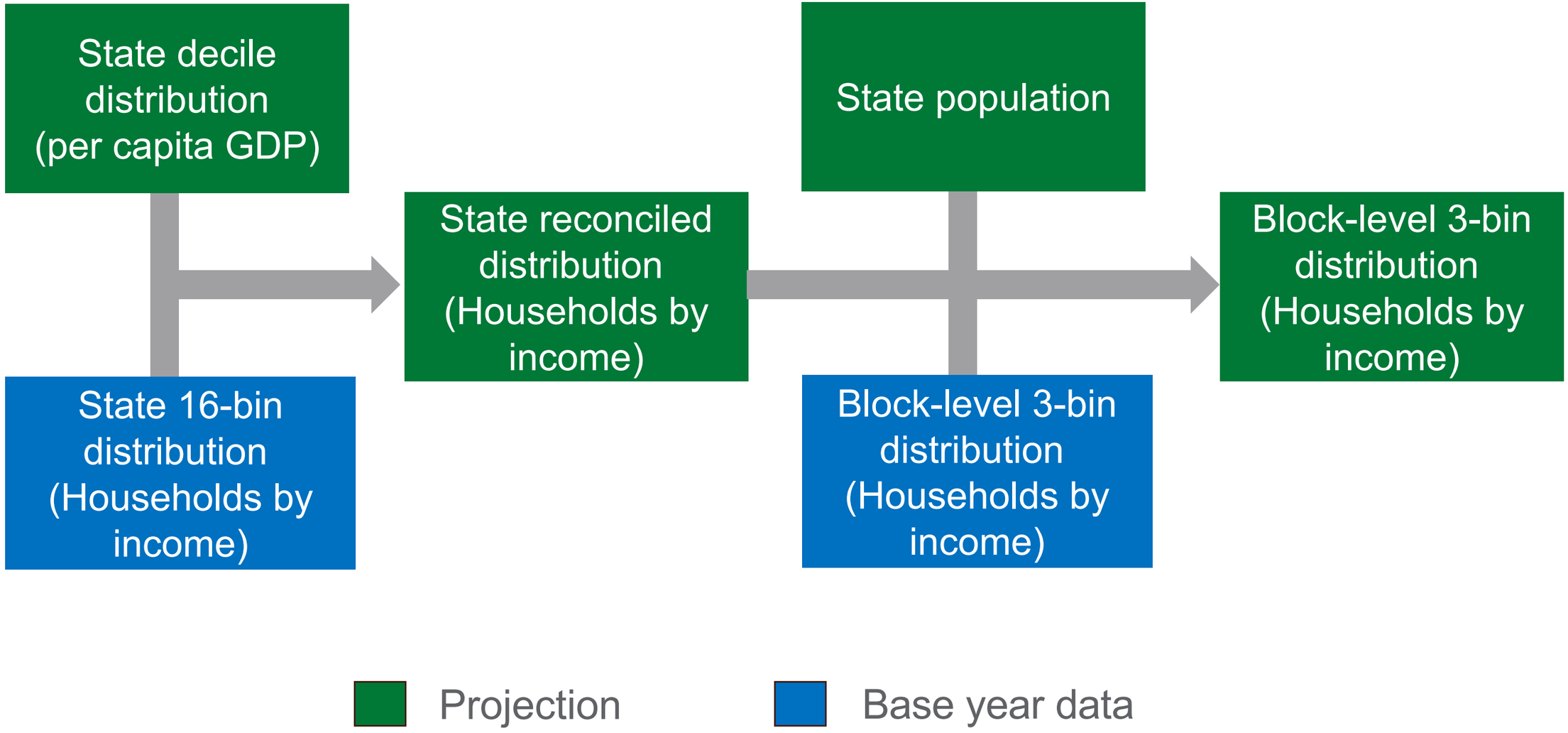
Palma Ratio (D10/(D1-4))



Projected income distribution, Washington – 2050



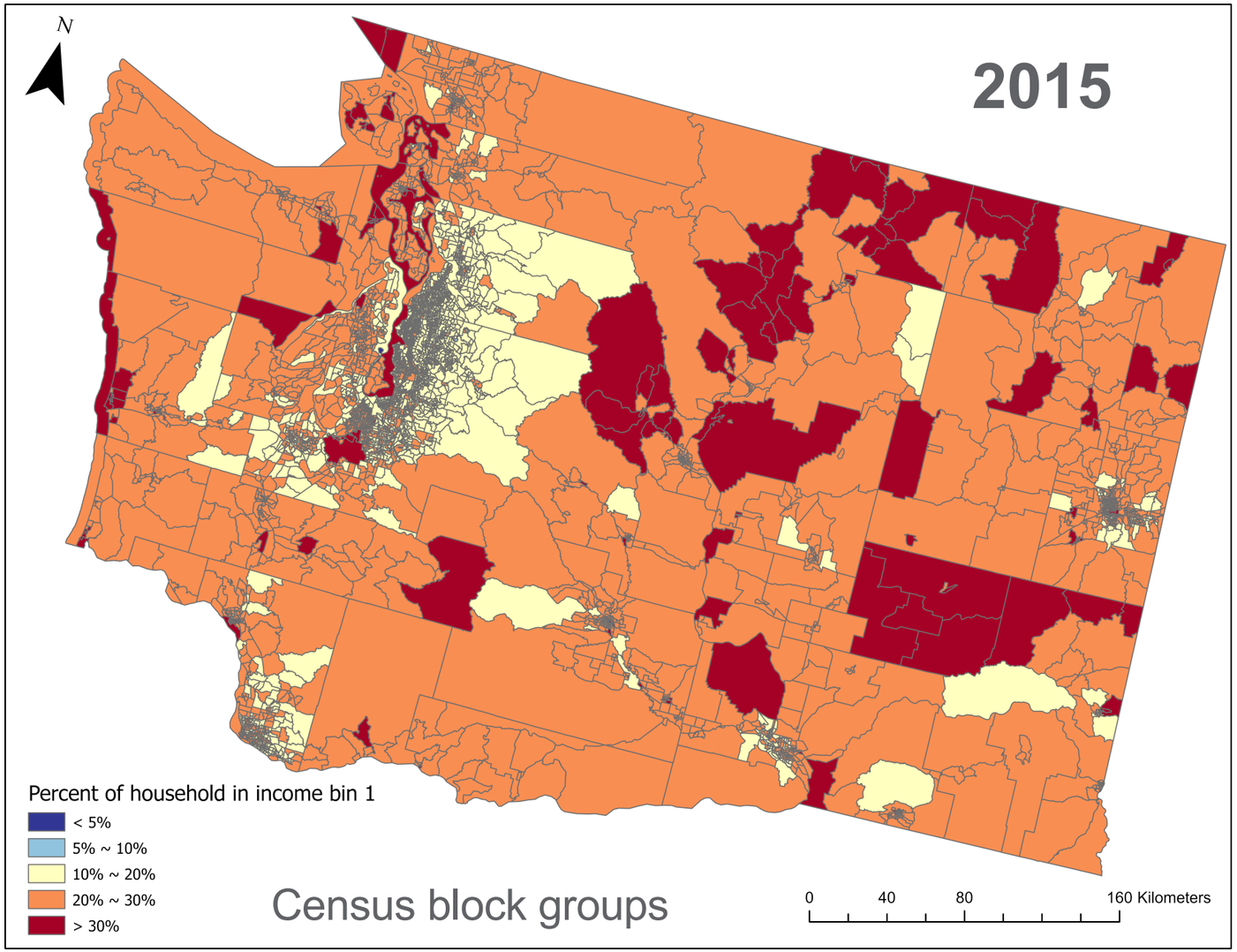
Downscaling Washington income distribution



Downscaling Washington income distribution

Percent of households in lowest income bin (<~$18k/yr)

- < 5%
- 5% ~ 10%
- 10% ~ 20%
- 20% ~ 30%
- > 30%



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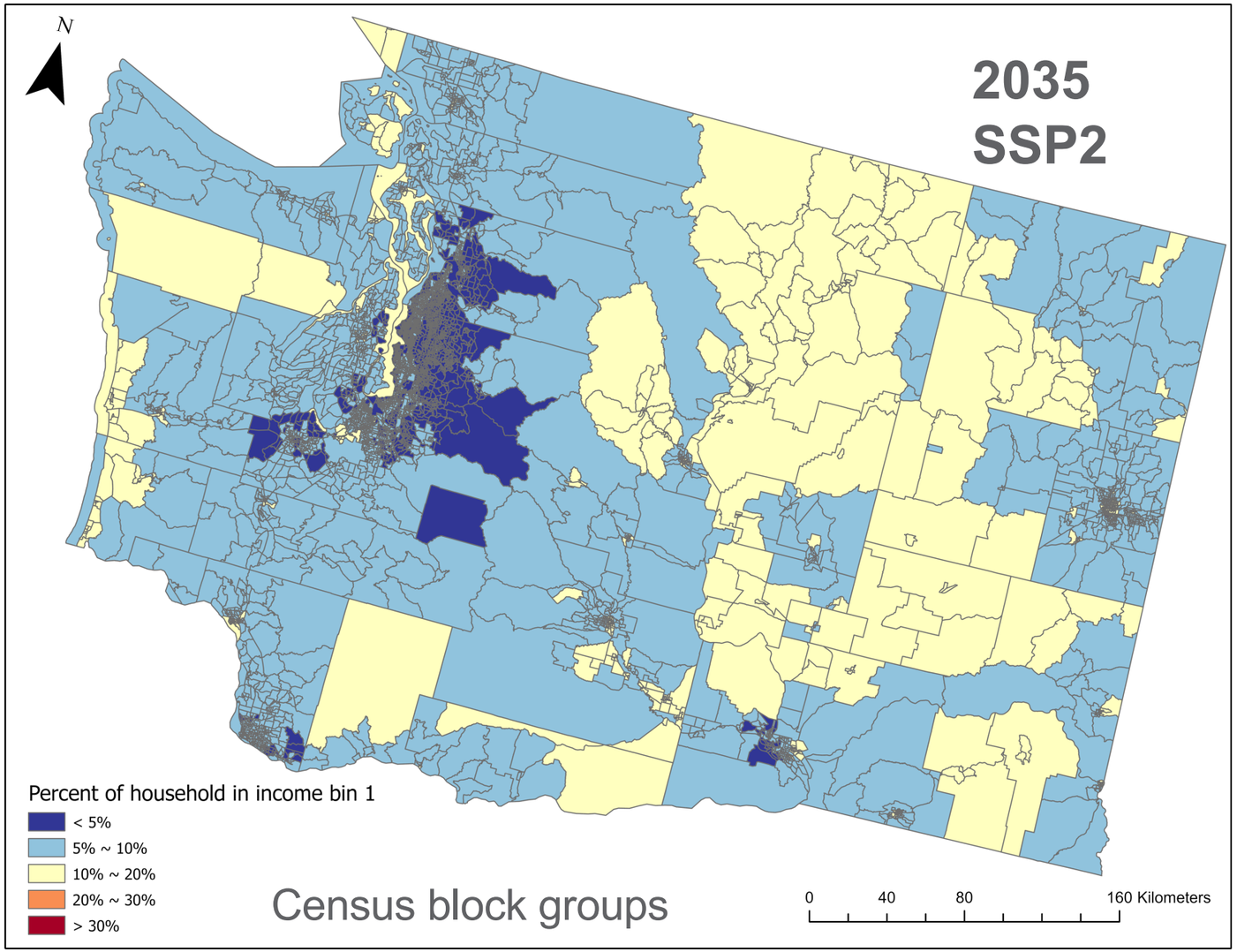

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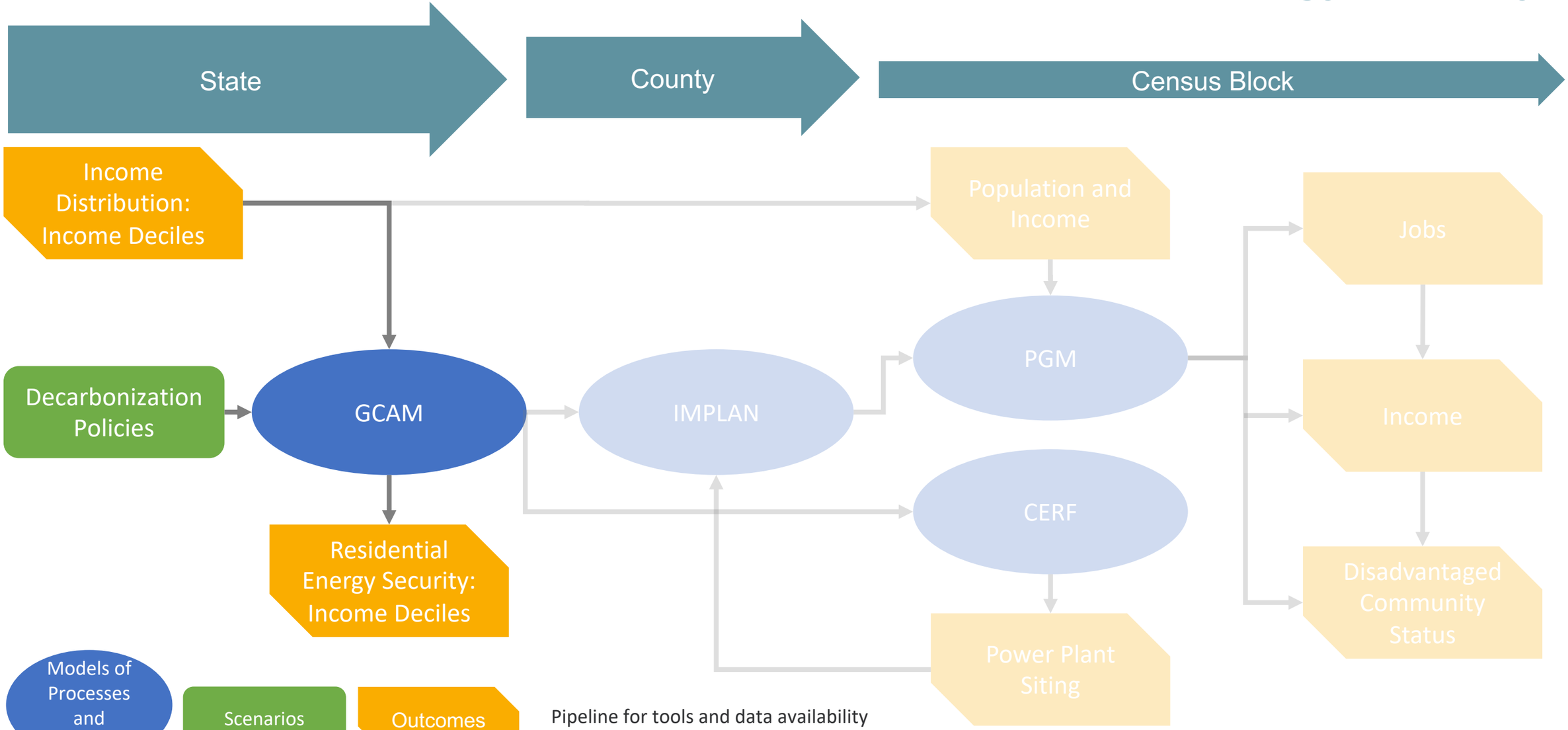
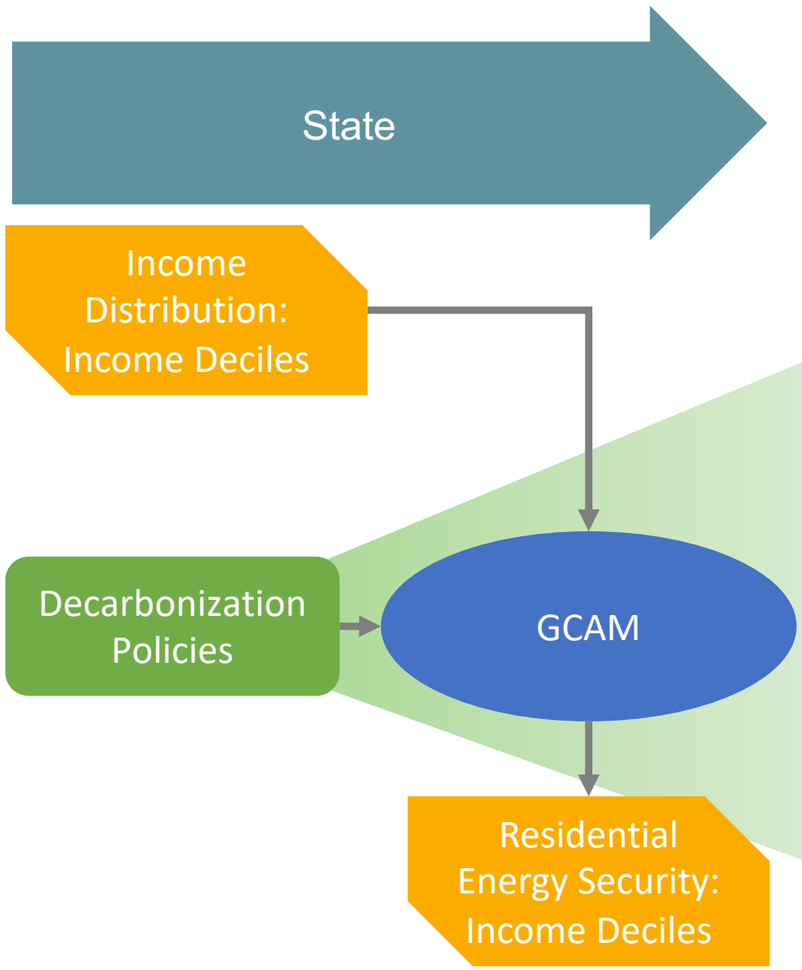
Question and Answer

Residential energy security



Residential energy security



Model Scenarios	Decarbonization Policies
BAU “Business-as-usual”	Existing state-level energy and emission policies
NZ “Net-Zero Policy”	Two national targets: • 50% net-GHG emission reduction relative to 2005 level and net-zero GHG emissions by 2050 • U.S. power grid achieves clean-grid by 2035

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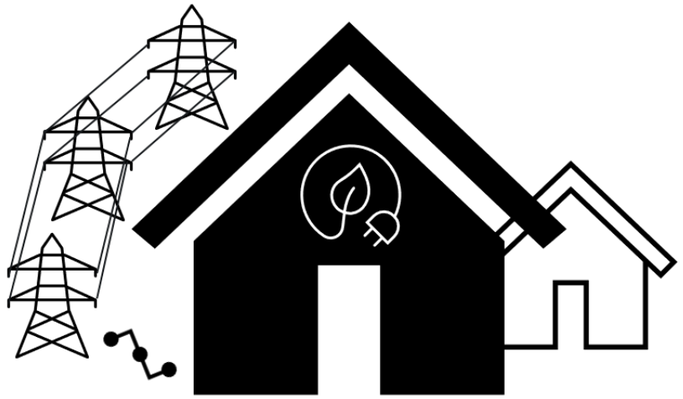
Residential energy security metrics

- Energy Service Consumption
  - Energy service received by consumers to meet their specific energy needs.
- Satiation Gap (a measure of comfort level)
  - Gap to which consumers feel that their energy needs are fully satisfied, and thus, they are no longer seeking additional energy services or improvements.
- Energy Burden
  - Percentage of household income that is spent on residential energy services.



Residential Energy Security

Acceptability	Accessibility
Availability	Affordability

"In 2020, 34 million U.S. households (27% of all U.S. households) reported difficulty paying energy bills or reported that they had kept their home at an unsafe temperature because of energy cost concerns."

– U.S. EIA

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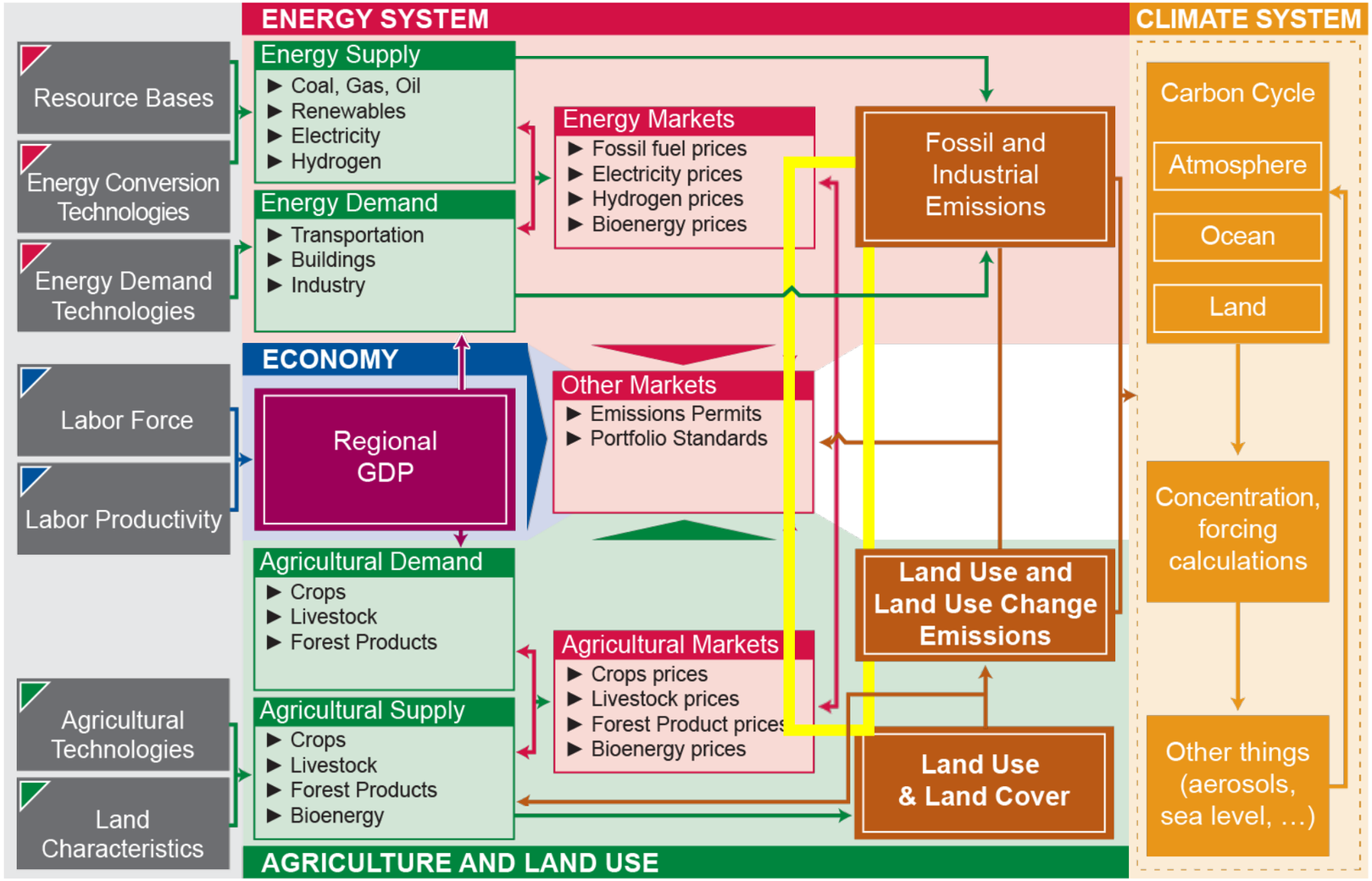
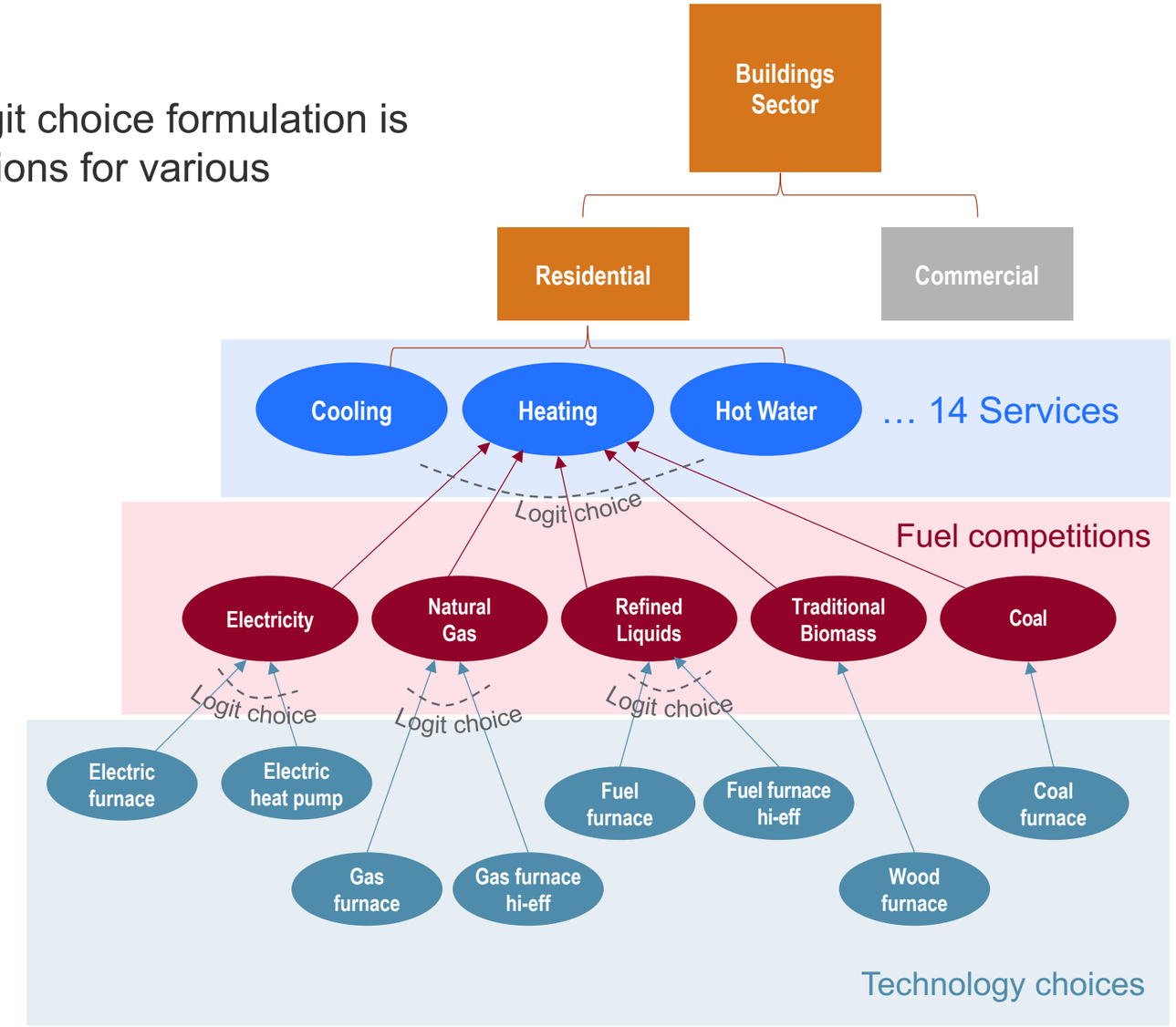
Global Change Analysis Model (GCAM)



- Open-source, well-documented **integrated multi-sector** model, which has evolved and expanded since the 1980s
- The model represents the behavior of and interactions between multiple systems/sectors
- Widely used to study **long-term** implications of various policy **scenarios** on global changes in the energy, land use, agriculture, water, and other related sectors
- **GCAM-USA** operates within GCAM with greater detail in the U.S.'s energy system

GCAM-USA's building sector

- In GCAM-USA, a nested structure based on logit choice formulation is used to represent fuel and technology competitions for various residential and commercial energy services.
- The future evolution of building energy use is shaped by changes in (1) floorspace, (2) the level of building service per unit of floorspace, and (3) fuel and technology choices by consumers.
- The energy consumption is calibrated in the historical period with of technology choice preferences captured in calibration parameters.
- Input assumptions of future technology costs, efficiencies, and lifetimes are based on the EIA Annual Energy Outlook (AEO) for baseline technologies.

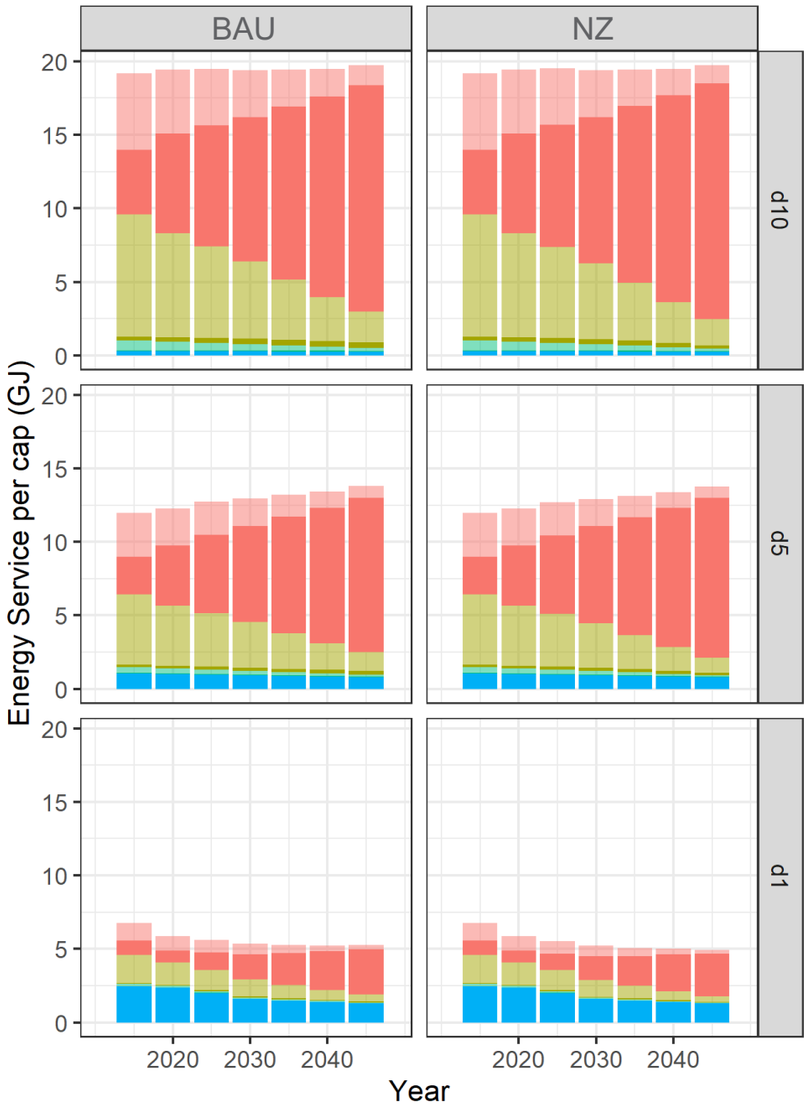


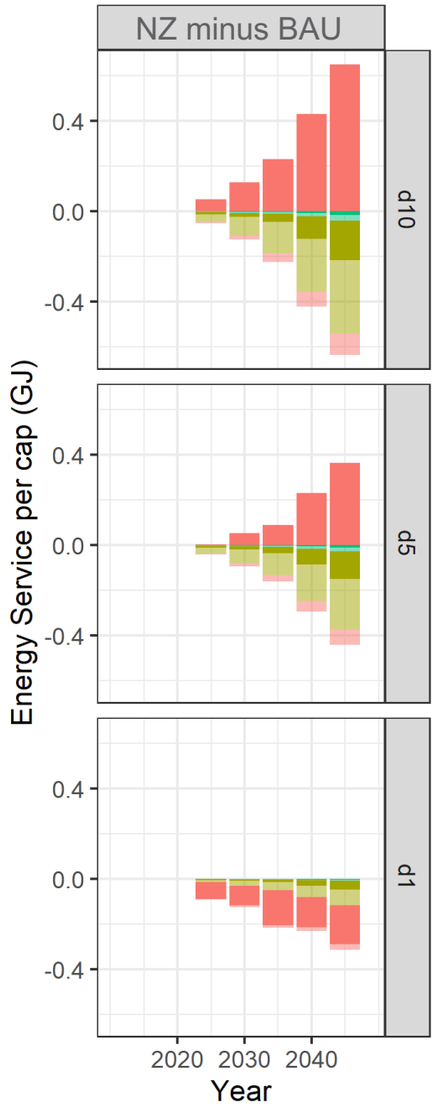
Residential heating service by technology in Washington State

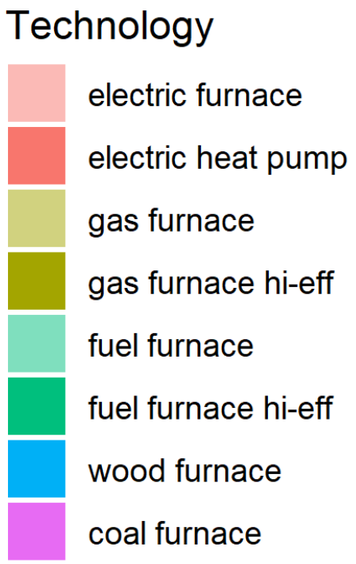
d10
Highest income group

d5
Middle income group

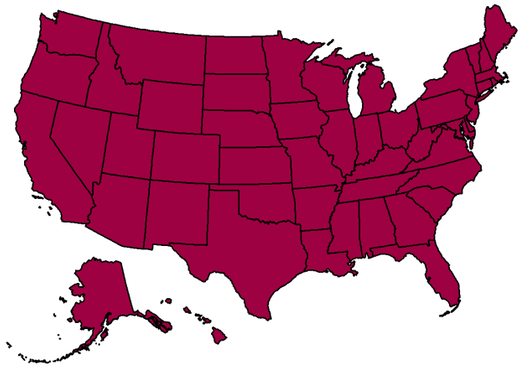
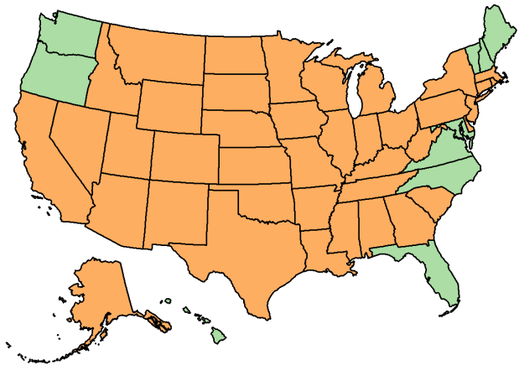
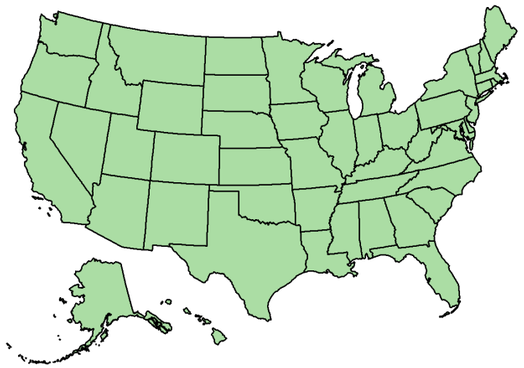
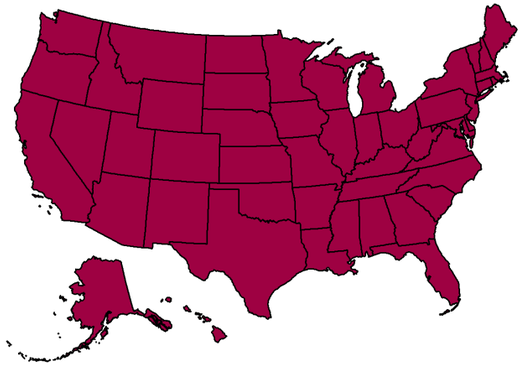
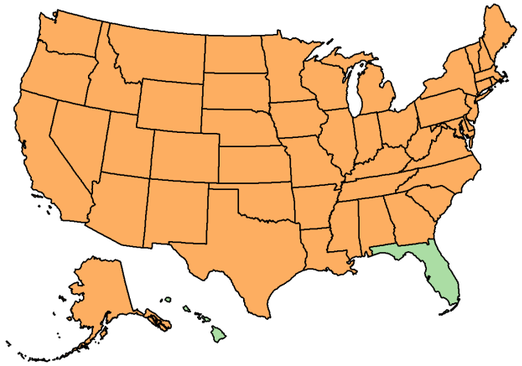
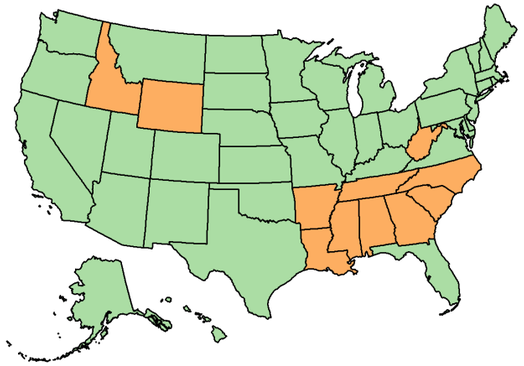
d1
Lowest income group







Satiation gap of residential modern heating service under business as usual

	d1 Lowest income group	d5 Middle income group	d10 Highest income group
BAU (2020)			
BAU (2045)			

"Gap to which consumers feel that their energy needs are fully satisfied, and thus, they are no longer seeking additional energy services or improvements."

Satiation Gap

- < 10% (High Comfort)
- 10% ~ 20% (Moderate Comfort)
- ≥ 20% (Low Comfort)

In 2020, roughly 23% of the U.S. total population fell into the "Low Comfort" category

24% fell into the "Moderate Comfort" category

53% fell into the "High Comfort" category.

Impacts of a net-zero policy on residential modern heating service satiation gap in 2045

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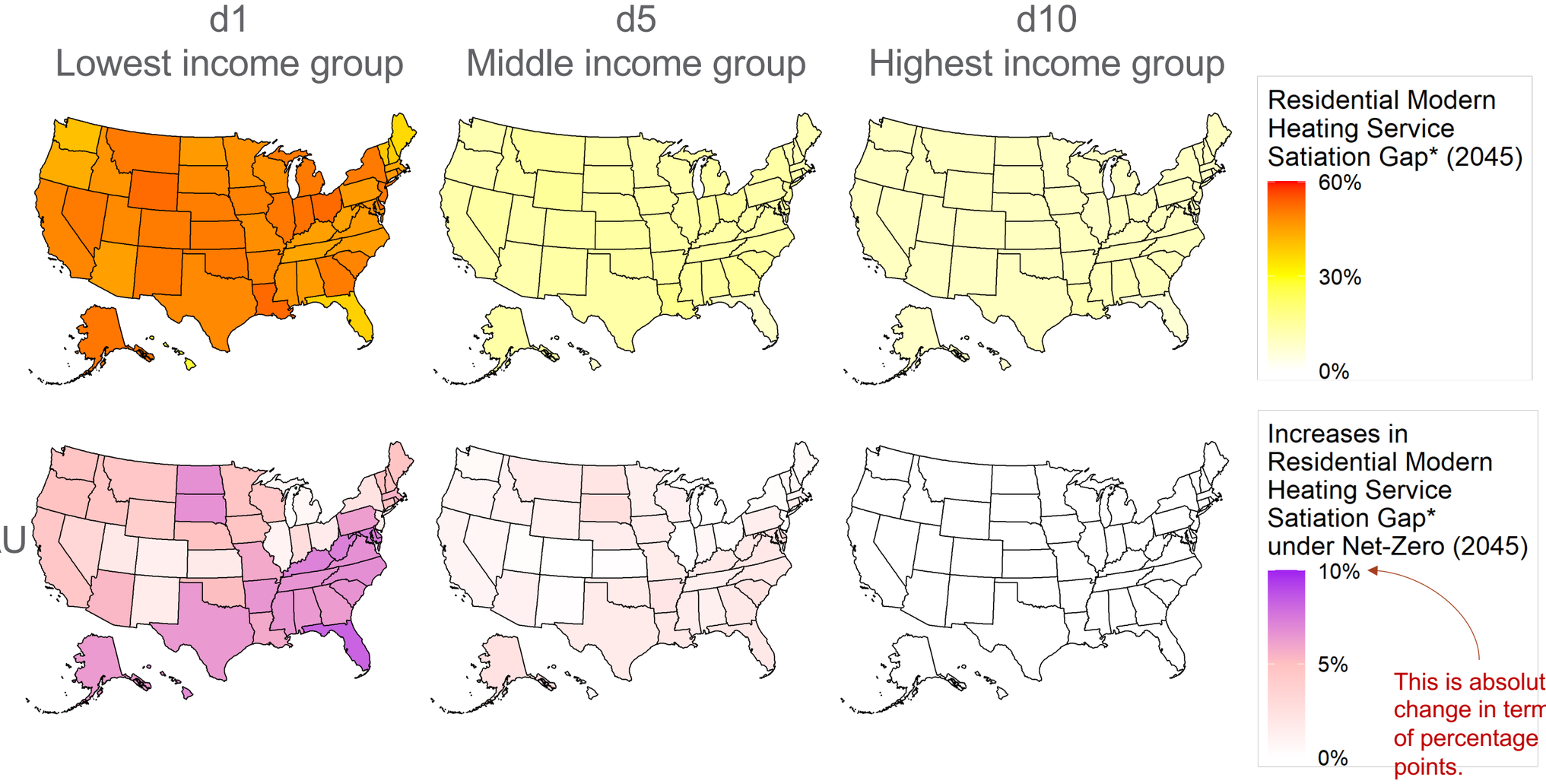
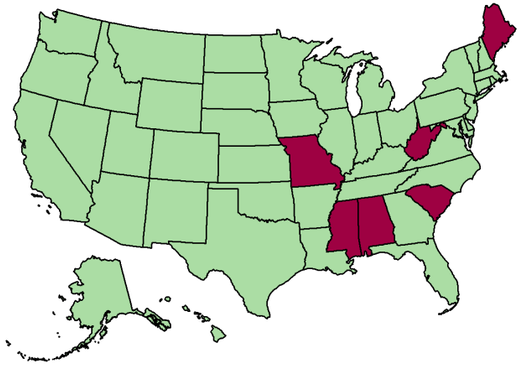
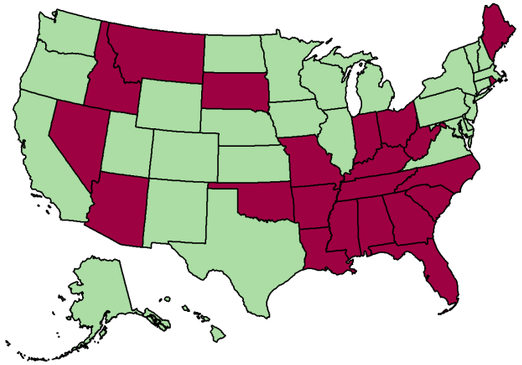
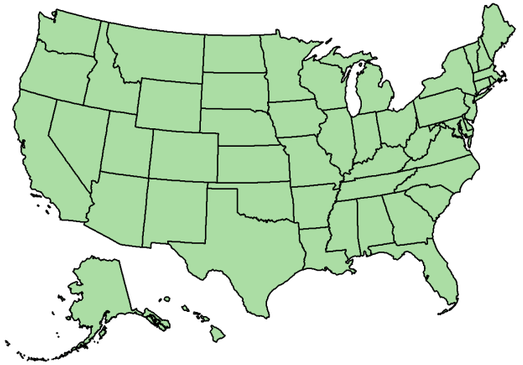
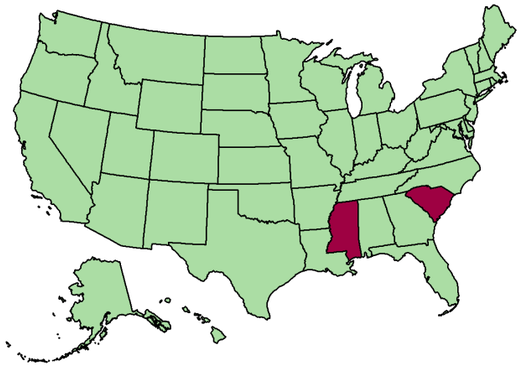
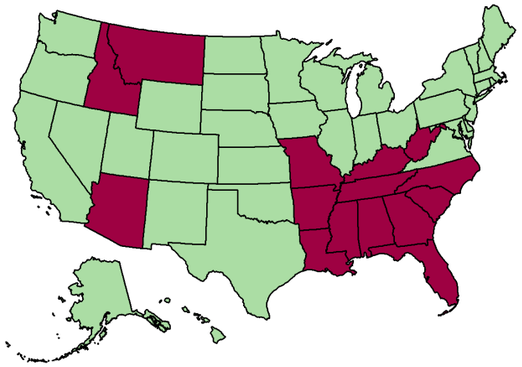
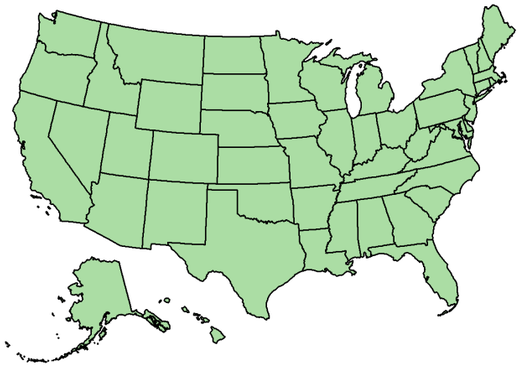
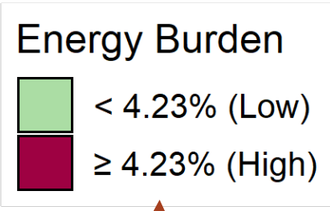


* $Satiation\ Gap_{i,j,k} = \left(satiation\ level_{j,k} - service\ output_{i,j,k}\right) / satiation\ level_{j,k}$ for income group i and service j in state k. Note that the satiation level and service output are per unit of floorspace.

Residential energy burden under Business as Usual

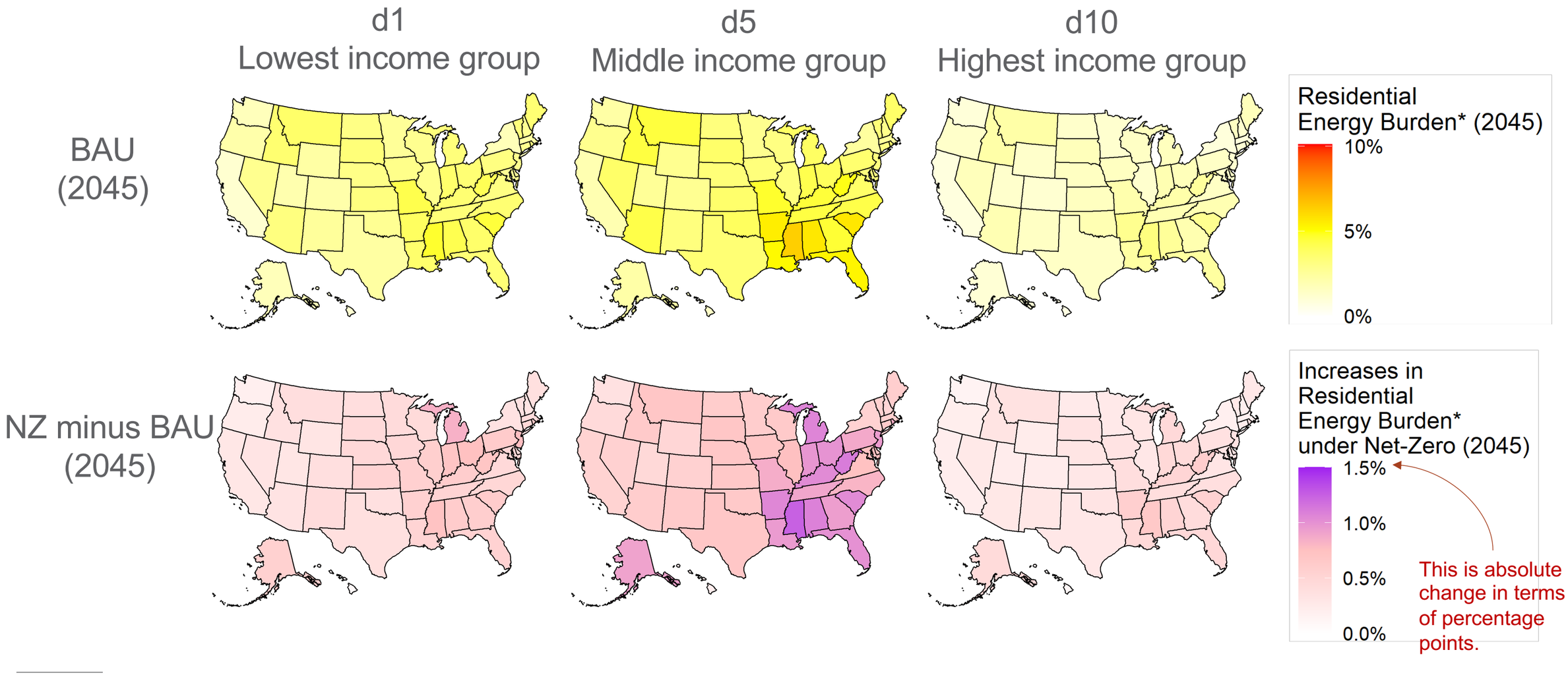
	d1 Lowest income group	d5 Middle income group	d10 Highest income group
BAU (2020)			
BAU (2045)			

"Percentage of household income that is spent on residential energy services."



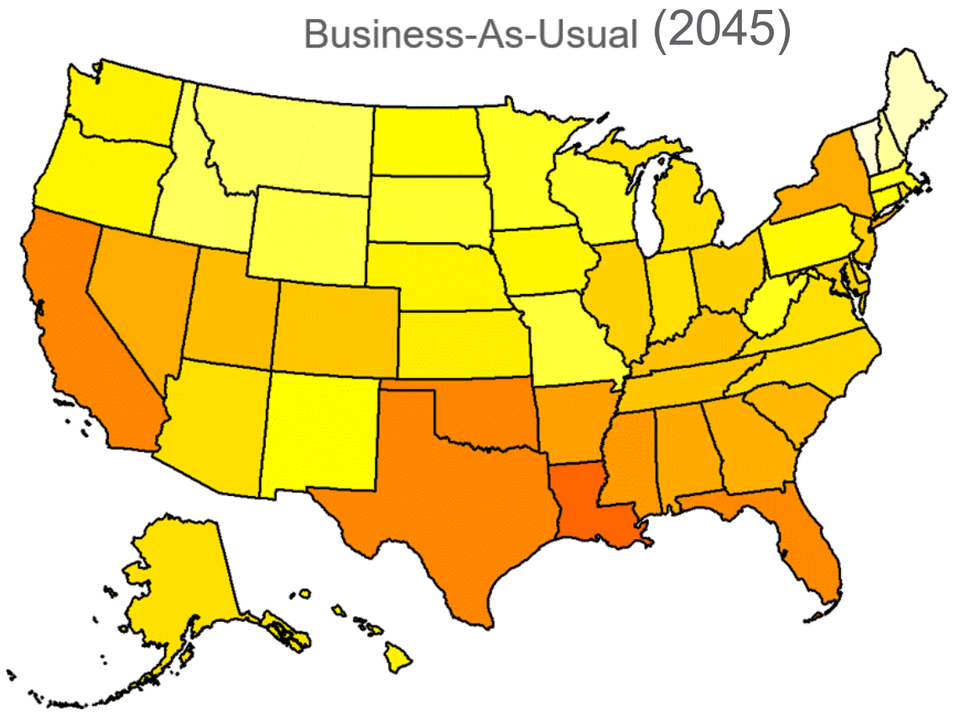
Threshold defined based on U.S. EIA report, such that in 2020, roughly 27% of the U.S. total population fell into the "High" energy burden category.

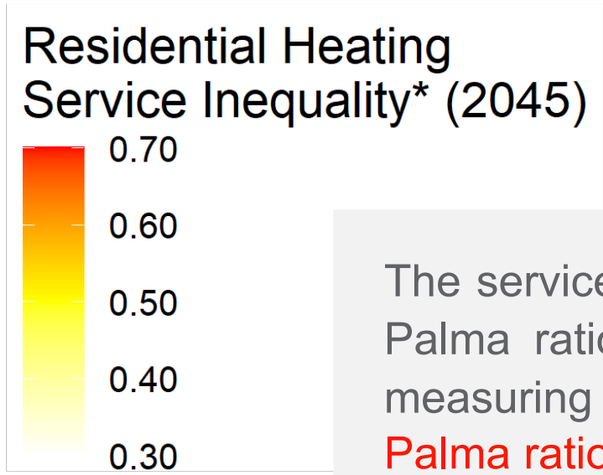
Impacts of a net-zero policy on residential energy burden in 2045



* $Energy\ burden_{i,k} = \sum_j (service\ output_{i,j,k} * service\ cost_{j,k}) / GDP_{i,k}$ for income group i and service j in state k. Note that the service output here is the total service output in state k.

Residential heating service inequality in 2045





The service inequality is similar to the Palma ratio, which is often used for measuring income inequality. A higher Palma ratio indicates a greater degree of inequality.

$$^{*}\ Service\ Inequality_{j,k} = \frac{S_{j,k}^{d10}}{\left(S_{j,k}^{d1} + S_{j,k}^{d2} + S_{j,k}^{d3} + S_{j,k}^{d4}\right)}$$

where S is the residential service output *per capita* for service j in state k

Key messages

- Our research analyzes and quantifies decarbonization impacts on residential energy security across different income groups and states
- Despite the influence of decarbonization policies, income disparity remains a significant factor affecting residential energy security
- The impacts of decarbonization policies on residential energy security vary across income groups
- The decarbonization policy scenario exacerbates existing disparities in energy services among income groups
- This research can help make informed decisions when it comes to designing equitable decarbonization policies.

Results presented are available at Zenodo –
Zhang, Ying, Waldhoff, Stephanie, Ou, Yang, & Iyer, Gokul. (2023). Projecting Residential Energy Consumption across Multiple Income Groups under Decarbonization Scenarios using GCAM-USA (v1.0.0) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.7988038

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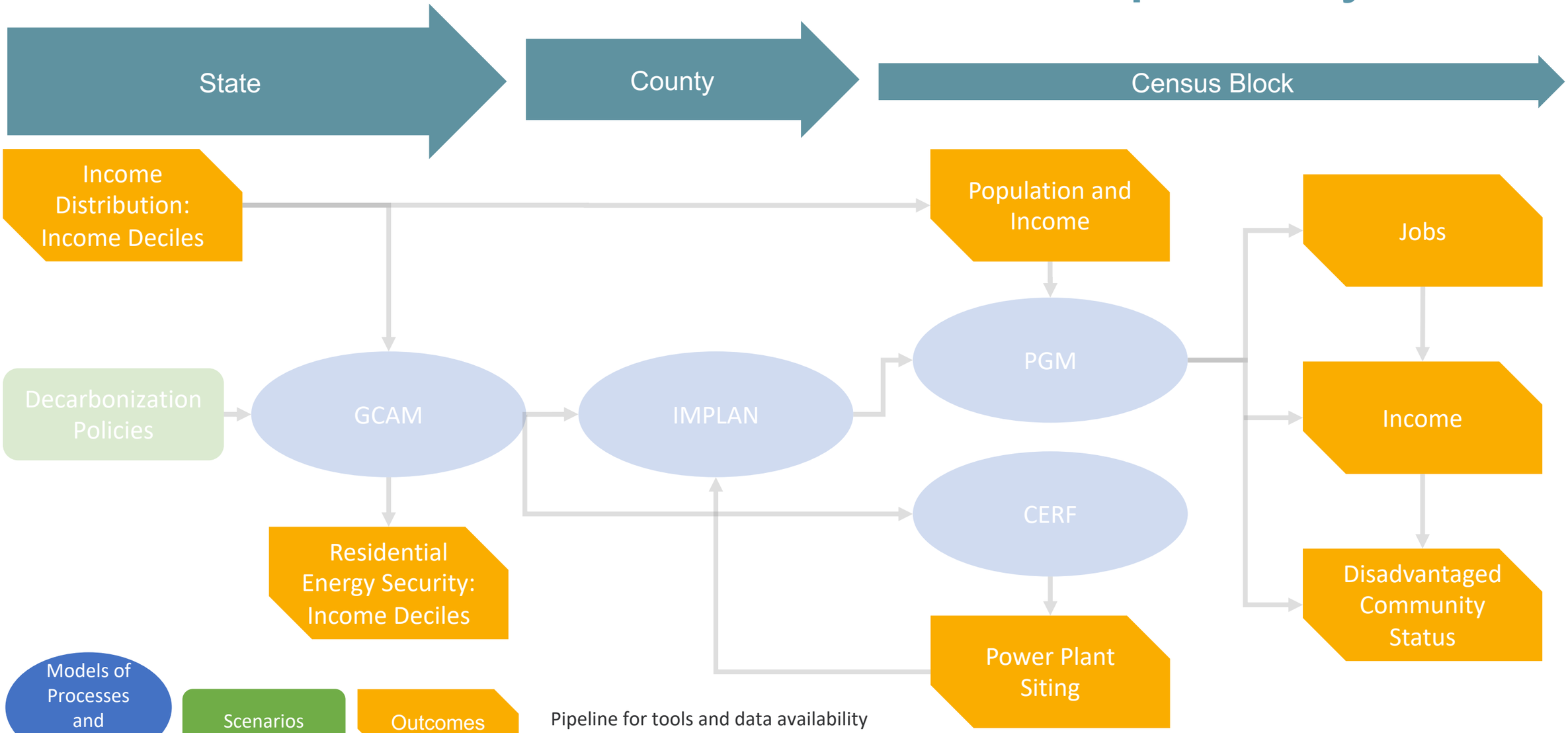
Question and Answer

Energy Justice-Visualization and Impact Analysis Tool



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Model Coupling for Geo-spatial Equity Impacts Analysis

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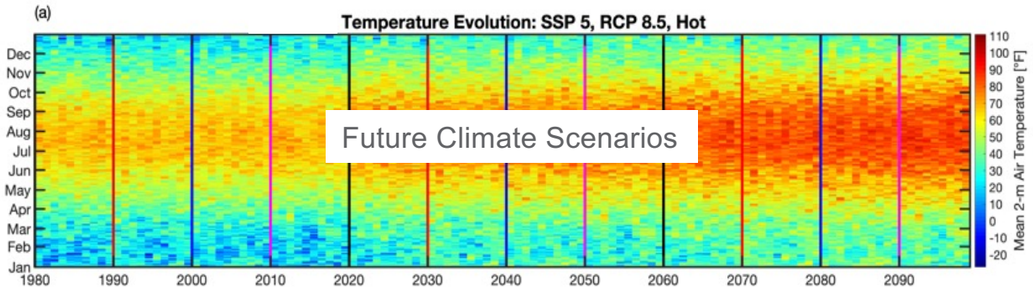
Grid Operations, Decarbonization, Environmental and Energy Equity Platform



Future Climate Scenarios

Model Coupling for Geo-spatial Equity Impacts Analysis

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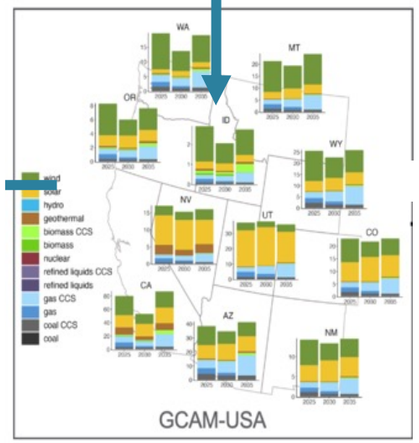
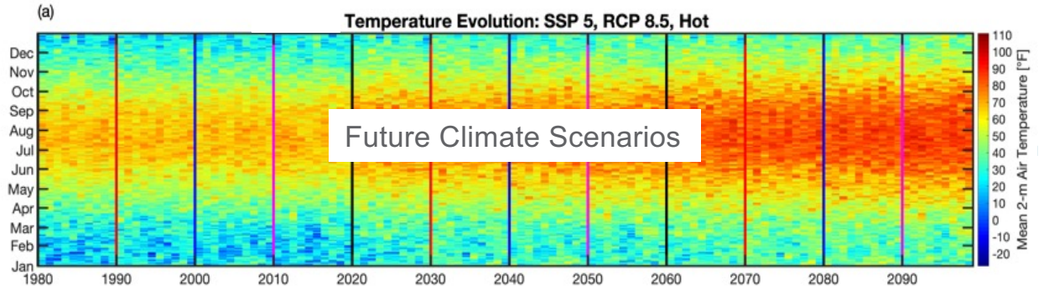


Decarbonization Scenarios



Future Climate Scenarios

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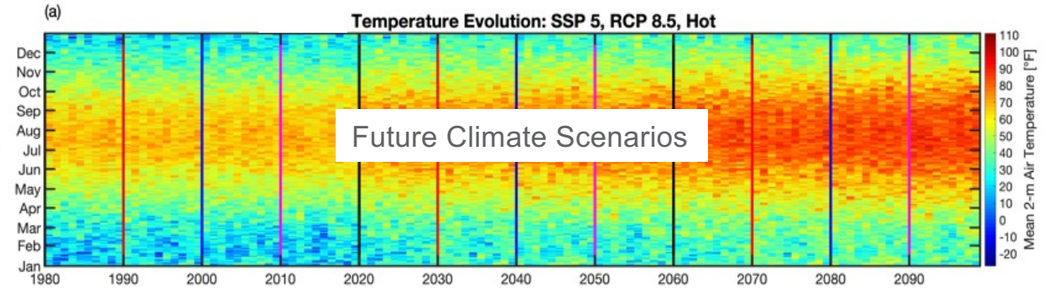
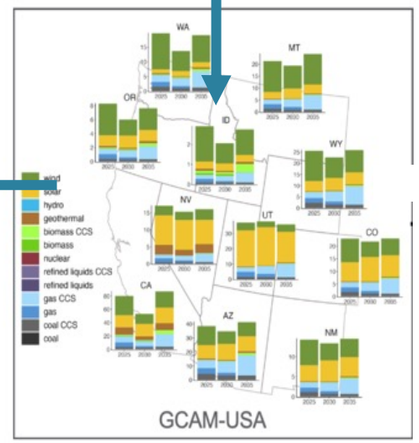


Future Climate Scenarios



GCAM-USA

Decarbonization Scenarios

Grid Network Topology

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Model Coupling for Geo-spatial Equity Impacts Analysis

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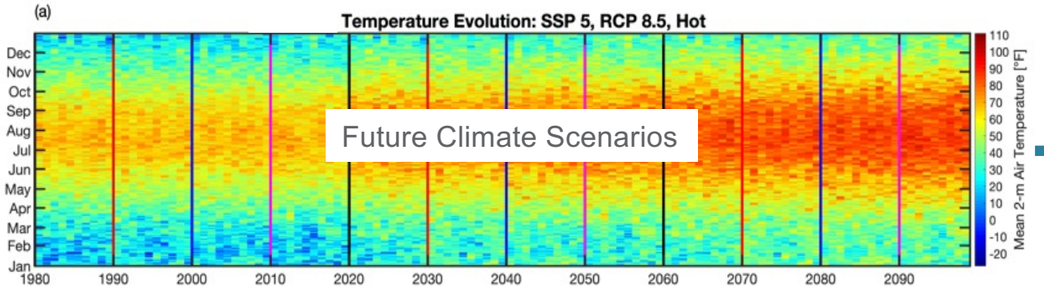
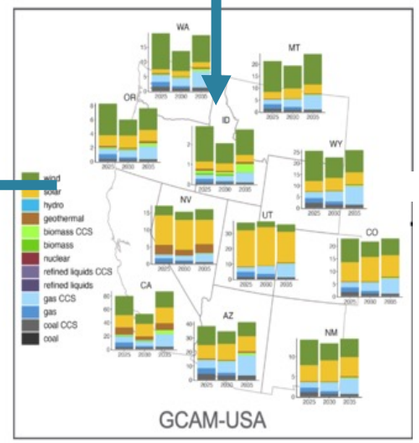
Grid Operations, Decarbonization, Environmental and Energy Equity Platform

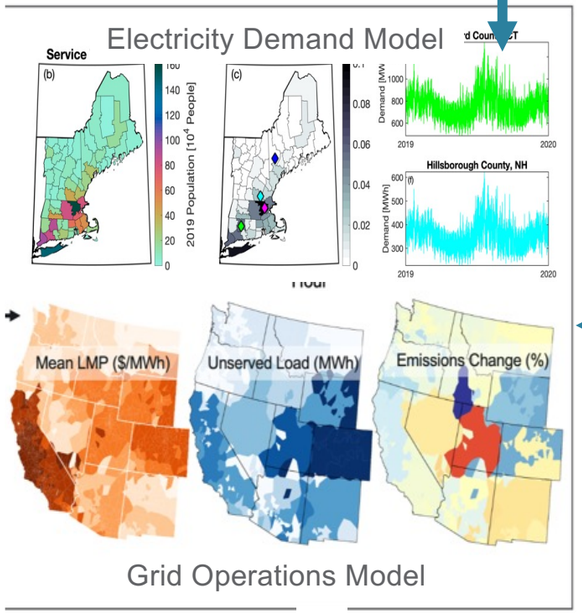




Decarbonization Scenarios

Grid Network Topology

Hourly Grid Response



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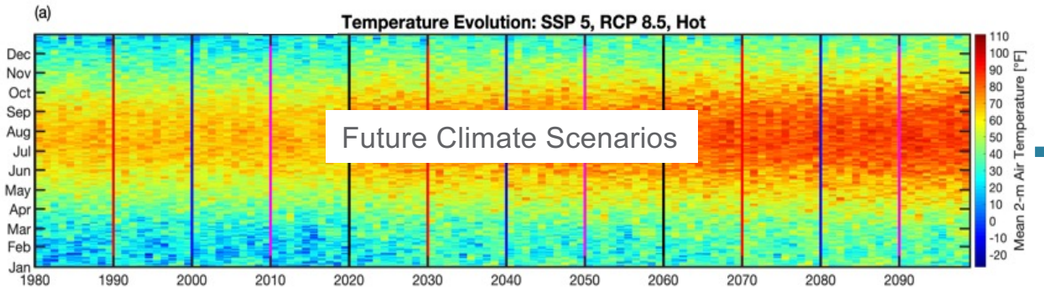
Model Coupling for Geo-spatial Equity Impacts Analysis

GODEEEP
Grid Operations, Decarbonization, Environmental and Energy Equity Platform



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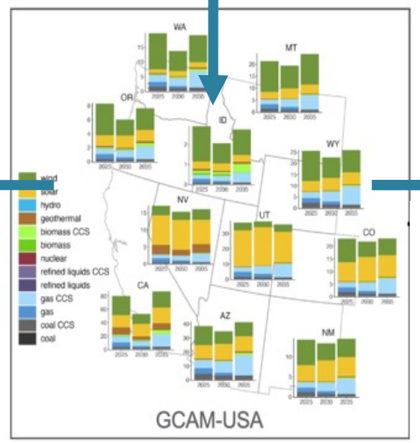
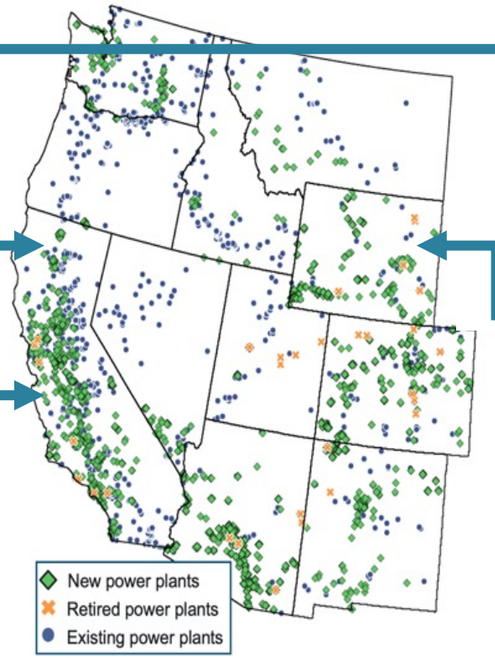


GCAM-USA

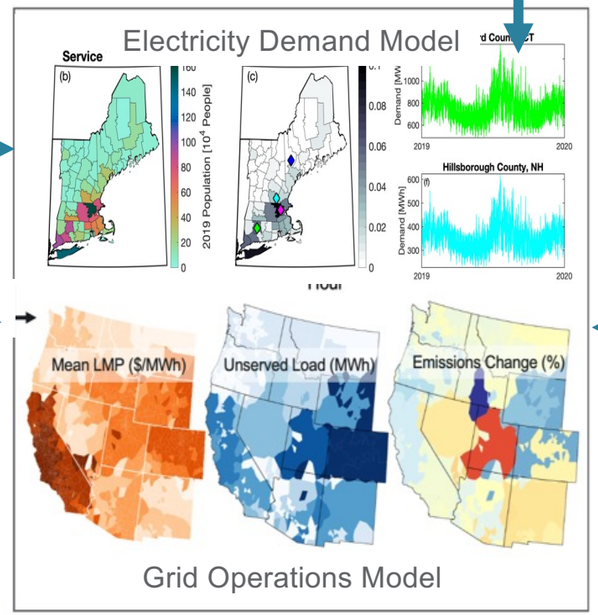
Decarbonization Scenarios

Grid Network Topology

Power Plant Siting



Hourly Grid Response



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Grid Operations, Decarbonization, Environmental and Energy Equity Platform

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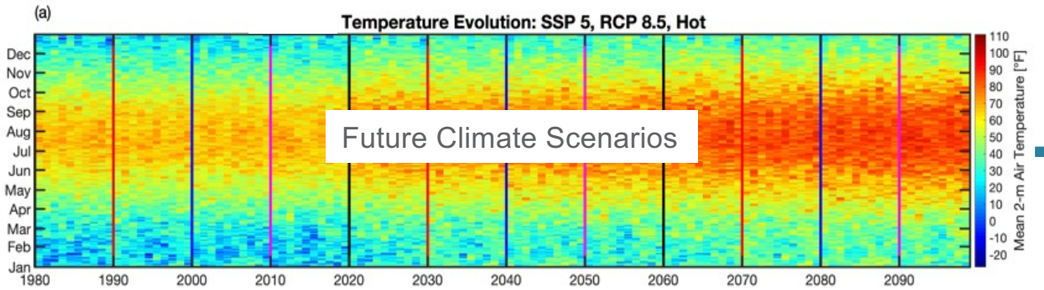

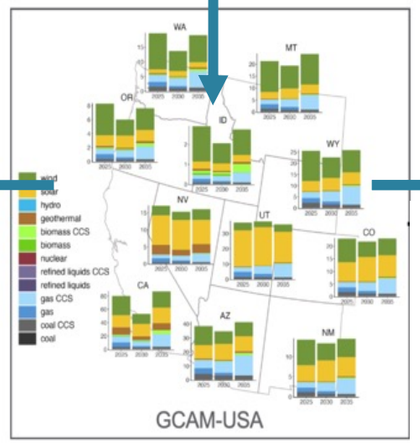

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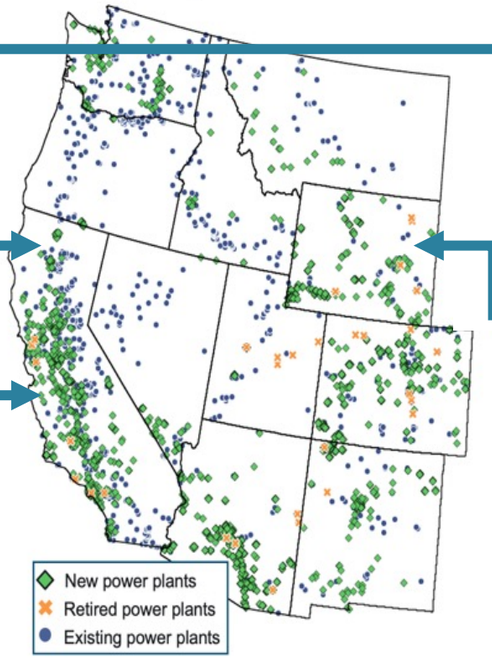

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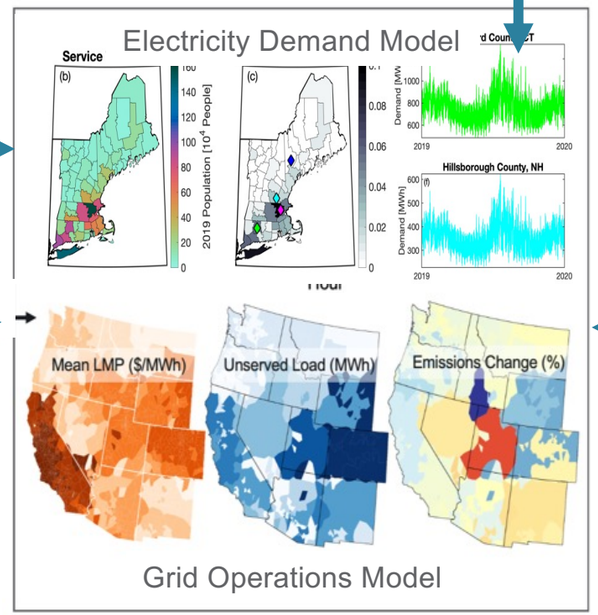

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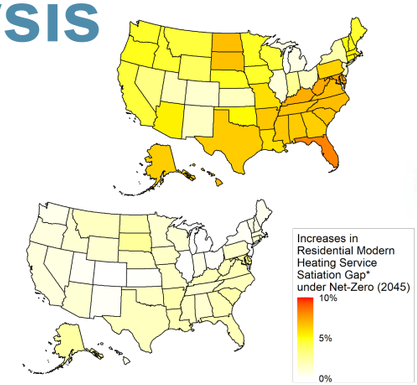

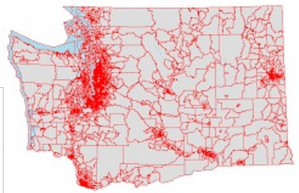

WA Census Block Scale
Jobs and income impacts

State-level residential
energy security impacts

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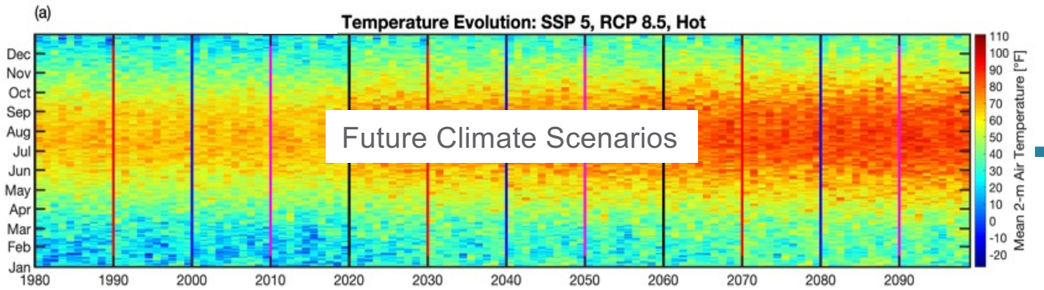
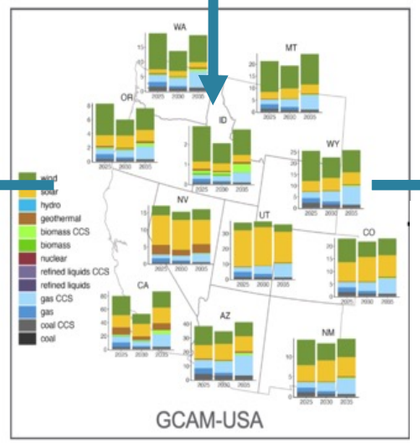
Grid Operations, Decarbonization, Environmental and Energy Equity Platform

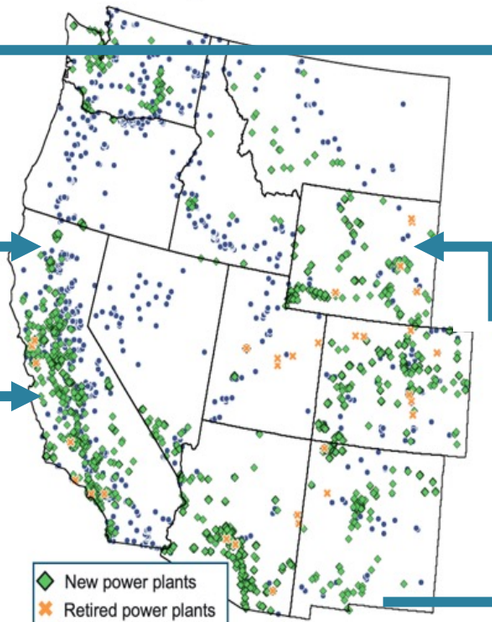
Model Coupling for Geo-spatial Equity Impacts Analysis





Decarbonization Scenarios

Power Plant Siting



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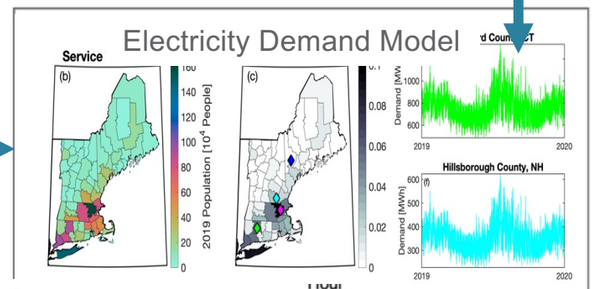
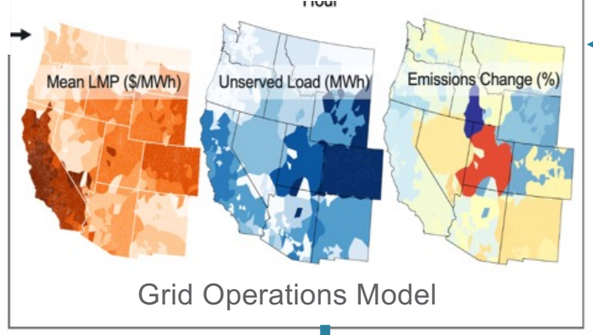
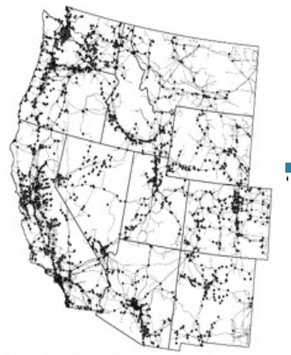
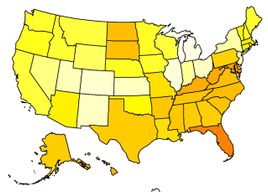
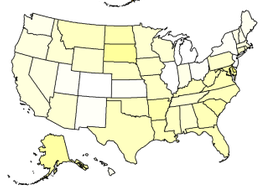


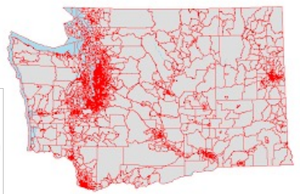




Grid Network Topology

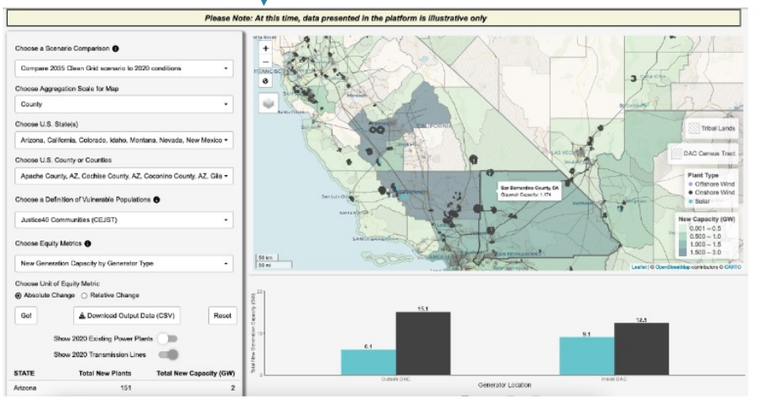






WA Census Block Scale Jobs and income impacts

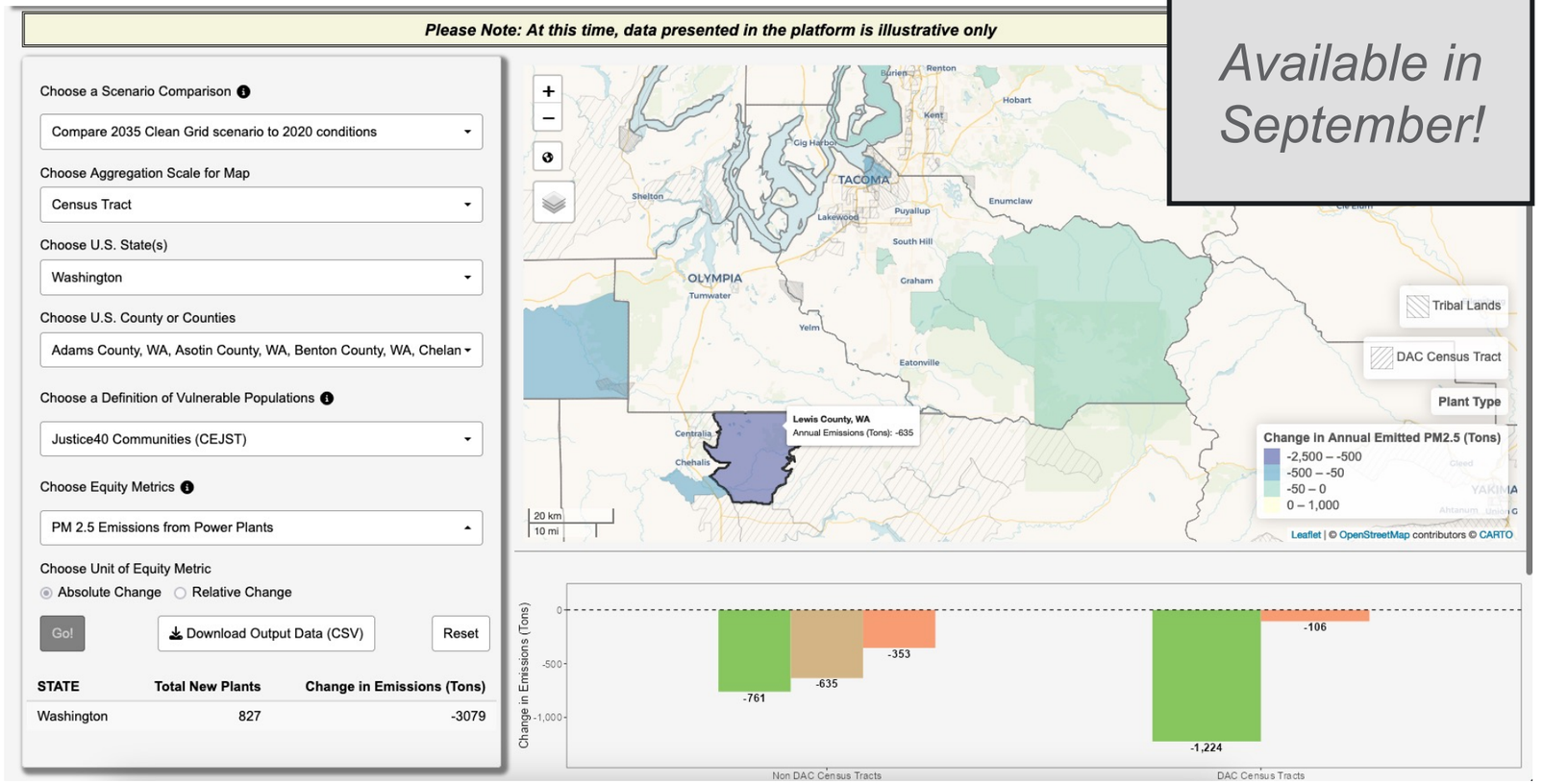
State-level residential energy security impacts



Equity Impacts Model

Energy Justice-Visualization and Impact Analysis Tool

- Forthcoming GODEEEP geospatial analysis tool
- Visualize and analyze equity metrics and DACs across decarbonization scenarios, geographic scales
- Filter and download datasets based on user inputs



EJ-VIA Metrics

Data Models

- GCAM-USA
- IMPLAN
- CERF (Power Plant Siting Model)
- GridView (Grid Operations Model)

Current Metrics

- New and Retired Generation Capacity by Technology Type
- CO2, SO2, NOx Generator Emissions
- Annual Generator Outage Duration
- Unserved Energy
- Avg. Energy Burden by Income Decile
- Total Job Changes for Washington State

Question and Answer

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Thank you

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