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GODEEEP WEBINAR SERIES

ON CLIMATE- AND EQUITY-INFORMED RESILIENT GRID PLANNING

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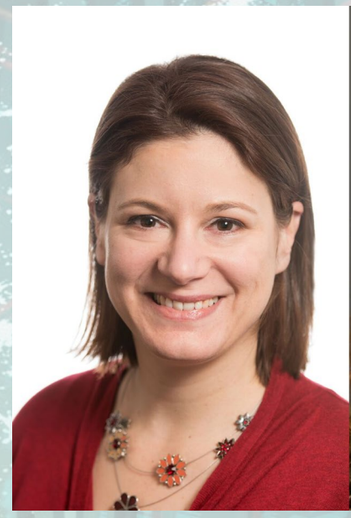
Overview of New Capabilities for Climate- and Equity-Informed Energy Resilience Planning

Hosted by: Jennie Rice
Expert Panelists: Nathalie Voisin and Stephanie Waldhoff
June 12, 2023



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Grid Resilience @ PNNL – GODEEEP Webinar Series

Climate- and Equity-Informed Decarbonization

Nathalie Voisin, Stephanie Waldhoff, and the GODEEEP team

June 12, 2023

U.S. DEPARTMENT OF ENERGY BATTELLE

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GODEEEP kickoff webinar

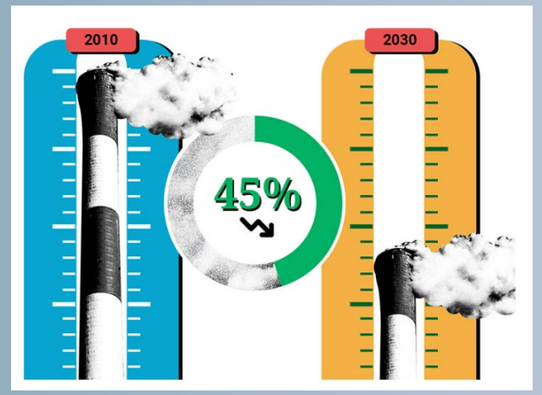
- Motivation
- **GODEEEP** research and outcomes
  - Platform, datasets, workflows
  - End-use cases/analytics
  - Sneak peeks to deep dives
- Programmatic relevance
- Discussion/Q&A

Net-zero economies are needed to maintain global warming below 1.5˚C above pre-industrial temperature

High-Level Roadmap to Net-Zero Economies

2015
Paris Agreement

2030
Keep Warming < 1.5 ºC



2050
Complete Transition to Net-Zero

https://www.un.org/en/climatechange/net-zero-coalition

Decarbonization to Achieve Net-Zero Economies is a Global Challenge

Drastic changes are required to achieve net-zero economy in the U.S.:

Economy-wide electrification and decarbonization

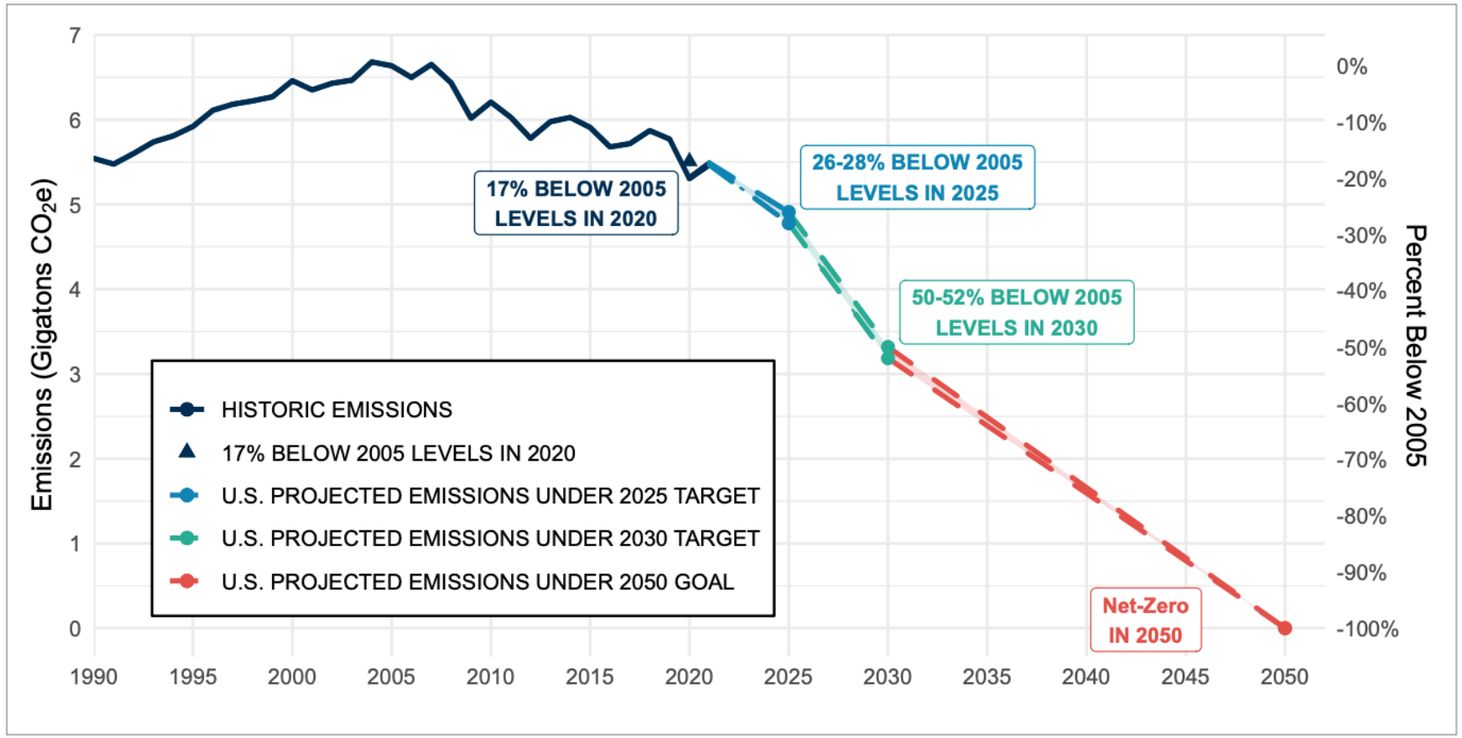


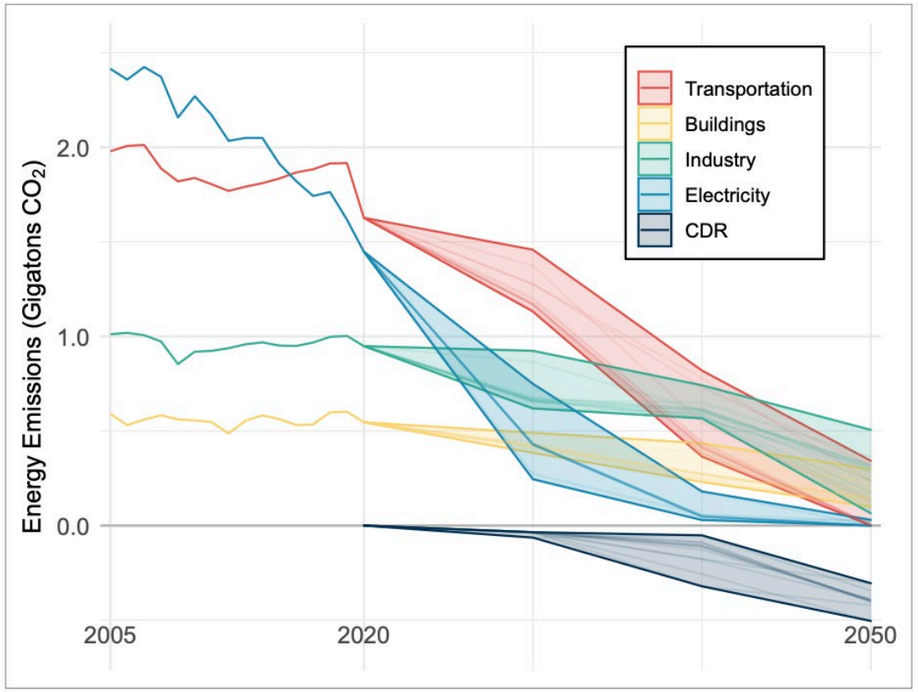
Figure ES-1: United States historic emissions and projected emissions under the 2050 goal for net-zero. This figure shows the historical trajectory of U.S. net GHG emissions from 1990 to 2019, the projected pathway to the 2030 NDC of 50-52% below 2005 levels, and the 2050 net-zero goal. The United States has also set a goal for 100% clean electricity in 2035; that goal is not an economy-wide emissions goal so does not appear in this figure, but it will be critical to support decarbonization in the electricity sector, which will in turn help the U.S. reach its 2030 and 2050 goals in combination with broad electrification of end uses.

The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050. Published by the United States Department of State and the United States Executive Office of the President, Washington DC. November 2021.

PNNL's GCAM model was used for this report.

The greatest reductions need to come from decarbonization of electricity generation, followed by electrification of transportation

Figure 4: U.S. Energy CO_2 Emissions to 2050 by Economic Sector. Electricity CO_2 emissions and direct CO_2 emissions from the transportation, buildings, and industry fall dramatically in all scenarios, with the greatest reductions coming from electricity, followed by transportation, and non-land sink carbon dioxide removals (CDR) increase. Notes: Historical data are from EIA Monthly Energy Reviews, projections include data from all LTS scenarios using both GCAM and OP-NEMS, projections are shown in ten-year time steps.



The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050. Published by the United States Department of State and the United States Executive Office of the President, Washington DC. November 2021.

How can we achieve these goals this quickly and still provide **safe**, **affordable**, **reliable,** and **resilient** electricity?

Federal and state regulations require the consideration of environmental and energy justice

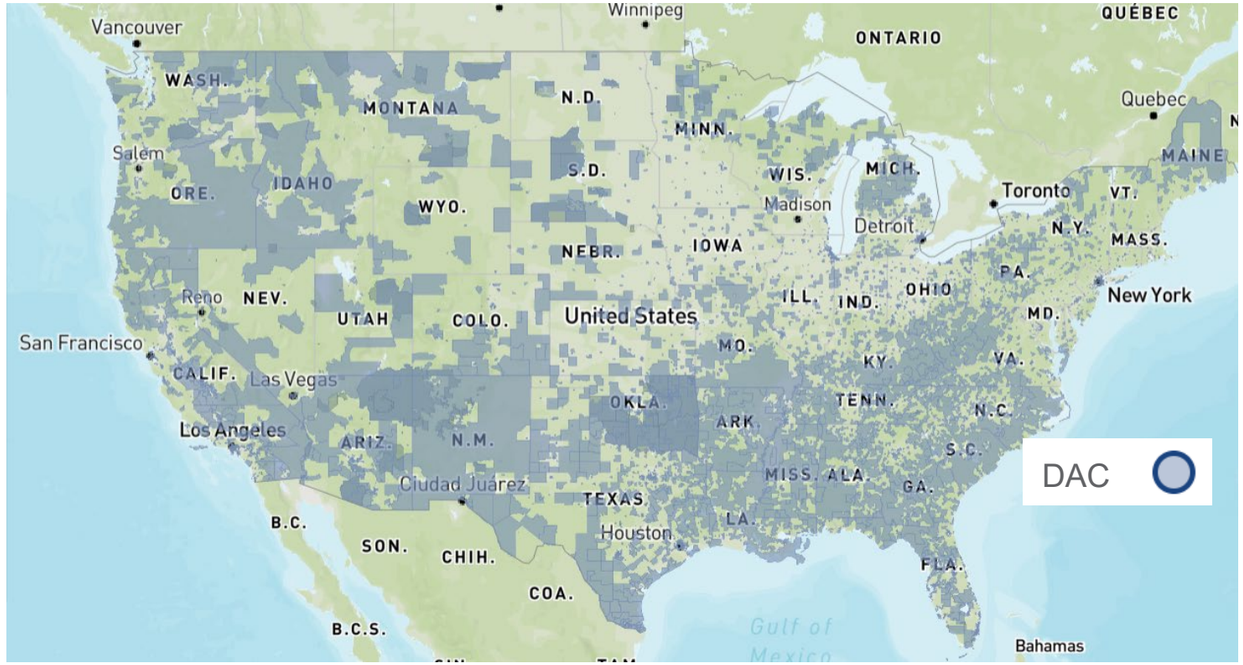
In 2022, **22 states** and the District of Columbia (D.C.) adopted energy-equity-related measures (PNNL, LBNL)

At least **11 states** require utility regulators to consider equity in their decisions

20 states plus D.C. have cost caps to limit increases in ratepayer bills due to renewable portfolio standards (NGA, 2023)

At least **7 states** currently require utilities to address equity and environmental justice in their integrated resource planning and other planning processes (100% Clean Energy Collaborative, 2022)

Disadvantaged communities (DACs) are widespread



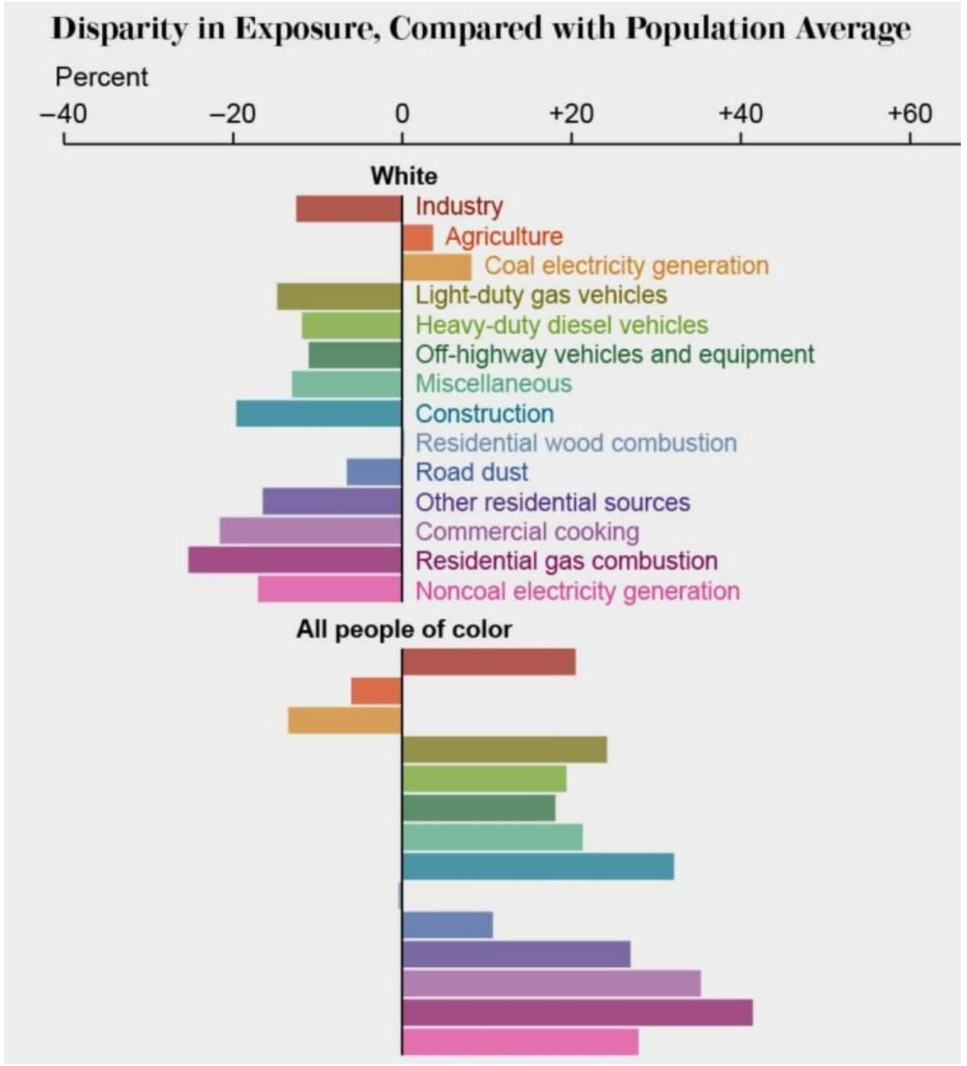
https://screeningtool.geoplatform.gov/en/#3.03/42.41/-95.97

Example of inequities: currently, there are significant inequities in exposure to air pollution

Decarbonization will affect all these emission sources, ultimately affecting:

- Air pollution
- Water pollution
- Soil pollution
- Noise pollution
- Electricity outages
- Affordable energy
- Access to clean energy

Need to understand which groups of people will be affected and how

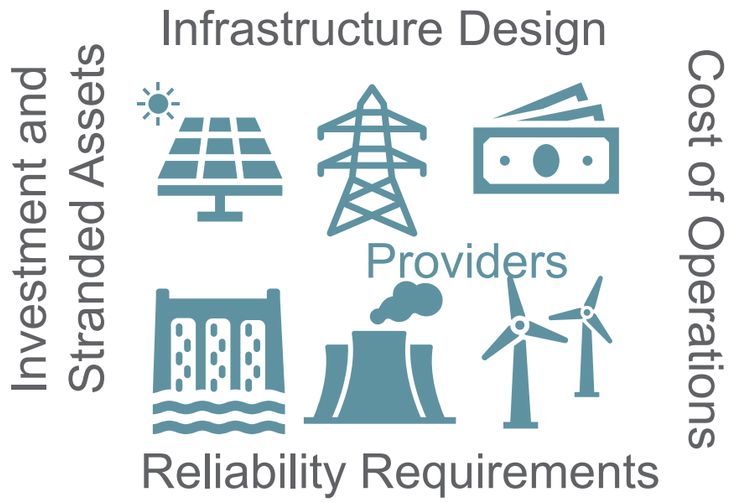


2014 data. Credit: Amanda Montañez; Source: "PM2.5 Polluters Disproportionately and Systemically Affect People of Color in the United States," by Christopher W. Tessum et al., in Science Advances. Published online April 28, 2021. https://earth.org/marginalised-groups-are-disproportionately-affected-by-climate-change/

Stakeholders (providers and consumers) **evaluate net-zero pathways from different angles**

Major transition in the energy system—the whole economy is affected. **Significant uncertainties** in how to move forward given the cost of the transition.

Successful decarbonization of the electric grid requires evaluation of outcomes for providers and consumers



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GODEEEP uses PNNL's expertise working across fundamental and operational research in climate, power grid, and multisector dynamics

Empowered Stakeholders

Transfer of methods, tools, datasets, and use cases

Decarbonization Pathways

Whole economy decarbonization with interactions across global markets

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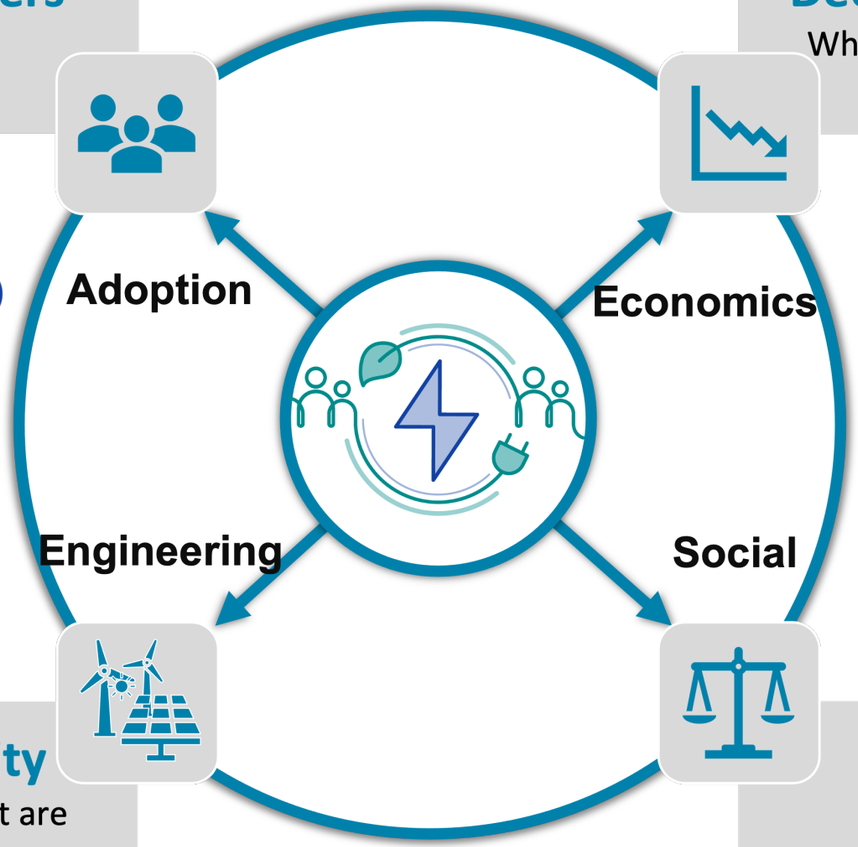


A $4 million PNNL R&D project

Coordinated research using staff expertise across renowned Climate and Bulk Electric Grid Programs in Fundamental and Applied Research across the Department of Energy's offices

- Atmospheric scientists
- Hydrologists
- Electrical engineers
- Social scientists
- Software engineers
- Stakeholder engagement experts

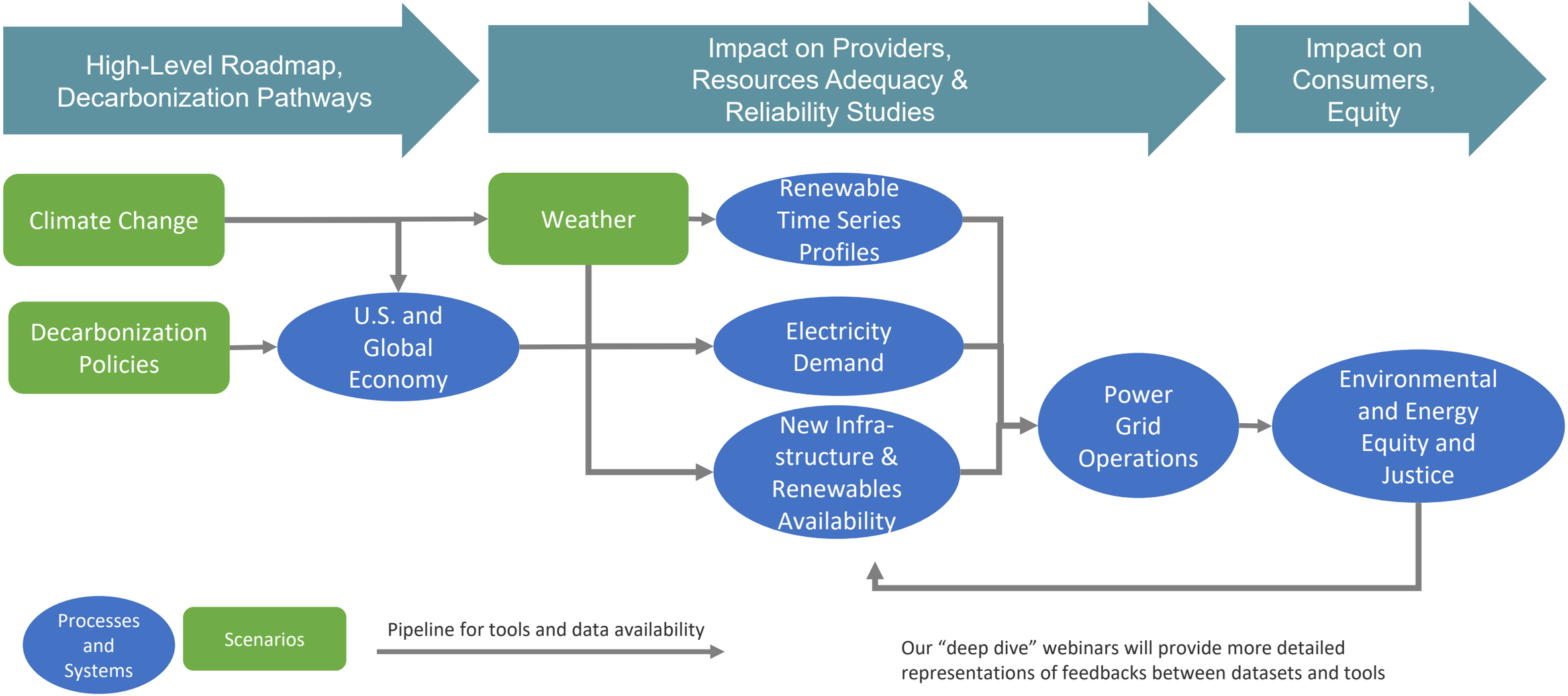
Resilience and Reliability

Infrastructure and operations that are responsive to climate change

Justice and Equity

Environmental and energy equity impacts of decarbonization

Consistent, open-source, end-to-end framework with intermediate datasets and tools for flexible customization



Our “deep dive” webinars will provide more detailed representations of feedbacks between datasets and tools

A web-based platform with open-source resources and detailed documentation

godeeep.pnnl.gov

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Grid Operations, Decarbonization, Environmental and Energy Equity Platform (GODEEEP)

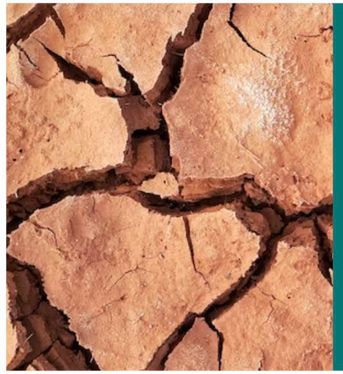
PNNL's GODEEEP helps scientists and industry decision-makers understand realistic, resilient, and equitable pathways to decarbonization.

Decarbonization Pathways | Resilience & Reliability | Justice & Equity | Resources & Guidance | About Us

Decarbonization Pathways

- How can the United States achieve net-zero within a short timeframe?
- What are the characteristics of a net-zero economy?
- How does an intensifying climate impact the pathways to net-zero?

Learn More



Resilience & Reliability

- How likely are renewable energy droughts?
- How can we design the decarbonized power grid to be resilient to extreme weather events?
- What are the tradeoffs between investing in storage versus transmission?
- How will electrification impact load profiles and electricity prices?

Learn More

Justice & Equity

- How will decarbonization affect household energy security across income groups?
- How will plant locations, emissions, reliability, and jobs impact disadvantaged communities?
- Can we predict the ways in which disadvantaged communities may change over time?
- Can we predict opposition to siting and permitting?

Resources & Guidance

Effecting positive change requires working together and sharing insights. We employ open-source models and reproducible workflows in our studies, and welcome collaboration and constructive feedback.

https://godeeep.pnnl.gov/resources/

Open-source resources

godeeep.pnnl.gov

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GODEEEP Webinar
Biweekly starting June 12
Join the GODEEEP team for live demonstrations of the tools and datasets used in our research! Discuss the assumptions and projections involved, and learn how to leverage our experience in your domain.
Register here!

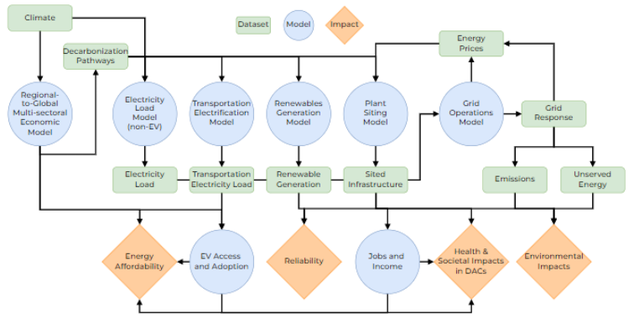
Decarbonization Pathways | Resilience & Reliability | Justice & Equity | Resources & Guidance | About Us

Resources & Guidance

The GODEEEP workflow provides consistency between models and domains as we study the pathways toward net-zero. The key to consistency lies in the interfaces between models, ensuring that assumptions and input data are clearly defined and tracked throughout the whole modeling chain. We are committed to open-sourcing, wherever possible, our code and datasets so that our techniques can be utilized with other models and assumptions.

We are constantly iterating and tuning the implementation details and will be publishing code, models, and datasets as they mature enough for public discourse, so check back often!

GODEEEP Workflow



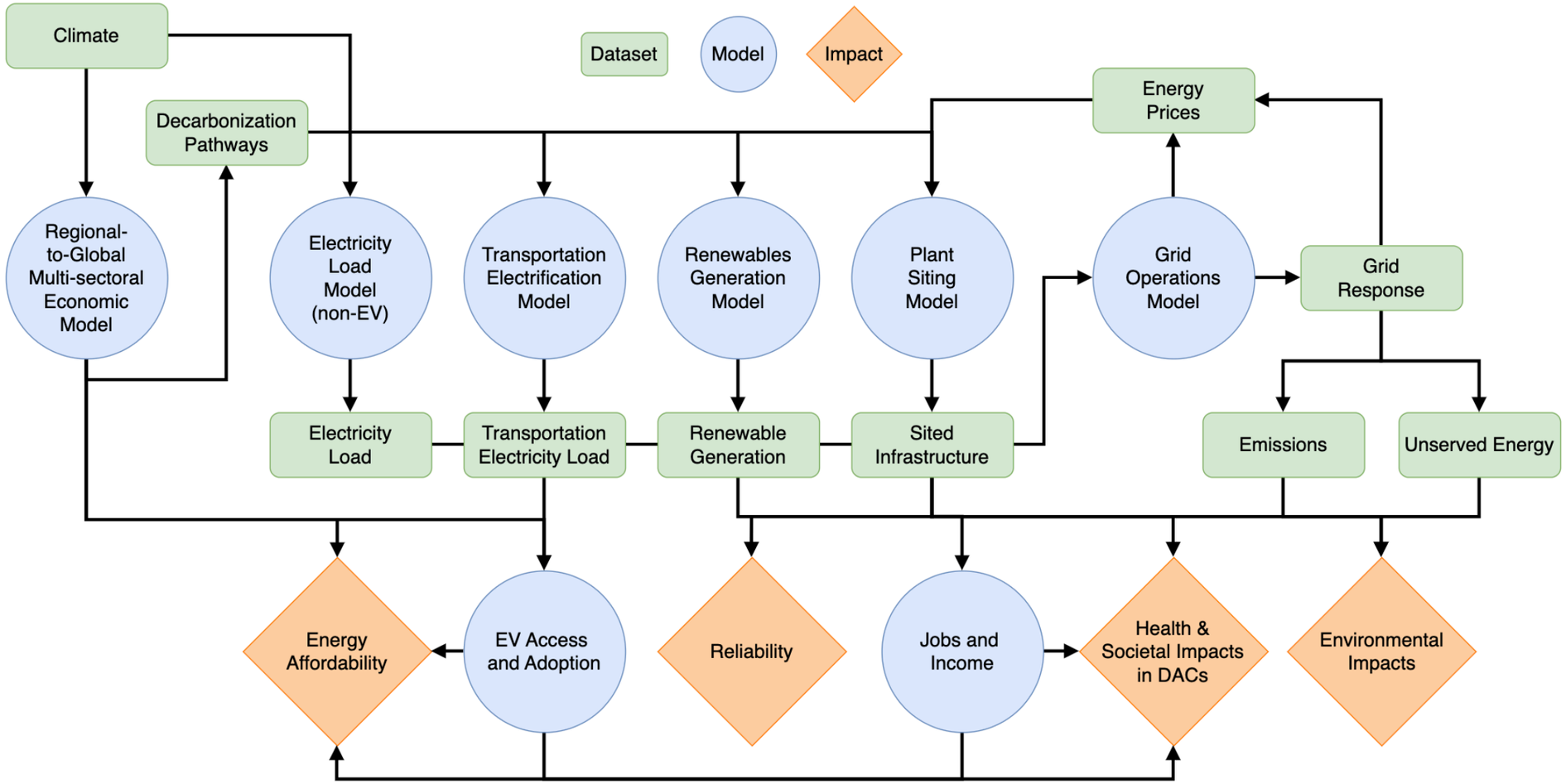
Open-Source GODEEEP Datasets

Topic ↓ \ Resolution →	State / County	Balancing Authority	12km	Substation / Plant / 1km	Census Block
Climate	Heating & cooling degree days in progress!				
Decarbonization	GCAM-USA Decarbonization Pathways				
Weather	U.S. County Projections of Hourly Meteorology under Climate Change	U.S. Balancing Authority Projections of Hourly Meteorology under Climate Change	Thermodynamic Global Warming Simulations		
Electricity Load	GCAM-USA Decarbonization Pathways	Transportation Electrification Load Profiles Hourly load (non-EV) in progress!		Hourly load by node in progress!	
Sited Infrastructure	GCAM-USA Decarbonization Pathways	2020 to 2050 in progress!		2020 to 2050 in progress!	
Wind & Solar		Wind and Solar Generation by BA	Gridded generation profiles in progress!	Wind and Solar Capacity Factor Profiles	
Hydropower				RectifHyd RectifHyd+ in progress!	
Deratings / Outages				Deratings in progress!	
Wholesale Energy Prices				2020 through 2050 in progress!	
Income	State-level Income Decile Projections Projecting Residential Energy Consumption across Multiple Income Groups under Decarbonization...				Block-level Income Projections for WA
Population	Population scenarios for U.S. states consistent with shared socioeconomic pathways				Block-level Population Projections for WA

Tools and scripts for aggregating and subsetting these datasets are under development and will be available soon.

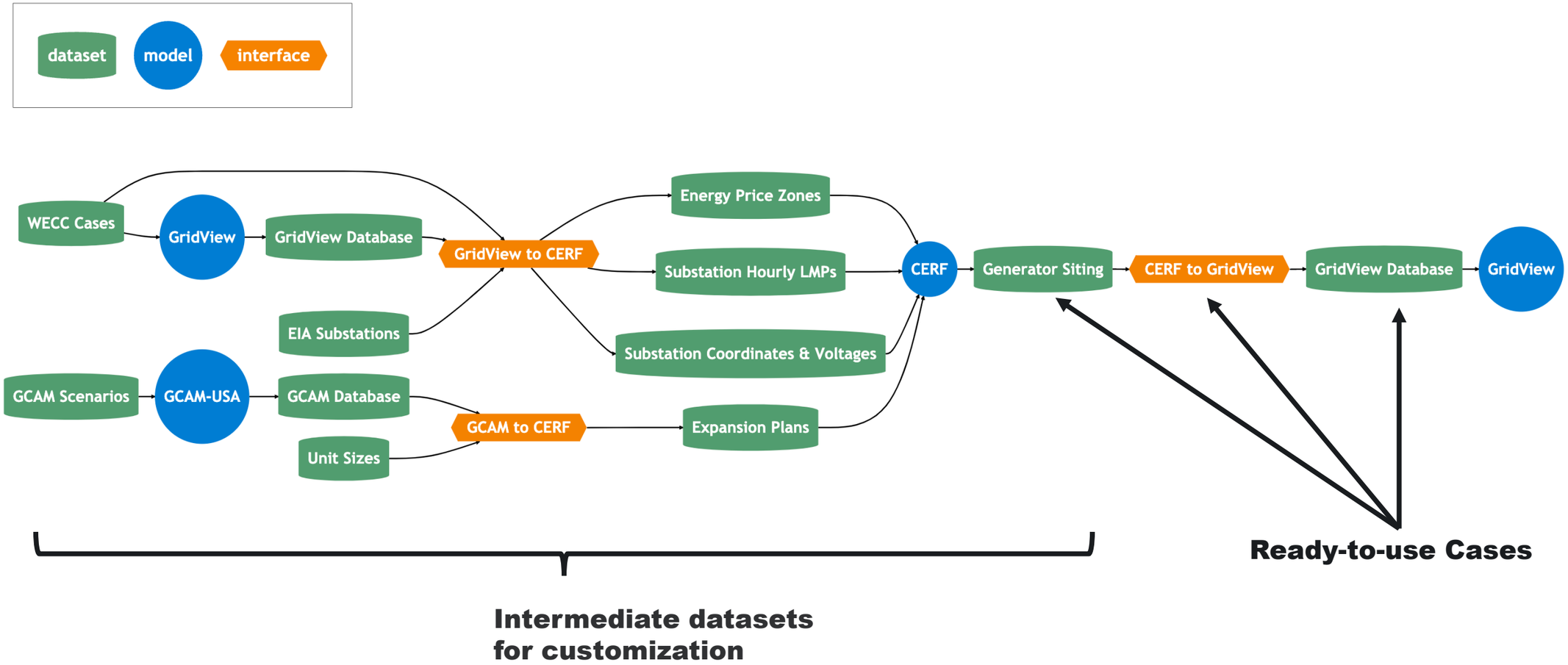
In the meantime, please reach out to us if you need assistance!

Platform Structure: end-to-end open-source workflows, datasets, and models*



*We are using GridView for the initial GODEEEP studies, but our workflows are adaptable to other production cost models

Example workflow: Can serve multiple stakeholder needs in a consistent fashion



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Reproducible open-source workflows

Search or jump to... / Pull requests Issues Marketplace Explore

4. Run CERF for each state and combine output sitings

Time ~ 7min on 6 cores

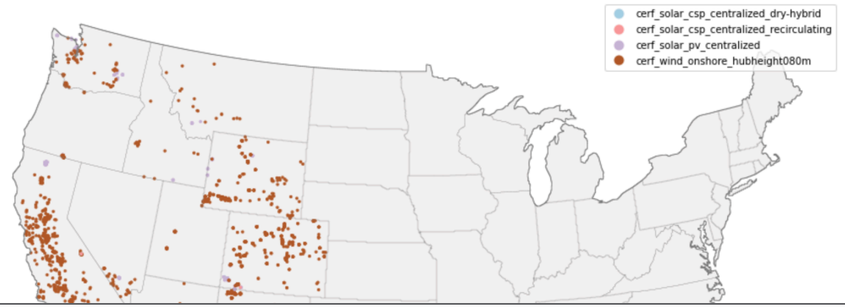
In [27]:

```
%%time

states_in_wecc = ['CA','OR','WA','AZ','NV','WY','ID','UT','NM','CO','MT']

state_abbreviation_to_name = {'CA': 'california','OR': 'oregon','WA': 'washington','AZ': 'arizona',
    'NV': 'nevada','WY': 'wyoming','ID': 'idaho','UT': 'utah','NM': 'new_mexico','CO': 'colorado',
    'MT': 'montana'}

root_path = str(Path(state_config_path).absolute())

parallel_tasks = 6

def run_cerf_for_state(state) -> pd.DataFrame:
    config = str(Path(f'{root_path}/cerf_input_{state}_2030.yml').absolute())
    model = cerf.Model(config)
    result_df = model.run_single_region(state_abbreviation_to_name[state])
    return result_df.run_data.sited_df

results = Parallel(n_jobs=parallel_tasks)(delayed(run_cerf_for_state)(s) for s in states_in_wecc)

df = pd.DataFrame(cerf.utils.empty_sited_dict()).astype(cerf.utils.sited_dtypes())
for i in results:
        # ensure some sites were able to be sited for the target region
        if i is not None:
            df = pd.concat([df, i])

df
```

Wall time: 6min 35s

In [28]:

```
cerf.plot_siting(df)
```



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Edit Pins | Unwatch 2 | Fork 0 | Starred 2 | Checklist

Projects 1 | Wiki | Security | Insights | Settings

Go to file | Add file | ...

ok; updated readme styles (#19 ... 5d5a8d4 18 days ago History

Updates (#16)	28 days ago
updated transportation workflow and notebook; updated readme styles (#19	18 days ago
add retirement and v o&m update logic (#14)	28 days ago
Updates (#16)	28 days ago
Updates (#16)	28 days ago
add retirement and v o&m update logic (#14)	28 days ago

RF generator sitings and retirements.

eting the CERF output file, the GCAM data provided from `gcamextractor`, the substation energy
ed substation coordinate and voltage file
ERF output file that includes variable operating and maintenance costs, offshore wind, and

y targeting this updated CERF output file and the GridView mdb database to update

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GODEEEP ready-to-use open-source datasets

Datasets	States	Balancing Authority	Lat-Lon grid, 12 km^2	Bus/Plant (WECC ADS 2030)	Census Block
Climate	✓		✓		
Decarbonization	✓				
Weather		✓	✓		
Load		✓		✓	
Sited Infrastructure	✓	✓		✓ (and at 1 km^2)	
Wind & Solar	✓	✓	In progress	✓	
Hydro		In progress		✓	
Derating and Outage				In progress	
Wholesale Electricity Prices				In progress	
Population	✓			(and at 1 km^2)	✓
Income Distribution	✓				✓

2 scenarios so far: RCP8.5SSP5 – BAU and NetZero w/o CCS

Analytics and examples of GODEEEP studies

Electrification of Transport	• Impact on load profiles • Compound impact of modified sensitivity to air temperature
Stranded Assets	• Power plants that might not reach end-of-life due to early retirement • Potential environmental and societal challenges to siting of power plants
Extreme Events Case Studies	• Worsening of extreme events, heat waves in particular • Heat waves characterization and standardization of severity, frequency and impact
Energy Droughts	• Potential grid vulnerabilities: coincident wind, solar, and peak load events • Energy storage siting and sizing
Affordability, Jobs, and Incomes	•Detailed impact of decarbonization on energy affordability by income classes
Disadvantaged Communities and NIMBY	• Analysis of grid operation impacts on DACs • Potential opportunities for positive impacts on DACs from retired power plants

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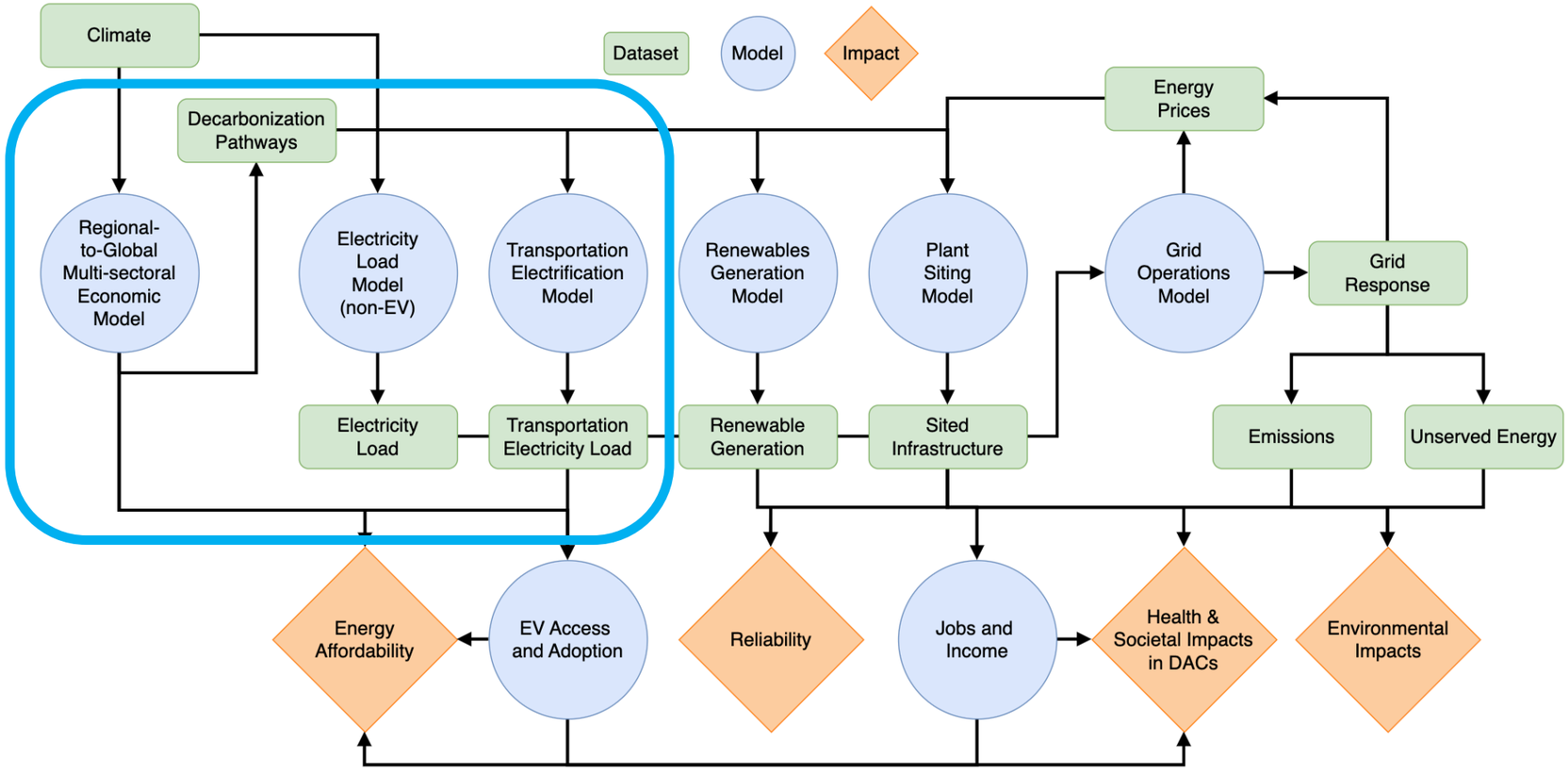
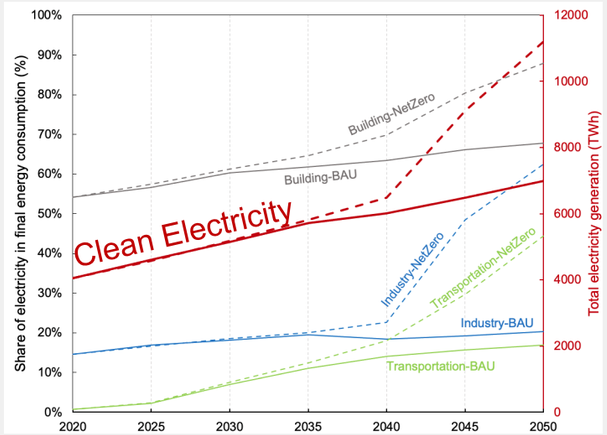
Deep dives on the science behind the tools and datasets

1. **Decarbonization and Climate Impacts on Hourly Electricity Load Projections (6/26)**
2. **Societal** and **Natural Resources** Impacts on Feasibility of New Infrastructure under Decarbonization (7/10)
3. **Vulnerability** of the Decarbonized Grid to Energy Droughts and Climate Extremes (7/24)
4. **Decarbonization** Impacts on Disadvantaged Communities (8/7)

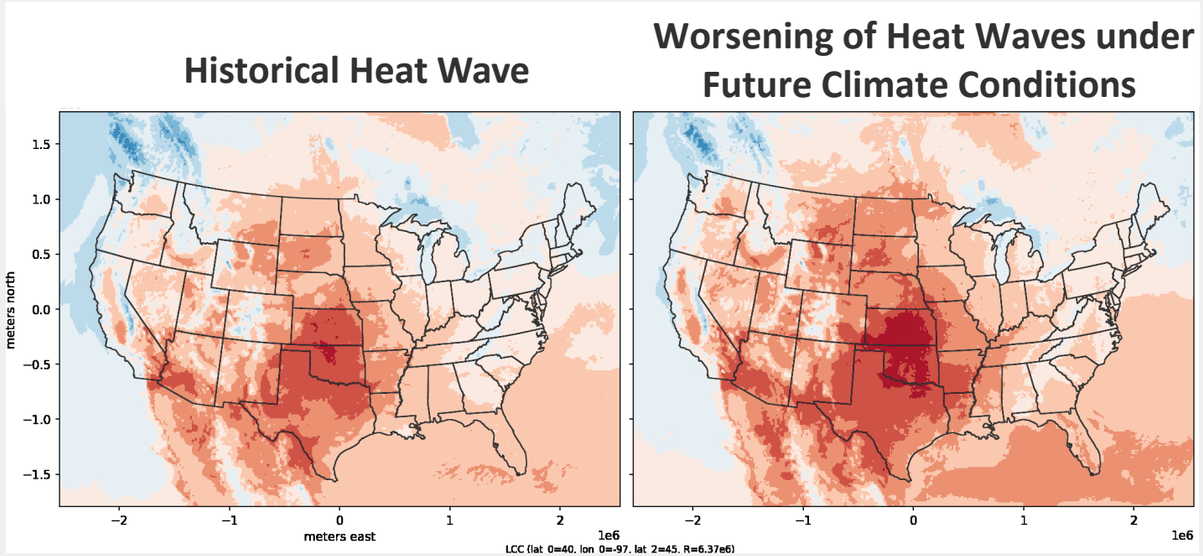


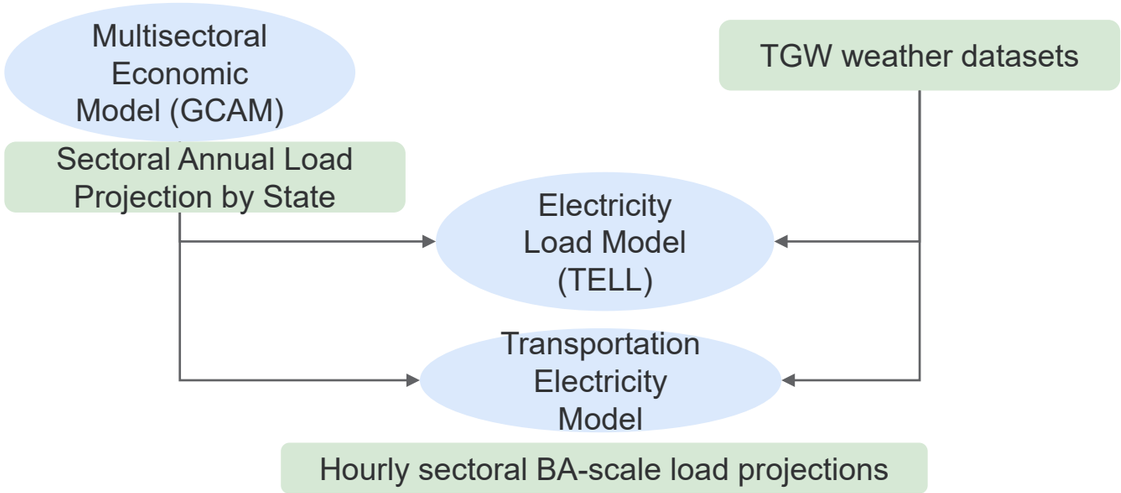
Deep Dive 1 (6/26): Decarbonization and climate impacts on hourly electricity load projections

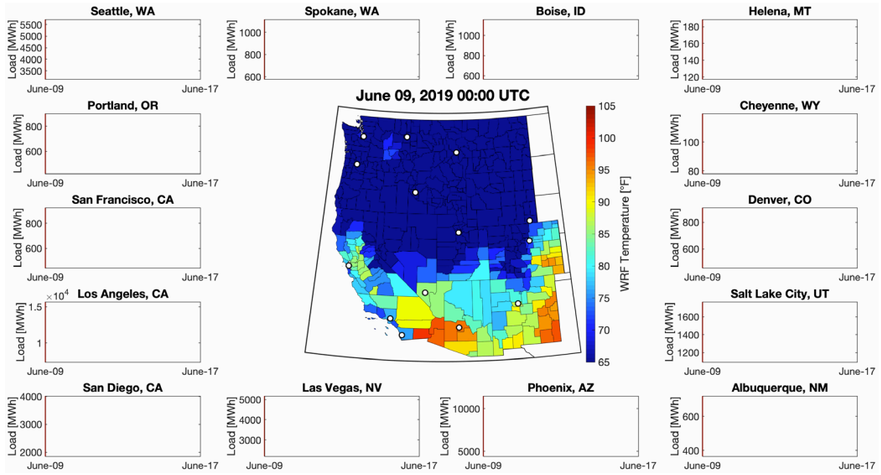
Decarbonization Pathways
Business as Usual & Net Zero w/o CCS



https://doi.org/10.5281/zenodo.7838872







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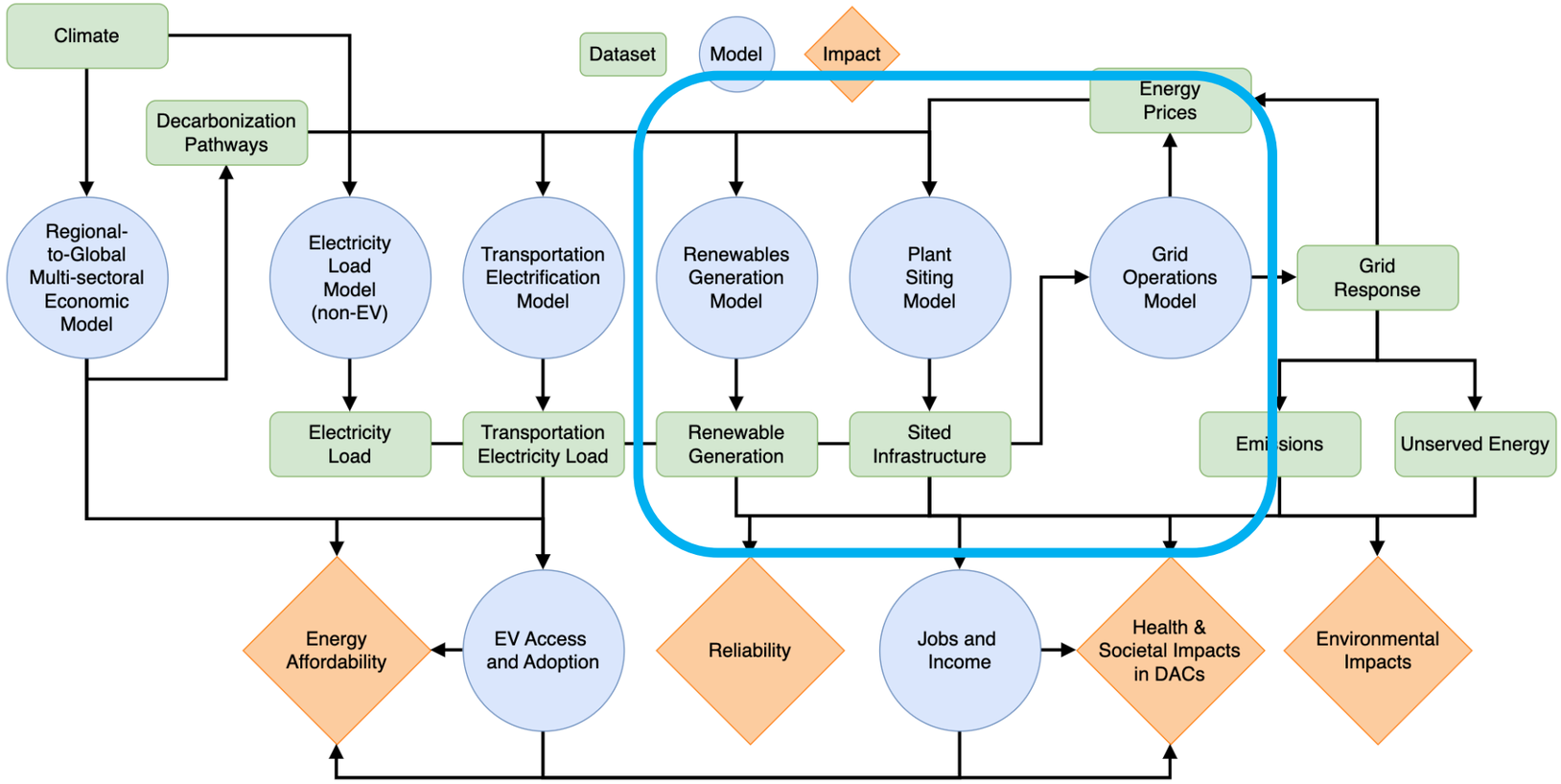

Deep Dive 2 (7/16): Societal and natural resource impacts on feasibility of new infrastructure under decarbonization

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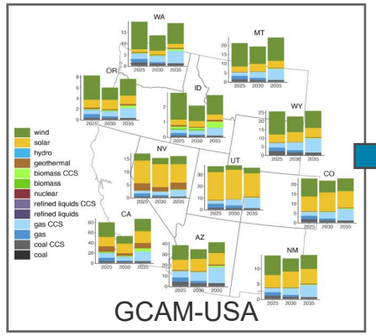
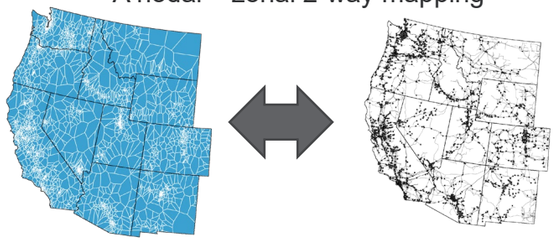
Capacity Expansion



GCAM-USA

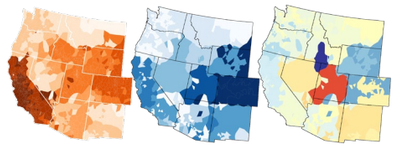
Plant siting model (CERF) and workflow

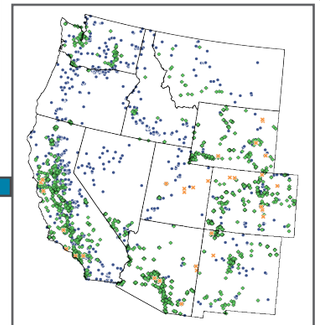
A nodal – zonal 2-way mapping



- Energy price geospatial polygons created from substation coordinates
- 1 km^2 geospatial modeling of natural resource and policy-based siting constraints of feasibility and suitability information layers
- Economic optimization addressing interconnection costs to electric grid, gas pipelines, water sources, and locational energy prices

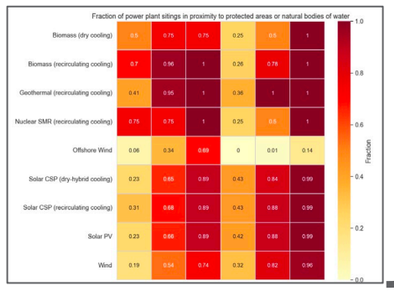
New climate-sensitive time series GridView evaluation



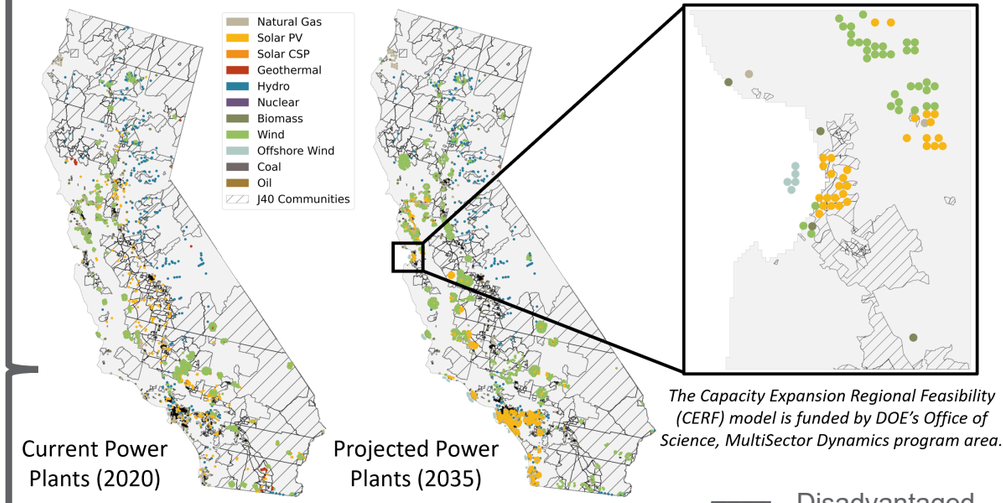


Sited new generators

Fraction of new capacity potentially facing local challenges



Incorporating equity into siting decisions



Current Power Plants (2020)

Projected Power Plants (2035)

The Capacity Expansion Regional Feasibility (CERF) model is funded by DOE's Office of Science, MultiSector Dynamics program area.

Disadvantaged Communities

High-resolution datasets and visualization that support stakeholders in developing and evaluating future infrastructure with equity considerations

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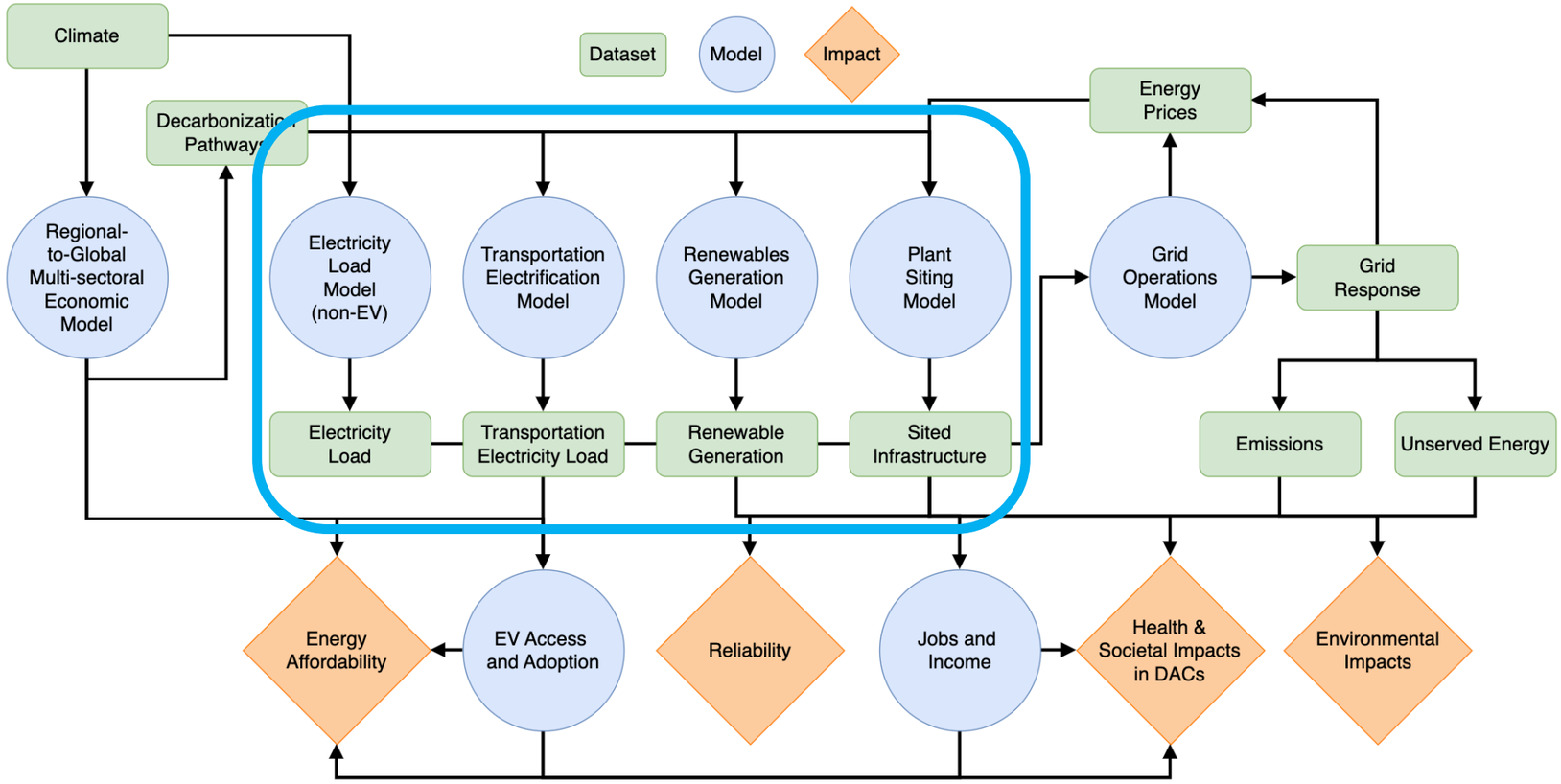
Deep dives on the science behind the tools and datasets

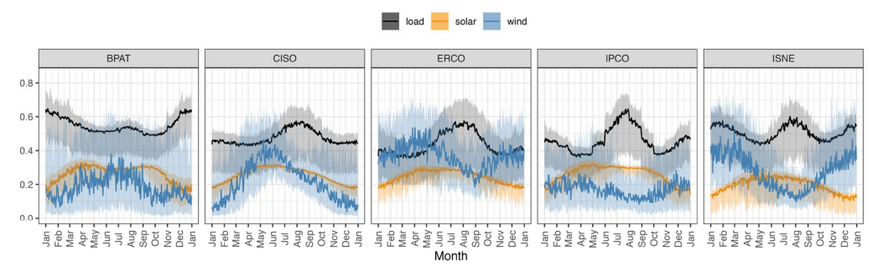
1. **Decarbonization** and **Climate** Impacts on Hourly Electricity Load Projections (6/26)
2. **Societal** and **Natural Resources** Impacts on Feasibility of New Infrastructure under Decarbonization (7/10)
3. **Vulnerability of the Decarbonized Grid to Energy Droughts and Climate Extremes (7/24)**
4. **Decarbonization** Impacts on Disadvantaged Communities (8/7)



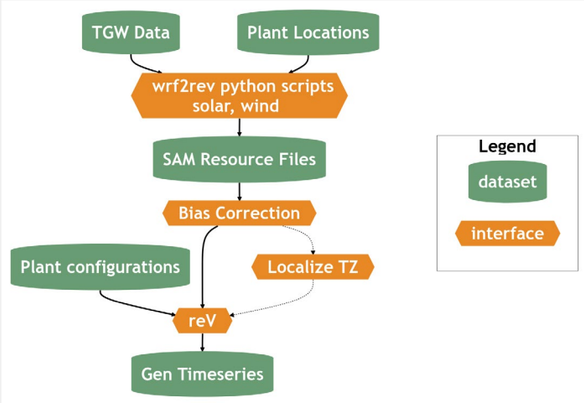
Deep Dive 3 (7/24): Vulnerability of the decarbonized grid to energy droughts and climate extremes

Coincident Wind, Solar and Load Datasets

Capacity Factors and Generation Time Series for 2020 infrastructure (EIA plant configuration), BA and nodal scales across CONUS

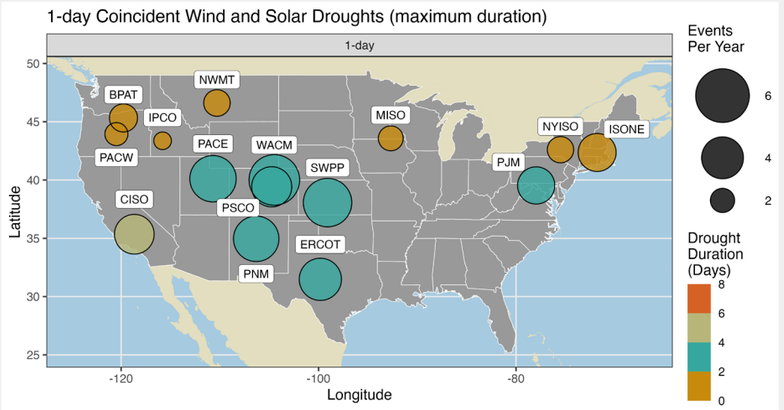


https://doi.org/ 10.5281/zenodo.7991871
https://doi.org/10.5281/zenodo.7901615



Standardized Benchmark of Wind-Solar Energy Drought across CONUS

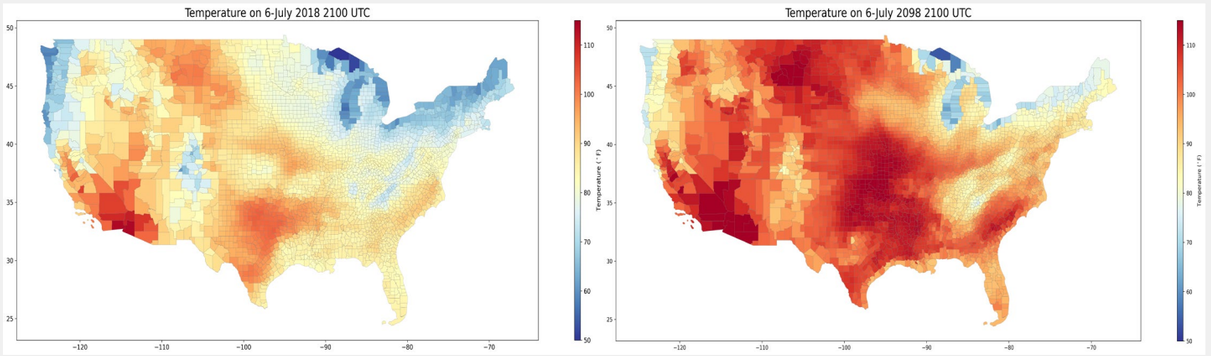
Drought duration in hours and days by balancing authorities to inform storage management including incentives for hydropower storage



https://zenodo.org/record/8008034

Extreme Events Used in the National Transmission Planning Study

Coincident wind-solar-load extreme events worsened under climate conditions



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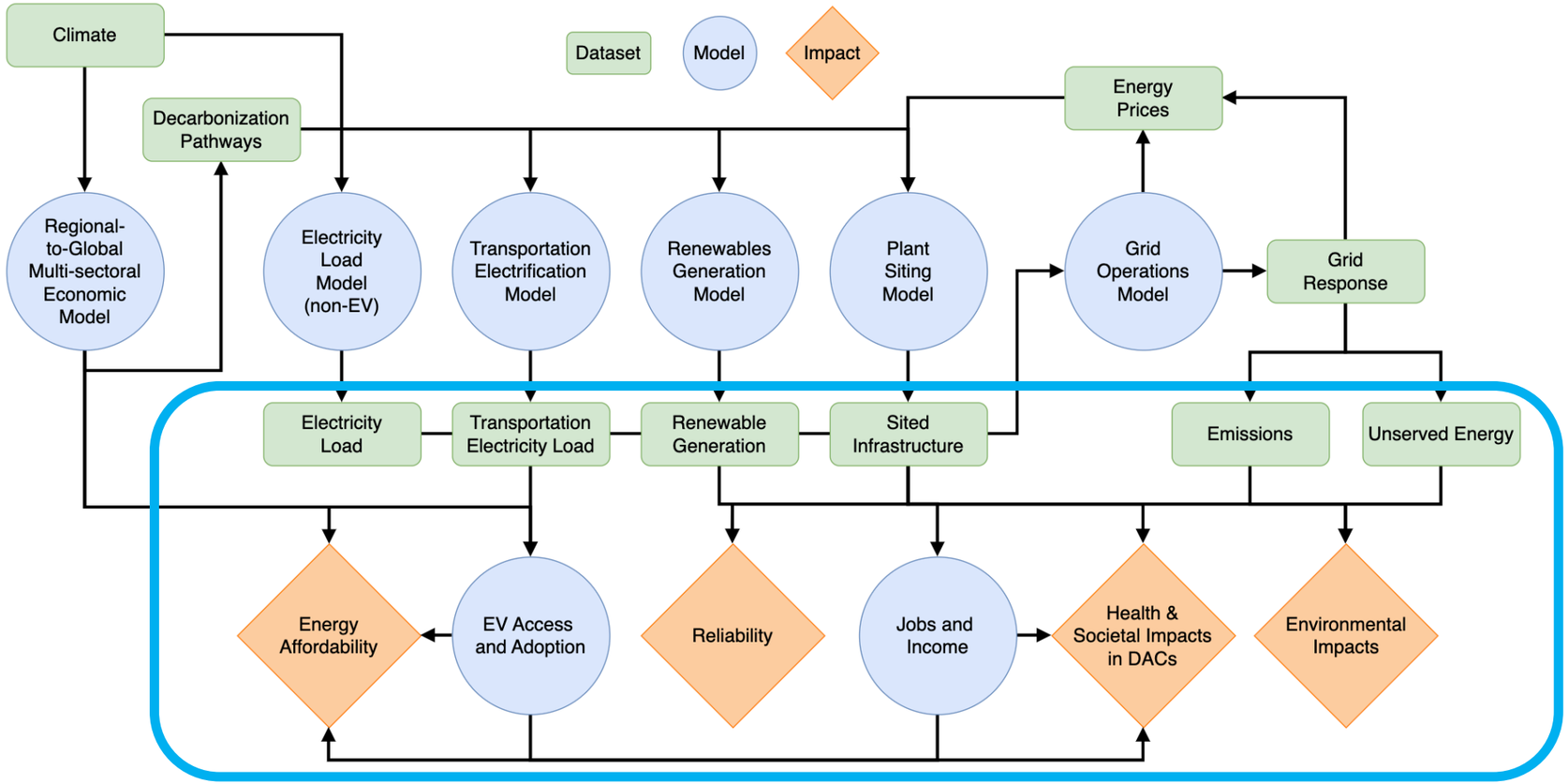

Deep Dive 4 (8/7): Decarbonization and climate impacts on equity and energy justice

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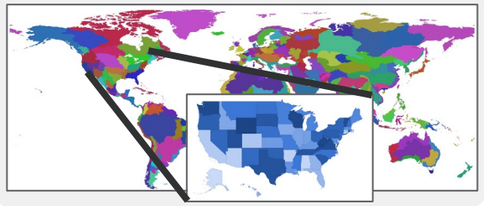
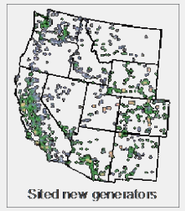
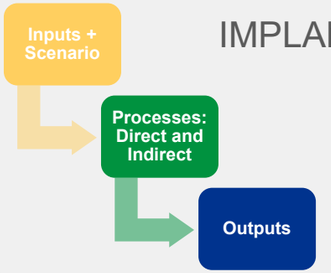


CERF



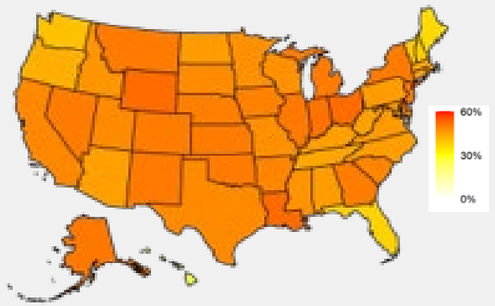
IMPLAN



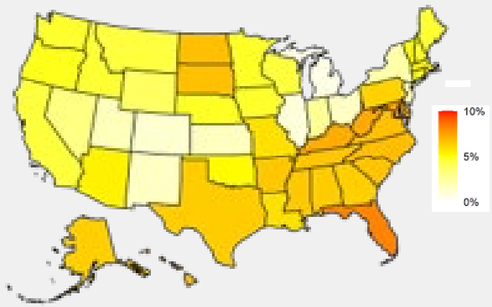
Satiation gap* in heating service: 2045, Decile 1

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

Reference



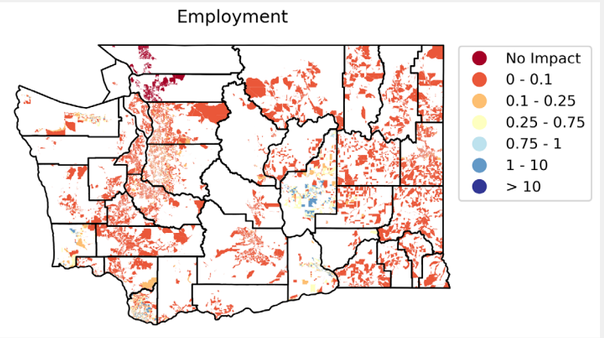
Net Zero w/o CCS - Reference

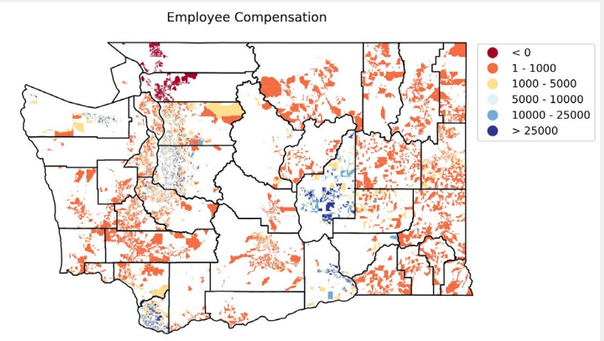


** Difference between heating consumption and the "ideal" heating or "satiation" level.*

Employment and income changes in Washington State: 2035

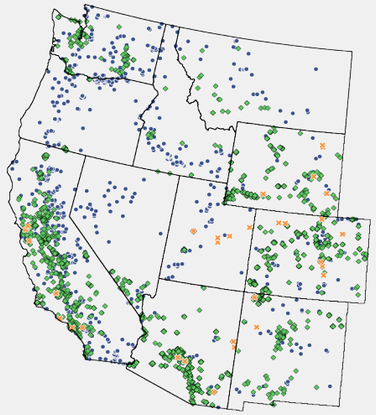
Employment and income are impacted by both direct and indirect effects of decarbonization





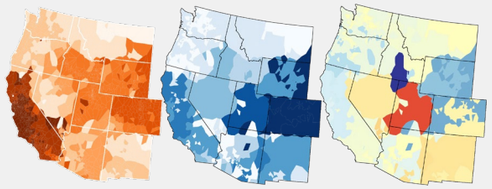
Deep Dive 4 (8/7), cont.:
Decarbonization and climate impacts on equity and energy justice

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



CERF sited new generators

New climate-sensitive time series GridView results

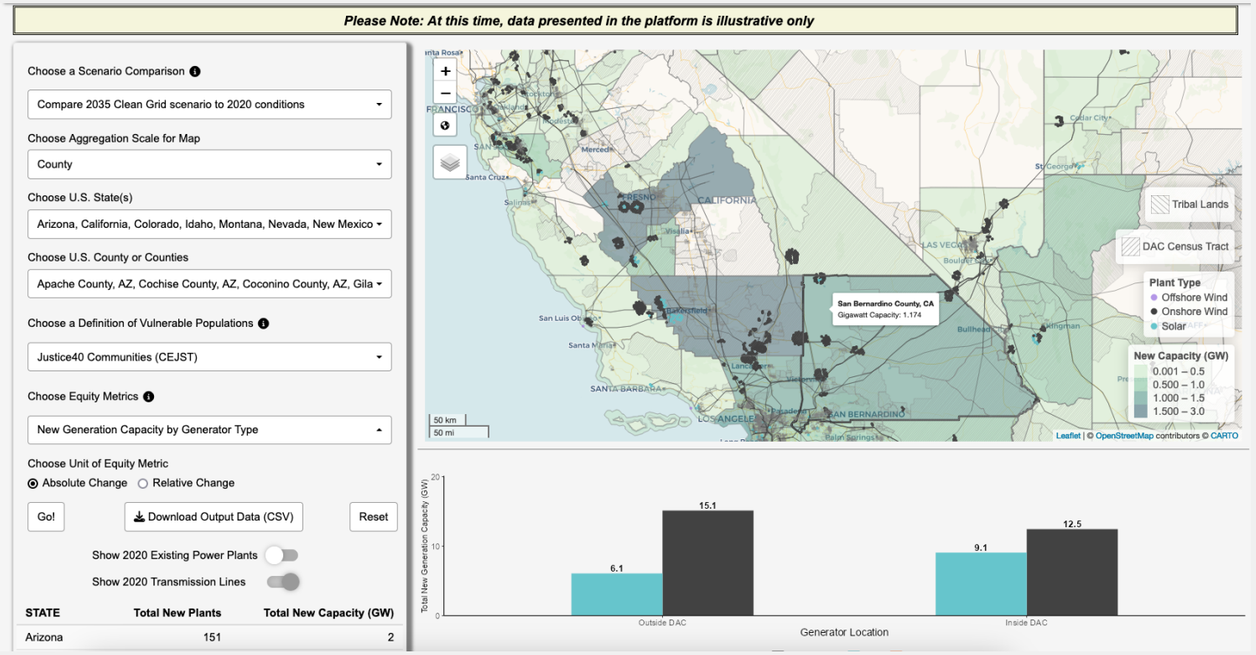


Multiscale

- 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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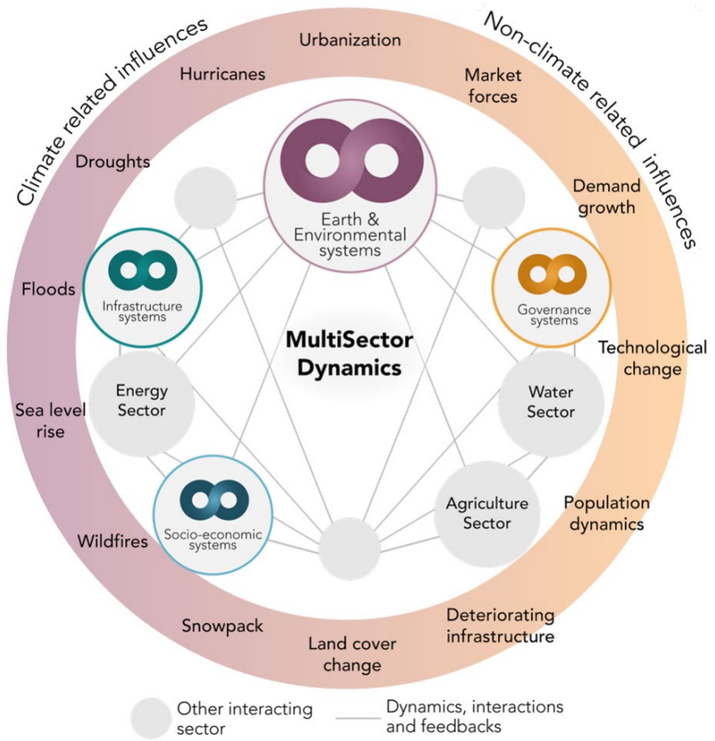
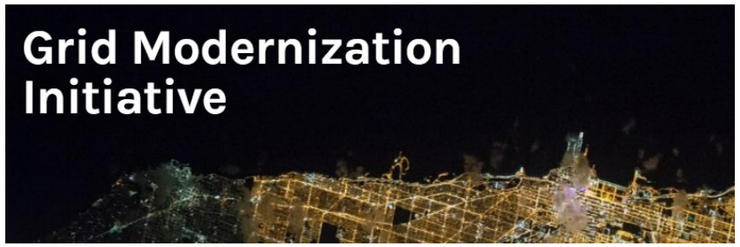
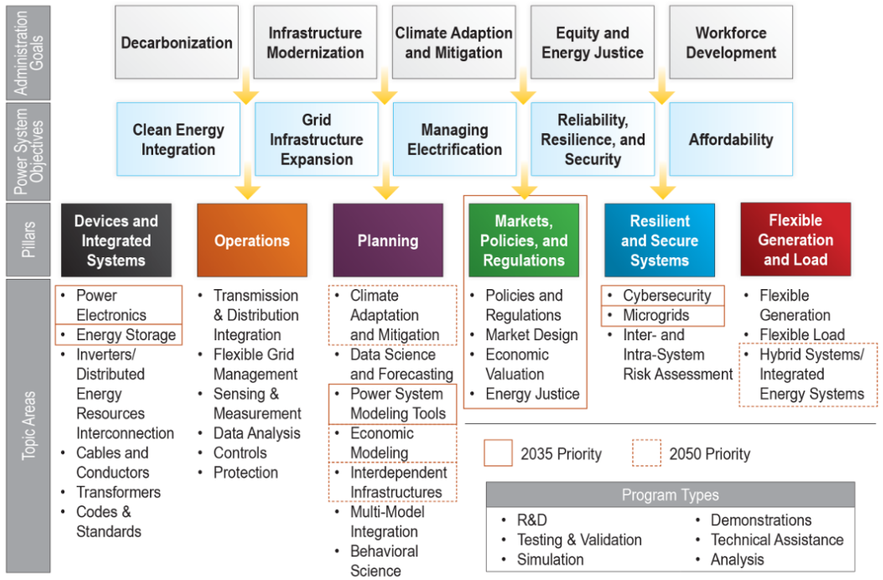
While internally funded, GODEEEP is strategically aligned with roadmaps across DOE fundamental and applied research programs, such as…

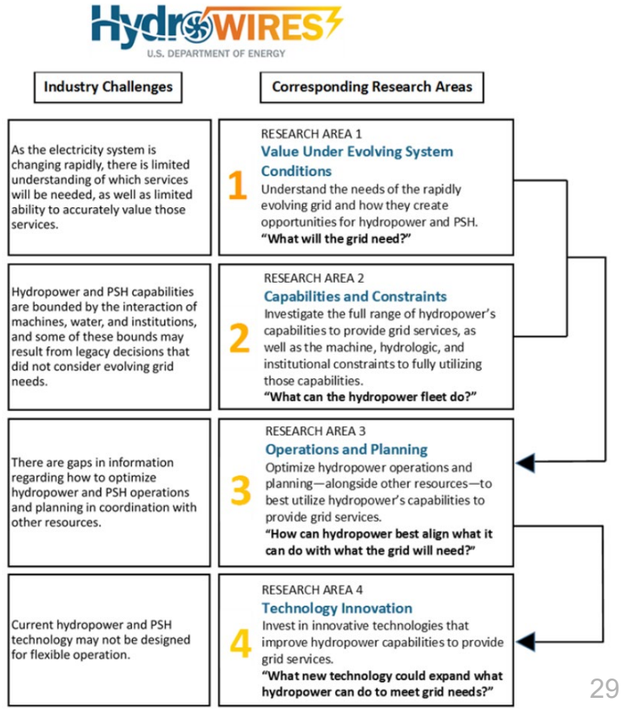






U.S. DEPARTMENT OF ENERGY
Building a Better Grid
National Transmission Planning Study

- Resilience in the face of extreme weather events
- Pathways to new, dependable, cleaner and less expensive electricity
- Economic growth
- Decarbonizing the grid and addressing climate change



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Technical advances and a platform for test-beds that allows consumers, providers, agencies and researchers to communicate and collaborate on climate- and equity-informed decarbonization

Empowered Stakeholders

Transfer of methods, tools, datasets, and use cases

Decarbonization Pathways

Whole economy decarbonization with interactions across global markets

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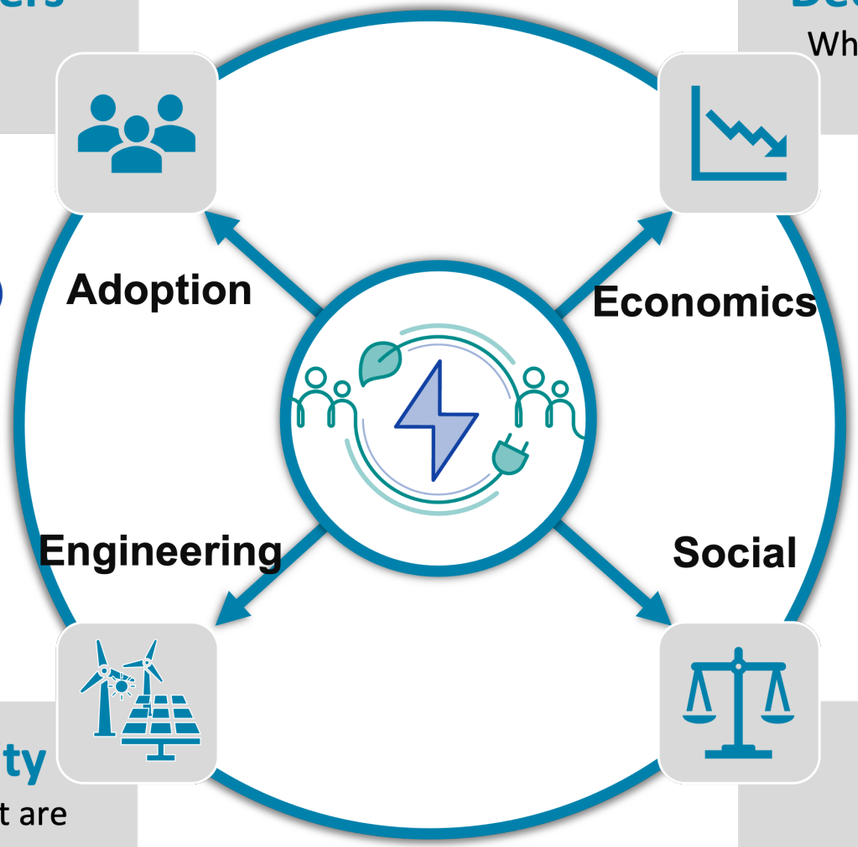

Resilience and Reliability

Infrastructure and operations that are responsive to climate change

Justice and Equity

Environmental and energy equity impacts of decarbonization

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Upcoming Webinars

Come to learn more about the tools and datasets
during our Deep Dives (meet the experts)
Mondays 10 a.m. PT (1 p.m. ET) every other week

https://www.pnnl.gov/events/godeeep-webinar-series

June 26, 2023
Deep Dive 1 – Decarbonization and Climate Impacts on Hourly Electricity Load Projections

July 10, 2023
Deep Dive 2 – Societal and Natural Resources Impacts on Feasibility of New Infrastructure under Decarbonization

July 24, 2023
Deep Dive 3 – Vulnerability of the Decarbonized Grid to Energy Droughts and Climate Extremes

August 7, 2023
Deep Dive 4 – Decarbonization Impacts on Disadvantaged Communities

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Thank you

On behalf of the whole
GODEEEP team

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